Reliability, Availability and Maintainability Study of Critical Vehicle Maintenance Equipment in a Highly Demanding Automobile Workshop

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***Abstract*— An automotive maintenance workshop equipment represent backbone of having good vehicle maintenance, especially with vehicle fleet operator. The workshop equipment should be at high level of the availability as automotive service and maintenance workshop is one of the important sectors. Retaining the vehicles in services condition during their service life have a high demands by every single vehicle user and vehicle fleet organization, especially if it's related to defense. This study was carried out with the intention to implement the RCM on selected few critical vehicle maintenance equipment and workshop in general. The scope of study was restricted to most frequently and most widely used equipment viz. Two post vehicle lift, four post vehicle lifts, Electric Power Air Screw Compressor and Tyre changer. All four equipment chosen for study has a good availability level which was due to the low operating period (relatively new) and the preventive maintenance. The air screw compressor has the lowest failure probability, and preventive maintenance strategy may be attributed for this. The equipment complexity effects on their availability of the spare parts. The least failure probability was on the Air screw compressor and the highest was on the four post vehicle lift. The four post vehicle lifts represent the highest reliability equipment. The vailability of the equipment for the two and half year life's period was high. The air screw compressor has the lowest failure probability, and in-house preventive maintenance strategy is attributed for this. The complexity and the availability of the spare parts of the equipment increase the MTTR. It was important to keep the availability of the equipment to the high level through controlling the related parameters.**

***Keywords*— Mean Time to Between Failure (MTBF), Availability, Reliability and Maintenance**

I. INTRODUCTION

Due to the importance of the availability and the reliability of automotive workshop equipment, it is necessary to have an appropriate method of maintenance for the equipment used in the automotive workshop. The purpose of equipment maintenance is to extend their lifetime and the mean time to the next break-down [1]. Two to sixteen percent of annual turnover may be lost by most of large company due to machine downtime [2]. It is important to extend equipment workshop lifetime but maintenance will always call for high expenditure, if not performed properly, either too little or too frequently. According to Awosope, S. et. al [1], the balance had been expected by extrapolating the experience obtained from accessible system by using the rule of thumb methods as it was in the past. The maintenance also reacts to the changing of expectation, which include a fast growing awareness of the degree to which equipment failure affect safety and environment. A growing awareness of the relationship between maintenance and product reliability, and increasing pressure towards achieving better equipment availability was another concern. The Khandelwal [3] defines Reliability as "the probability that system operates without interruption during the interval of interest under specified conditions" and the availability is "the probability that the system is in an operational state at the time of interest". According to Sukhwinder et. al [4] in the past, 'Reliability' was not used specifically, yet consequences of the failure of a system were always considered. Their study reflect that the importance of reliability in fast increasing complexity and automation system. The reliability has become inextricably linked with all major phases of the genesis and use of commercial, military and space systems at the all levels of design, development, procurement, production, operation and maintenance [4].

There was much concern on the availability and reliability of Automotive Equipment at service and maintenance workshop. The increasing in complex frame work conditions demands new maintenance approaches and required frequent risk assessment through employee knowledge and experience [5]. Implementation of PM recommendation without considering equipment critical equipment condition may result in too large workload which is difficult to achieve [6].

Maintenance has been used for long time in various fields. According to Moubray, [7], three maintenance generation growths of industry and technology were observed. The systematic maintenance was not required on first generation.

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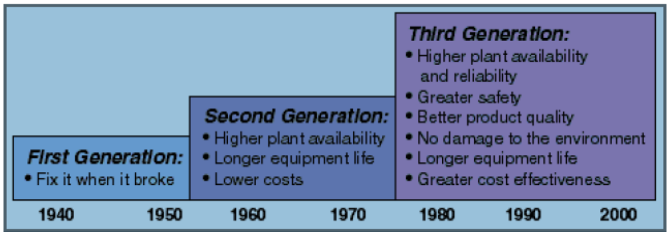


Fig. 1: The growing expectation of maintenance processes [7]

Preventive maintenance, maintenance planning and control system concepts were found on second generation. Since mid-seventies, down time effects, reliability and availability, quality standard, safety and environment consequences, operating and growing cost and the rise of maintenance cost were considered. The growing expectation of maintenance processes as it listed by Moubray [7] is shown in

Fig. **1**.

Asset operating age and how likely they fail as it represented by Bathtub Curve is shown in

Fig. **2**. It describes the relative failure rate of the complete products over time and is used as a visual model to demonstrate the three main periods of product failure [8].

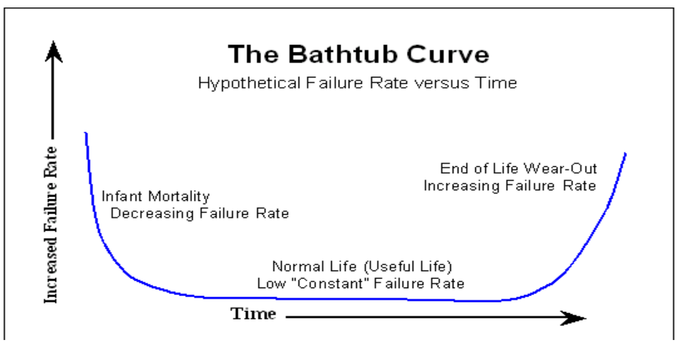


Fig. 2: Bathtub Curve [8]

Wilkins, [8], adds that the failure rate in the infant mortality period is decreased, whereas the failures during normal life occur at accidentally but with a comparatively steady rate when measured over a long period of time. In the third part of the curve, there is an increased rate of failure which known as wear-out failures where the material life is due to fatigue or depletion. As plotted by CUI Inc. [9], and is referred to bathtub curve, failure rates against time during assets life cycle or equipment shown in Fig.3.

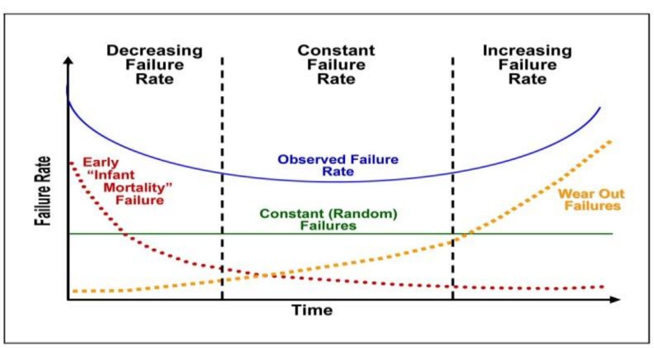


Fig.3: Failure rates against time [9]

The reliability is used to assess the probability that a component or a system works when no maintenance is made. A system with a high reliability thus has minimal maintenance requirements; it is a robust system. The reliability theory forms the basis. Of the concepts studied by Sonny Myrefelt [10], the functional availability is judged to best reflect the overall characteristics of the technical systems and the human element. Studies carried out by Qing Fan and Hongqin Fan [11], equipment reliability assessment serves as one of the decisive tools in selecting the right maintenance strategy. It is essential to find more scientific and precise way to analyze and predict cortical equipment failures before they happen. Qing Fan and Hongqin Fan [11], developed time series models for construction equipment reliability analysis and forecasting failures with emphasis on its delivery of the reliability characteristics such as expected numbers of failures per interval and mean time between failures (MTBF). Their results conclude that, the time series models can be used for forecasting of reliability metrics of construction equipment with very reasonable accuracy. Most reliability models assume that the up and down times of the components are exponentially distributed. This assumption leads to a Markovian model with constant transition rates. The analysis in such cases is relatively simple and the numerical results can be easily obtained [12].

Studies carried out by Suleiman K. et. al [13], indicates that system availability and profit increases with repair rates and decreases with failure rates. Their study indicate that, failure rate increases, the availability goes on decreasing and as repair rate increases, the availability goes on increasing. Further, optimum combination of failure/repair rates, which maximizes the system availability subject to the cost and system.

Equipment reliability analysis adds further information on their performance expectation during their services life. Smith R.G [14], stated that the reliability is the probability that an item will perform its intended function for a specific interval under stated condition. The maintenance- related downtime was the biggest contributor to low the availability [15]. Therefore, further analysis of the maintenance function was required. Different types of failure parameters used for reliability assessment. One of used was the mean time between failures (MTBF) for the reliability and the mean time to repair (MTTR) for maintainability. It was important to increase the reliability and decrease the maintainability for better output. The standard for the availability for general industry expectation was about 95% [14]. Different sources influenced on the MTBF and MTTR. These could be from of lack required parts, lack of proper equipment and lack of proper maintenance.

The MTBF calculated by dividing the operating hours by the number of the failures, whereas the inverse of it is the failure rate (λ). MTTR factor has an influence on the equipment availability. The repair could be done either onsite or offsite of the equipment location. The lower the MTTR leads to better the equipment availability.

II. SYSTEM DESCRIPTION/ EQUATIONS

It was important to know how long it takes to maintain the equipment and bring it to its restored function condition. This was determined by the equipment design and the length of repair times. It was about the maintainability which represents the simplicity and quickness of repair and maintenance actions with which equipment can be reinstated to operating condition [14]. The equipment was considered with the limited process due the lack of the availability of the required data. The considerations were on some of the equipment parts functions, function failure, failure consequences, and the availability, reliability and maintainability with other related parameters for the RCM process such as MTBF. The detail of the equipment was pulled from manuals, interviews and experience. Some of data were drawn from Garage Equipment Associated (GEA) site. Equipment function, failure, failure mode, failure consequences and maintenance process play an important role in implementing RCM process, hence these was obtained during the process. In the current study, two post vehicle lifts, four post vehicle lift, Tyer changer and Air compressor were selected due their availability importance and the most regular used equipment in automotive workshop process.

A) Two post Vehicle lift.

As stated in HSE [16], Two Post lifts were used widely throughout the motor vehicle repair (MVR) industry. It is the backbone of the vehicle service industry and has gained good recognition over the last 20 years and was used for inspection, routine service, and free wheel application and for major work. The main function of the two post lift is to raise vehicles and trucks for easy access to wheel assemblies and the underside of the vehicle [17]. It is normally consist of two vertical columns – a master or powered column plus an auxiliary or slave and some columns are connected by a structural overhead beam and were available in different configuration, capacity, arm configuration, width overall, drive through clearance, ceiling height required, adjustable height standards. According to Automotive Lift Institute [ALI], [18], the existing standard in North America that directs the design and construction is ANSI/ALIALCTC and more than ninety-five percent of all licensed lifts are certified under the ALI. A typical two post lift from the automotive workshop is shown in Fig. 4. According to the workshop manual, it consists of more than 58 parts. Some of lifts parts which have impact on the safety, maintenance cost and operation factors were considered. This includes lift columns, lift arms, locking-latch, equalizer cables, power unit, cable sheaves (pulley), air houses and hydraulic houses.

Fig. 4: Typical four post lift from the automotive workshop

B) Four post Vehicle lift

A typical four post lifts is generally consisted of four standard upright columns, two runway, two yokes, an electric/hydraulic power unit, and a variety of hoses, pulleys, and cables, air filter, regulator and adjustable latch bars. The main function of the four post lift is to raise and lower vehicles and trucks with wheels on the runway. All of vehicle doors can be opened without any restriction. A typical four post lift is shown in

Fig. **5**. According to the workshop manual of a typical selected four post lift, it is consisted of more than 40 parts which are available in its workshop manual. Critical lifts parts are considered in this study.

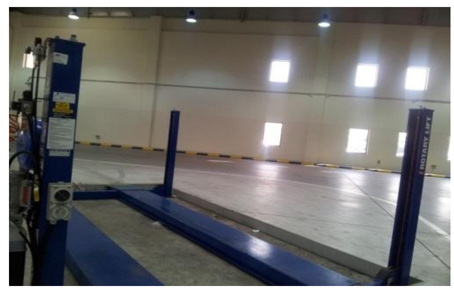


Fig. 5: Typical four post lift from the automotive workshop

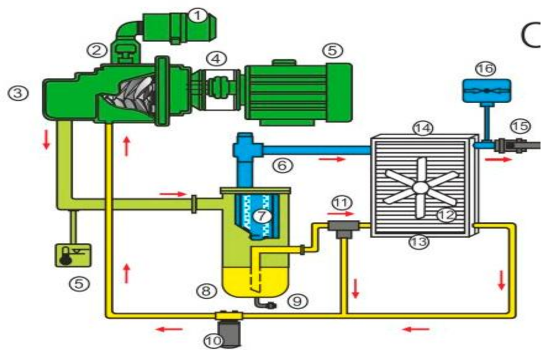
C) Air compressor

A typical air compressor for this study is an ELGI (E 18-10) Electric Power Air Screw Compressor which is the rotary screw air compressor of single stage shown in

Fig. **6**.

Fig. 6: ELGI Electric Air Screw Compressor

Functional description is presented at ELGI Electric Power Air Screw Compressor operation, maintenance and parts manual. The compressor is initiated when its air end driven by an electric motor. The male and female rotor were meshed with each other and turned. The air is trapped between the flutes and the lobes of the rotor results in progressive compressed air. The compressed air flows out towards the discharge port, the process clarified by Fig. 7.



1. Air intake filter	5.Electric motor	9.Drain valve	13.Oil cooler
2.Intake valve	6.Minimum pressure valve	10.Oil filter	14.After cooler
3.Airend	7.Seperator element	11.Thermal valve	15. Ball valve-service line
4. Drive coupling	8.Seperator tank	12.Fan	16. Pressure transmitter

Fig. 7: Schematic compressor operation [19]

The compressor consisted of different systems with various parts and function. Air inlet system, control system, discharge system, cooling system, lubrication system, canopy system and motor based assembly system. In the current research, the focuses were on some of the critical parts of the compressor and some of these systems data available in its workshop manual.

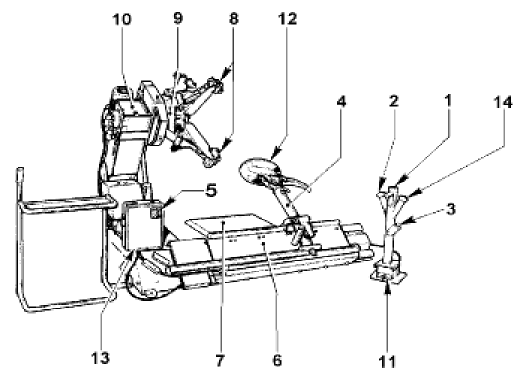
D) Tyre Changer

Changing Tyres required skilled staff and proper equipment.Tyrechanger machine is one of important machine in the automotive workshop. Different sizes grips were used in tyre changer machine toward making the process of changing theTyre; easy and quick with fewer difficulties and with the cost consideration. It should be available and reliable and safe usage at any time. Therefore, proper maintenance process should be implemented to retain their actual requirement for long time during their service life. The main functions of thetyre changer are to remove and replacetyre. It was equipped with different components that have specific function. A typical tyre changer machine that used in this study is Electro HydraulicTyre Changer. It is a John Bean T5600tyre changer. According to its workshop manual, it is used to demount and mount tubeless truck tyre and is not suitable for to inflatetyre. Thetyre changer is shown in

Fig. 7. The consisted parts were shown in Fig. 8 were each of these parts has specified function, however, the critical parts will be considered on this study. Additional information is available in workshop manual.

Knowing the failure consequences data of the equipment is vital through the detecting the meantime between failure (MTBF), mean time to repair (MTTR), during the equipment operating period were important. Fig. 10 shows these concepts which have high influence on the reliability, availability and maintainability of the equipment.

Fig. 7: John Bean T5600tyre changer



1. 8 position switch	6. Toolholder carriage	11. Chuck rotation control pedal
2. Chuck switch	7. Footboard	12. Mount/demount tool
3. Emergency stop	8. Jaws	13. Electric cabinet
4. Toolholder arm	9. Self-centering chuck	14. Tool holder arm switch
5. Main switch	10. Chuck arm	

Fig. 8: John Bean T5600 Tyre changer parts

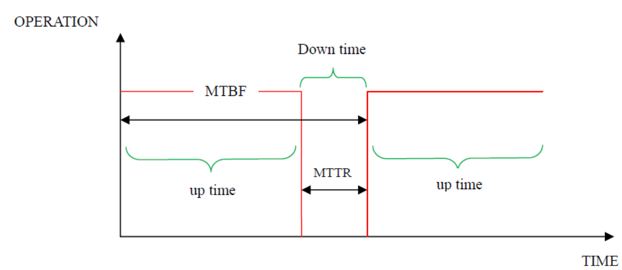


Fig. 9: The up time and the downtime for the equipment during the operating Period [20]

The following equations were used in calculating the required information:

$$\text{MTBF} = \frac{\text{Total device hours}}{\text{Total Number of failures}} \quad (1)$$

$$\text{or} \quad \text{MTBF} = \frac{\text{Operating time}}{\text{Number of failures}} \quad (2)$$

$$MTTR = \frac{\text{Total Repair time}}{\text{Number of failures}} \quad (3)$$

$$\lambda(\text{lamda}) = \frac{1}{MTBF} \quad (4)$$

$$\text{Availability} = \frac{MTBF}{MTBF + MTTR} \quad (5)$$

$$\text{Reliability} = R(t) = e^{(-\lambda t)} \quad (6)$$

t is the required operating time in hrs.

$$\text{Maintainability} = M(t) = 1 - e^{(-t/MTTR)} \quad (7)$$

$$= 1 - e^{(-\mu t)} \quad (8)$$

μ, is a constant maintenance rate.

$$P(t) = e^{(-t\,/\,MTBF)} \quad (9)$$

III. RESULTS AND DISCUSSION

The relationship between the reliability, maintainability and the availability is shown in Table 1. This was declared by reliability engineering web site. The system downtime was proportional to a function of component downtimes.

Table 1: The relationship between the reliability, maintainability and the availability [21]

Reliability	Maintainability	Availability
Constant	Decreases	Decreases
Constant	Increases	Increases
Increases	Constant	Increases
Decreases	Constant	Decreases

E) Reliability and availability analysis of Two Post vehicle lift

Information on failure data of the two post vehicle lift was gathered from operator diaries. The failures were noted on some of lifts parts during the service life of two and half year. Since the lifts operation dependent on the availability of its parts proper function. It was assumed as one single system. The selected lifts were working for 35 hrs. / week. Assuming that 25 number of two post lifts was tested for 122 weeks (i.e., January 2012- April 2014).During the test, 7 failures were detected. The estimated of the MTBF is measured by substituting the above value in below equation. This data is shown in Fig. 11.

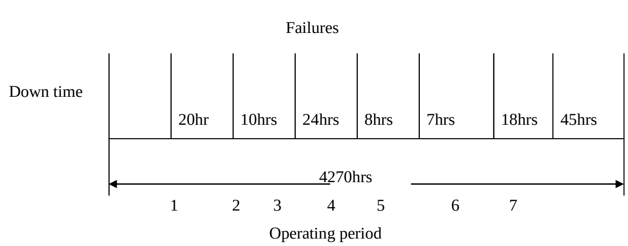


Fig. 10: Operating period with detected failures for Two Post vehicle lift

A) Reliability and availability analysis of Four Post vehicle lift

The unavailability of the lifts failure recorded data that were gathered leads to make an assumption. As it been declared by lifts operators (i.e., mechanics), very minor failure were noted from these type lifts which implies that the availability of the lifts were high during the two and half service life. It was assumed that the selected of 15 number of four post vehicle lifts were working for 35 hrs. /week for the period between January 2012- April 2014 (i.e., 122 weeks) and 3 failures was recorded. Assuming that it is a simple operated vehicle lifts. Figure 12 shows the operating period with the failures for Four Post vehicle lift.

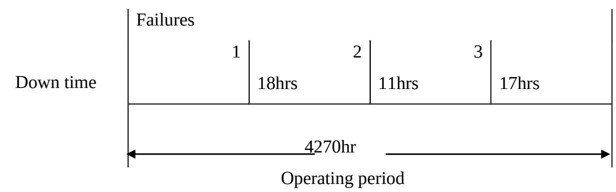


Fig. 11: Operating period with detected failures for Four Post vehicle lift

B) Reliability and availability analysis of Electric Power Screw Air Compressor

The electric power screw air compressor was maintained under maintenance annual contract which is held by the most automotive workshops. From the actual collected data for typical compressor used for one year (i.e., April 2013- April 2014) as it was shown early. The compressor was working for 50 hrs. / week. (i.e., 2600hrs/year). There were a total of 4 compressors at this location. One of them was used as replacement for any failed compressor. Assuming that the three compressors having the similar failures during above service life. The total down time for the compressor was 64hr. There were 7 failures during that period. This is shown in Fig. 13.

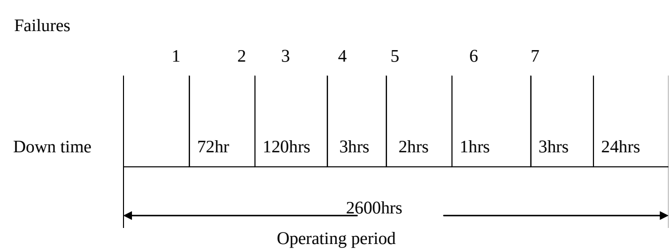


Fig. 12: Operating period with detected failures for Electric Power Screw Air Compressor

C) Reliability and availability analysis of Tyre Changer

When following the actual failure history for this equipment, it was understood that the history of failure record where not available. However, Technician dairies had reported that the equipment had not come across major failure for the last two and half years (i.e. January 2012 to April 2014). Three failures were detected during that period. The failures were on the hydraulic oil leak and air pressure leak. The estimated of the MTBF is measured and whereas the down time was assumed. Fig. 14 shows the operating period and the failures.

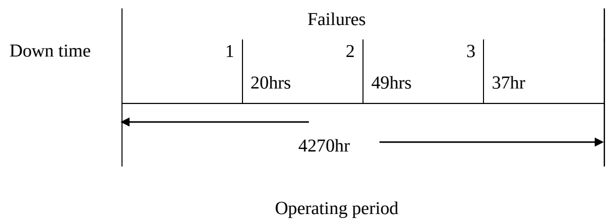


Fig. 13: Operating period with detected failures for Tyre changer

During the reliability studies, it important that total repair time is accurately accounted. In this regard, host of investigation was carried out at the workshop, floor. As the data was not available accurately due to improper recording mechanism employed at the workshop. Hence, the total repair time was approximated and linked to the total down time. In order to obtain the accurate hours for total repair time, the survey was conducted among staff (manger / supervisor, vehicle technician and maintenance technician) from different locations of automotive workshop where the equipment were used. Based on the response to the survey, the total repair time is estimated and values for each equipment under the study are tabulated as given below:

Table 2: Estimated total repair time for all the equipment considered for study

S. No.	Equipment Description	Estimated total repair time
1	Two Post Vehicle Lifts	30% of the total down time
2	Four Post Vehicle Lifts	40% of the total down time
3	Electric Power Air Screw Compressor	30% of the total down time
4	Tyre Changer	35% of the total down time

Based on the above data, the availability and reliability calculation were performed results are summarized in the following tables and figure. Table 3 shows the detail of the MTBF, MTTR and the Downtime for the equipment.

Table 3: The MTBF, MTTR and the Downtime for the Equipment

No.	Equipment	MTBF (hrs.)	MTTR (hrs.)	Down time (hrs.)
1	Two Post vehicle lifts	15250	5.66	56.26
2	Four Post vehicle lifts	21350	6.13	19.06
3	Air screw compressor	1114.42	32.143	225
4	Tyre changer	14233	12.367	106

The Table 3 shows that highest downtime was for the air screw compressor, whereas the least downtime was for the four post vehicle lifts. The MTTR highest level is also on the compressor where the lowest was on two post vehicle lifts. The comparison between the failure probability, availability, and reliability for the equipment is shown in Fig. 15.

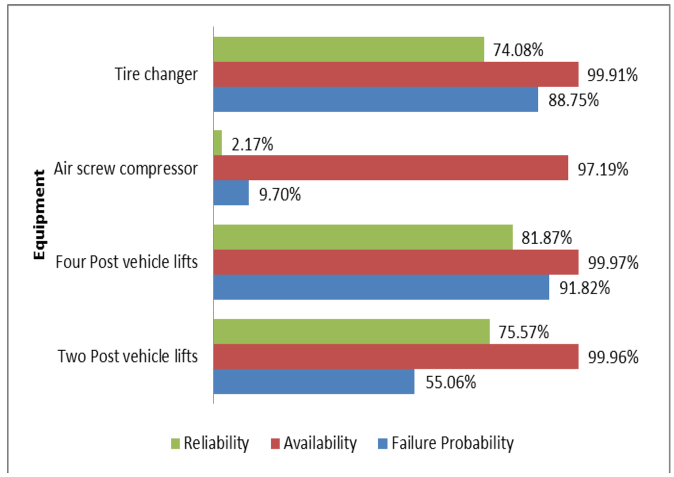


Fig. 14: The comparison between the availability, reliability and the for the equipment

The above Fig. 15, it is evident that all the equipment record the high availability level and the highest availability were on the four post vehicle lifts. The least failure probability was on the air screw compressor whereas the highest failure probability was on four post vehicle lifts. Further the maintainability of all the equipment were unity as most the equipment were under warranty, hence the repair was attended by the suppliers.

IV. CONCLUSION

From the experimental study on four types of automotive workshop equipment the availabilities studies on the chosen equipment show that:

- The availability of the equipment for the two and half year life's period was high. The air screw compressor has the lowest failure probability, and preventive maintenance strategy may be attributed for this.
- The complexity and the availability of the spare parts of the equipment increase the MTTR. It was important to keep the availability of the equipment to the high level through controlling the related parameters.

Following recommendations could be drawn based on the above discussion and facts:

- The maintenance strategy of the workshop should be aligned such as to increase MTBF with reduction in MTTR.
- There should be a consideration of workshop staff training, immediate report on any abnormal

operation of the equipment, ensure about the availability of the equipment spare parts.

- Equipment failure should be recorded aptly and history of the equipment service life should be centrally registered.

ACKNOWLEDGMENT

The authors would like to thank the Management of Caledonian College of Engineering and extend sincere thanks the automotive workshop management and staff for their support during the course of this work. The name of the automotive workshop is considered as classified.

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