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Reliability Analysis of Diesel Locomotive Engine

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Abstract – Performance measure of the system is one of its most important characteristic. Diesel locomotive engine is a mechanical system with the complexity of different equipment that leads to failures and hence the aspects of reliability analysis of such systems come into mind. The failure of machineries and equipment results an interruption in the functioning of the system and also increases the cost of maintenance. It is an important part of Indian Railways and for the smooth functioning and operations, reliability of such mechanical system has to be ensured. This paper ascertains the reliability and availability of the diesel locomotive engine. To estimate the reliability in term of availability of the diesel locomotive, an ambient study has been carried out to collect the accurate facts at the level of detail considered suitable to analyse the reliability. Pareto distribution is used to analyse the reliability of system and the results can be used in railway industry for reducing the undesirable interruptions and will enhance the reliability of diesel locomotives.

Keywords* – *Diesel locomotive engine, Availability, Maintainability, Reliability, inventory optimization.

I. INTROUDUCTION

The analysis of the reliability of a system must be based on precisely defined concepts. Since it is easily accepted that a population of presumably identical systems, operating under identical conditions, fall at different points in time, then a failure case can only be described in probabilistic terms. Thus, the concept of reliability of a system comes from probability theory. [1-2] System reliability states that the probability, that a system including all equipment, will satisfactorily perform the task for which it was designed or intended, for a specified time and in a specified environment. This paper attempts to describe the concept of system reliability engineering.

Indian Railways is a standard system of transport in India and diesel locomotive engines are the most important channel of traction in Indian railways. The adequate availability of traction is necessary for smooth functioning of railway services without loss of punctuality and compromise with safety and comfort [1].

The increasing demand of production and services with tolerable level of reliability, availability, maintainability, and safety increases pressure on operations and maintenance management. Once the facility is designed and installed for the required result, it's the operations and maintenance management coordinate to obtain productivity in a sustainable manner. Such coordination at each scale of management needs a handful of scientific concepts and tools to work in an impressive style. This makes maintenance a multi-objective and inter-disciplinary environment to work with.

A credible and trouble free process of passenger and freight transportation is demarcated by the selected mode of use of rolling stock [3], efficient application of technical maintenance and repair systems, as well as strict work and technological discipline. When operating a rolling stock fleet, it is very important to enhance the indicators of its reliability and economic efficiency. This depends on the rolling stock design, technical maintenance and repair system, existing repair complex, organization of repair works, and qualification of the staff. It is very important to perceive and to adapt information technologies in the proper way which would enable to systemize the existing information and answer the following main questions when using it: at what periodicity scheduled repairs should be performed without using additional funds seeking to maintain the necessary technical condition of the rolling stock, how many spare parts should be held in storage in order to perform scheduled and unscheduled repairs with the minimum costs, how to enhance the reliability of equipment components and aggregates. All the factors listed are directly associated with unscheduled repairs.

II. MEASURE OF RELIABILITY

A reliable and safe process of passenger and freight transportation is determined by the selected mode of using of rolling stock, efficient application of technical maintenance and repair systems, as well as strict work and technological discipline. For this, maintenance policy need a modification to be managed with proper considerations of critical factors related to effective use of the resources and business strategy. This paper presents supervisory actions required on maintenance for achieving desired

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availability and reliability of the locomotive output. Reliability defined as the probability of an equipment to perform its purpose for the substantial period of time intended under the operating conditions encountered.

A. Statistical Failure [2]

Any loco which is unable to work its booked train up to destination or suffers detention 30 min in coaching trains or more (20 min in case of Shtabadi and Rajdhani Express trains) or 60 min loss in block section of goods train on account of Diesel loco trouble is termed as statistical failures (ST). These Failures are reported to Railway Board & on monthly basis [2].

B. Non – Statistical Failure [2]

If loco gets under repair after completing its journey and not available for return trip or train loco after major schedule, failures in departmental services, overdue schedule for more than 24 hours, loco loss due to bad weather or poor visibility, shortage of fuel, cattle run over etc. termed as non-statistical failures (NST). The zonal bulletin covers all ST as well as NST failures on monthly basis.

C. Set – Outs[2]

In order to provide a high degree of reliability, every line message is important for the purpose of intro - inspection and failures analysis to make an effective action plan to curb these failures. Thus, these messages do not have any adverse effect on operation but very important for the base shed. These massages are termed as set-outs, irregularities, or messages. Obviously, this list is inclusive of all statistical and non – statistical failures on monthly basis.

III. PARETO DISTRIBUTION

When faced with a range of issues, it is often difficult to know which to work on first. To resolve this problem, the most useful thing to do is to apply Pareto's rule. It can be described as the 80/20 rule applied to quality-control [10]. The 80/20 rule was originally formalized by Vilifredo Pareto, after studying the distribution of wealth. He noticed that about 80% of wealth was held by about 20% of the population. Several years later, Joseph Juran applied the principle to quality-control, and Pareto Analysis was born. Pareto Analysis essentially states that 80% of quality problems in the end product or service are caused by 20% of the problems in the production or service processes. Once these problems are identified, the 20% that are causing 80% of the problems can be addressed and remedied, thus efficiently obtaining quality. It can be used in a technical sense to try and improve a process by eliminating defects.

The distribution was originally developed to model income in a population. The probability density function (pdf) of the Pareto distribution was given by:

$$f(X;\ \alpha,\beta) = \frac{\alpha\beta^{\alpha}}{X^{\alpha+1}}\ ;\quad \beta \le X \le \infty$$

The cumulative distribution function of Pareto was given by the equation:

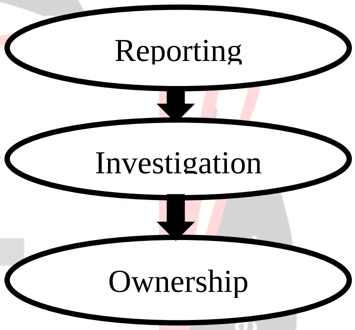
$$F(X;\ \alpha,\beta) = 1 - \left(\frac{\beta}{X}\right)^{\alpha}$$

The reliability of Pareto distribution was given as:

$$Reliability = \left(\frac{\beta}{X}\right)^{\alpha}$$

IV. FAILURE RECORDS

Failure report describes all the details related to a failure of locomotive [4]. It also includes details of failure component and subsequently taken preventive action and its compliance. Presently, the failure investigations are limited in finding out the initial observations and detailed findings. The desired failure analysis for preventive action requires failure investigation in very clear aspects, uniform standards, and integrated approach. To ease the understanding, the presented approach for line failures and out of course repairs is shown schematically in figure. Every failure of locomotive should contain following basic elements or stages. This is described in following diagram



Flow chart for Failure Records

If a computerized system is adopted for recording of above details using codes, the analysis of incidences should be carried out to investigate the major contributors of failures on various attributes. In this, Pareto's principle shall be applicable to segregate the failures into ABC groups. These elements of failure report are described in following headings.

V. REPORTING

When a loco pilot running the locomotive, faces problem in locomotive, it is his duty to troubleshoot it. When he is unable to do so, he reports the abnormality in locomotive as failure message to power controller in respective division. The control room receives the message of failure consisting of following elements.

i. Loco No.
ii. Load (Train No., Freight Load)
iii. Location (Block-Section, Station, Division, Railway, Gradient)
iv. Line Message
v. Description of Failure (Events)

Along with other details, the description of failure is also reported on the Repair Book of the locomotive kept during running.

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VI. INVESTIGATION

The technical investigation of failure may be considered to be in following four sub-stages:

A. Before Arrival

The technical investigation of the failure starts from the receipt of message itself [7]. People starts asking about the schedules (due and done), previous history and out of course repairs, trends of health indicators. The trends of following details must be examined from the failure message itself when the locomotive is on-line

i. Health indices
ii. Last work done

Health indices of a locomotive include various measurable parameters. These can be grouped also operational indices and maintenance indices. Operational parameters include booster air pressure (BAP), fuel oil pressure (FOP), and Water Temperature etc., which are basically reported by drivers in repair book kept in the locomotive itself. Maintenance indices include the parameters measured during or after the maintenance.

B. On Arrival

On arrival of failure locomotives, all the information collected before its arrival should be used to investigate the failure. The driver's repair book is studied and its abstract is included into the failure message. The failure locomotive is investigated visually in dead condition itself to identify the reason of failure as earliest as possible. It is because, superior levels are eager to know the reason of failure, and there seems to be a competition in giving the information as earliest as possible. The arrival date and time need to be recorded in failure message to know the time taken by traffic in sending the failure locomotive to its base shed.

C. On Platform

Based on the priority, the failure locomotive is given a placement in the platform for its thorough examination through initial testing like procedure or even an in-depth investigation on the related main assembly or sub-assembly. In fact, this is known as failure investigation in conventional sense. Initial observation basically includes the two sets of indicators of the health of the locomotive. These are the tell-tale signs and operating parameters. In fact, for most of the cases, the initial observation itself becomes the gateway of detailed findings. The investigation team of experts identifies the responsible sub-assembly or component and the locomotive is accordingly subjected to corrective action in the form of out of course repair. Every failure of a locomotive involves a main component. It may or may not be the failure of this component, but its malfunctioning. Based on initial observations, the detailed findings are investigated. It includes finding out the responsible component and nature of defects. It may also require various facts such as

i. History of schedule and works
ii. Trends analysis of basic parameters
iii. Chronology of failure events
iv. Remarks of driver on the repair book
v. Fault logs

VII. ASSESMENT

After the component responsible for failure is identified, in-depth investigations are made regarding its last fitment, involved manpower (technician and supervisor), material receipts, make, model, material quality etc. This is done to identify the responsibility factor of failure. The assessment of failure involves following set of elements

i. Root cause
ii. Responsible factor

Root Cause: Root cause of the failure is the basic nature of defect observed in the failure. It depends upon the attribute of the failure. It explains the root of failure.

Masterdom: Responsible factor is used to ascertain the responsibility of failure in an overall aspect.

VIII. COMPUTERIZATION

The analysis is to be done using computers; hence it is basic step to devitalize the data of failure through MS – Excel to generate a computerized database. Being requisite for analysis [9], this computerized database shall offer following basic advantages

i. Records can be edited
ii. Easy to validate
iii. Easier to search records
iv. Less risk of data to be lost
v. Data filtering/sequencing
vi. Information can be searched quickly
vii. Easy to modify data
viii. Information is easy to access any time
ix. Reduces data entry, storage space and retrieval cost
x. Easy to communicate or transfer

Table – 1 Weekly failure data recorded

Week	Pump	Traction Motor	Cylinder Head	Piston	Expresser	Heat Exchanger	Turbo Charger	Control Cabin
1	2	1	2	1	1	-	-	2
2	1	-	1	2	2	-	-	1
3	2	1	1	1	1	1	-	1
4	2	-	2	-	2	-	-	1

Fig – 1 Graphical representation of weekly failure data

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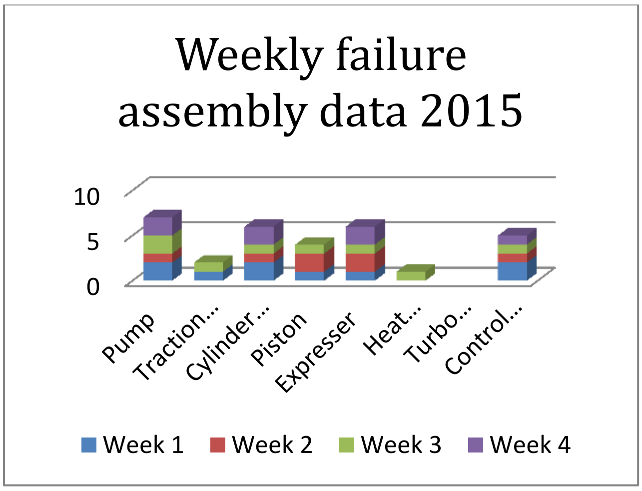

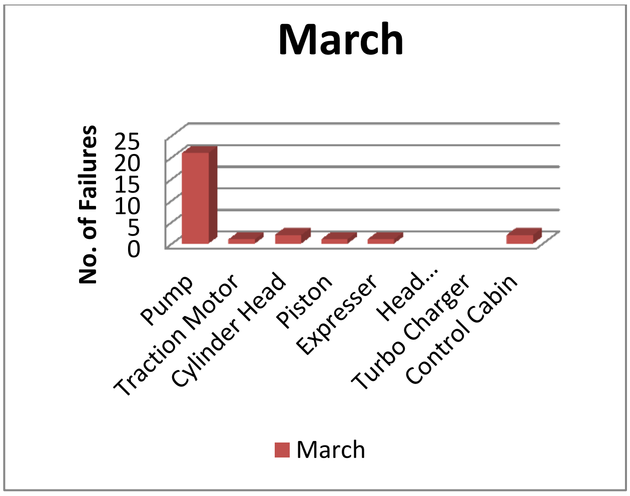

Fig – 2 Graphical representation of No. of failures in March 2015

Table 2, 3 & 4 containing the data of assembly failure over a three year (2013 – 15)

Table – 2 No. of failure of assembly 2013

Assembly	Failure	Cumulative Failure	Cumulative Percentage
Pump	280	280	34%
Control Cabin	145	425	52%
Cylinder Head	98	523	64%
Piston	92	615	75%
Expresser	65	680	83%
Traction Motor	56	736	90%
Turbocharger	24	810	99%
Heat Exchanger	12	822	100%

Table – 3 No. of failure of assembly 2014

Assembly	Failure	Cumulative Failure	Cumulative Percentage
Pump	275	275	40%
Control Cabin	125	400	58%
Cylinder Head	85	485	71%
Piston	75	560	82%
Expresser	50	610	89%
Traction Motor	45	655	95%
Turbocharger	20	675	98%
Heat Exchanger	12	687	100%

Table – 4 No. of failure of assembly 2015

Assembly	Failure	Cumulative Failure	Cumulative Percentage
Pump	245	245	54%
Control Cabin	100	345	76%
Cylinder Head	25	370	82%
Piston	25	395	87%
Expresser	20	415	92%
Traction Motor	15	430	95%
Turbocharger	14	444	98%
Heat Exchanger	8	452	100%

IX. Failure Exploration

The failures are very interesting and useful source of learning to improve the reliability of locomotive. With a positive view, failures are the opportunity and challenge for an organization. Hence, it is expected that once a failure has occurred, it should not occur in future. In fact, this is theme of preventive maintenance adopted in Indian

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Railways for the diesel locomotives [6]. Although, the failure reports get completed by any means, encompassing the investigation in the form of root cause and responsibility of failure, but its real outcome of this effort is to conclude into a strategic analysis which can help in planning for preventive action to improve the reliability of diesel locomotives. The objective of this analysis is to identify the weak areas where the costly and critical resources of maintenance should be directed for their optimum utilization, including the related agencies in the chain system. Thus, the strategy should be based on the Pareto analysis which segregates the incidences and costs. By applying the principle of scientific management the present approach emphasis to ease the understanding so that everyone can know and think uniformly about the failures and subsequent action for reliability. This shall also require readily available comprehensive analysis of exception statements on availability of maintenance resources, and subsequent preventive actions against the observed root causes. The findings must be communicated to every maintenance staff through proper counselling, training and testing.

Information related to every aspect of maintenance should be made readily available to inculcate responsive and responsible attitude. As other reports are prepared on monthly basis, this study recommends carrying out the failure analysis on monthly basis over the details of failure reports. The analysis is to be designed to meet various requirements discussed earlier and satisfy aspirations of superior levels. Hence, incidences of failure on following attributes should be examined under main headings. Based on the Pareto principle, the strategic analysis shall contain following elements.

i. Defect Analysis
ii. Root causes analysis
iii. Ownership analysis

X. Defect Analysis

From engineering point of view and assessment of the trend of failures, analysis of defects is the most important part of the proposed strategic analysis. Like every phenomenon, a given component may fail repeatedly due to same defect, may be originating due to various reasons. Hence, every failure component or assembly must be analysed for number of cases of incidences of similar defect. As explained earlier, the defects have origin as root cause. Repetition of same defects demonstrates that suitable action has not been taken after the previous incidences of similar defect. It helps in knowing the failure of system in identification of the root cause and subsequent accountable of ownership of the failure of component and, in turn, that of the locomotive. There is also probability that the root cause has been identified and ownership has been fixed, but still there is no action or the result may take time due to magnanimous of the system [5].

A. Root Cause Analysis

Root cause is the aspect from where the defect originates. The root cause of failure of a component should be seen from engineering point of view which shall necessitate the research and design aspect of the failure component or related system. For example, a shaft may be broken at any point over its span or length, but this is not the root cause of its failure, but it is only the defect. The root cause may be in the quality of material, design, assembly procedure, running maintenance, effects of other system, etc. These are few of the possible root causes. It is understood that if the root cause of repeated defects is identified and verified properly, the fixing of accountability is automatically done. Then, the next step of preventive action is to be planned.

One should also notice that defects which not occur in rarely or irregularly attract the attention only for once. It is called corrective action. Also, the defects with repeated incidences attract for attention. Such attention is called preventive action.

Repeated cases of root cause for a given defect explicitly conforms the failure of the decision on the ownership aspect. There is also probability that the responsible agency is not taking sufficient corrective or preventive action regarding the repeated root cause of a given defect.

B. Ownership Analysis

The ownership of a failure is the factor due to the root cause of the defect in the failure component. For a given period, may be months, the database of failures can be analysed to get the contribution of these agencies into the incidences of failures. In fact, this part of the analysis is most critical from the administrative point of view as various departments or sections are involved. Based on this criteria, the responsible agencies can be asked plan and initiate the preventive action in an effort to avoid failures at least on their accountably. It is observed that most of the cases of failures are dealt by diesel sheds, and other units may not be aware of the truth of the root cause of failures. Hence, it is understood that diesel shed need to regularly communicate the external units about the defects and root causes of failures.

Following agencies are accounted for failures
(1) Research Designs & Standard Organization
(2) Stores and Supplies
(3) Production
(4) Maintenance (Diesel Shed)
(5) Operation (Division)

This grouping is based on the control areas possible involvements. Ownership of every failure of the locomotive can be attributed on accountable of their ownership.

XI. Analysis of Failure Data

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To access the failure criticality of the assembly components the Pareto principle is used to analyse the data recorded over the years [8]. By using this technique the paper identifies the main vital components of the assembly which are non-trivial for the reliability of the locomotives. This in turn reduces the effort which is wasted in non-trivial components hence increases the system effectiveness and reliability. In Figure 3, 4 and 5, Pareto charts are plotted for assembly failure data recorded for year 2013, 2014 and 2015 respectively.

Fig – 3 Pareto Chart of year 2013

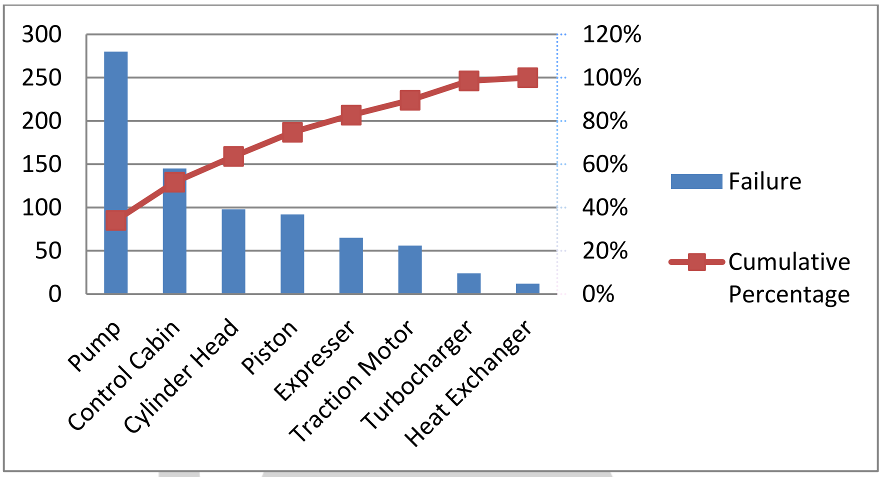

Fig – 4 Pareto Chart of year 2014

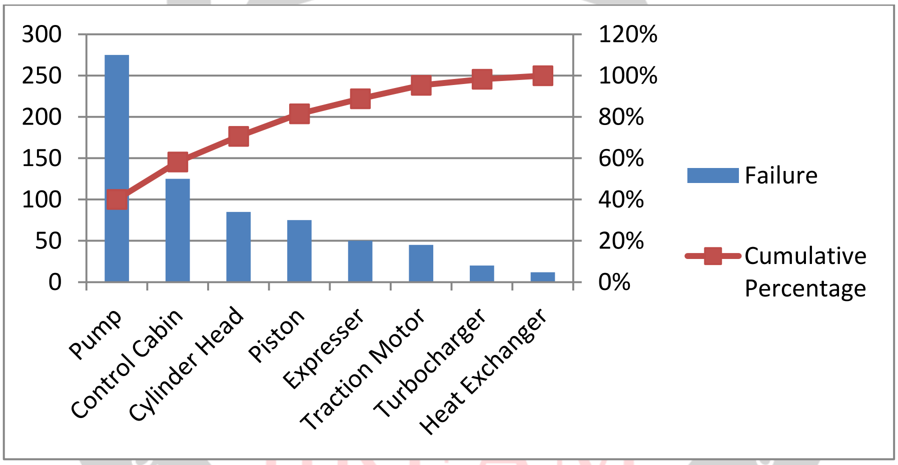

Fig – 5 Pareto Chart of year 2015

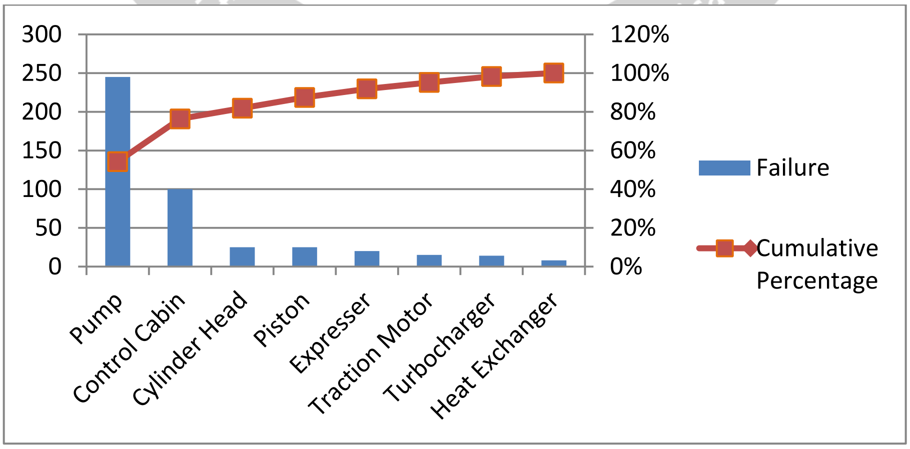

Fig 6 shows the yearly failure assemblies in diesel locomotive. From the plotting, it is clear that pump and control cabin are more sensitive in terms of failure.

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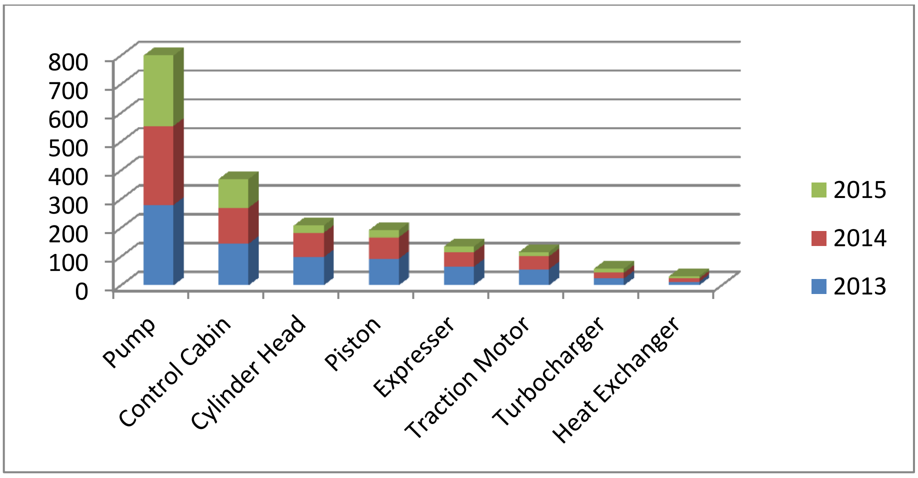
Fig – 6 Failure Assembly (Year-wise)



XII. CONCLUSION

Starting with the diesel engine technology, the article discusses the information related to role and current traction of diesel in Indian Railways. Based on the study, the paper derives a conceptual idea from the current maintenance and repair process and also identifies many points of motivation for the present subject of reliability and its analysis. Subsequently, paper briefly describes many topics of repair such as design considerations including maintenance, its objective, approaches and schedules. In addition to this, the study also considers basic theories of management.

Failures are the most important aspects in maintenance of diesel locomotives hence; scientific management is very essential feature for such a complex system. It requires similar understanding and approach towards record keeping and analysis related to reliability. In absence of such similarity in approach, the system fails in communication of failures and planning reliability to the root level of workmanship. Based on the previous studies, experience and observations, the study recommends an ideal system of recording of most commonly used parameter of reliability i.e. line failures. It includes various aspects related to failures for a comprehensive record. It suggests three stages of recording: reporting, investigation, and assessment. Looking on the various advantages, the study also recommends computerization of the database of the failure which shall be useful in the analysis. To simplify the study hypotheses, every failure should be counted for a defect in a component. Every defect has its origin in its root cause, and in turn, every root cause has its ownership. In addition to the proposed Locomotive System Theory, based on this principle, the paper recommends a hierarchical system of analysis of failures which can be utilized for strategy and decision making. To summarize, the present study basically contributes following aspects:

(1) System of Recording and Database of failures

(2) Locomotive System Theory and its applications

(3) Hierarchical system for strategic analysis of failures

In this work a detailed failure data analysis of the locomotive assemblies was carried out by using Pareto Method. From the analysis components which are critical to the assembly failure were identified. Analysis suggests reliability of the locomotive is largely govern by Pump and control cabin failures. Eventually, the study observes that every failure of a component, or in turn, a locomotive involves many complexities.

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