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Failure Rate Analysis of IC Engine Components

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ABSTRACT: *The main aim of this paper is to analyze the failure of IC engine components. By analyzing the failure rate of the components in IC engines and also to find out failure range for each and every component. For doing, the real time failure data's and their life periods for each components in the IC engines has been analyzed, from these data's the amount of defects in their original production activities and also defects after the design modification work also been concluded. Based on the failure data's the criticality for each component has been ranked out and risk priority number (RPN) and the corresponding transformed scale for each component has been sorted.*

Keyword(s): *risk priority number, failure range, transformed scale, Design modification.*

I. INTRODUCTION

Internal combustion (IC) engine is a complex power generating machines and used widely in automotive industry, which the failure rate is high. Carrying out the IC engine fault diagnostic methods have been studied and still a lasting topic for scientists. Failure rate is the frequency with which a component fails. The failure rate of a system depends on the time, with the rate varying over the life cycle of the system. Failure rate is defined as the total number of failures within an item population divided by the total time expended by that population, during a particular measurement interval under stated conditions. Engine failures result from a complex set of conditions, effects, and situations. To understand why engines fail and remedy to those failures, one must understand how engine components are designed and manufactured, how they function, and how they interact with other engine components. The failure rate is often thought as the probability that occurs in a specified interval beforetime. Failure is often denoted by the Greek letter λ (lambda) and is important in reliability engineering. In practice, the mean time between failures 1/λ (MTBF) is often reported instead of the failure rate. If the failure rate is assumed constant, it may be useful. The MTBF is an important system parameter in systems where failure needs to be managed, in particular for safety Systems. The MTBF appears frequently in the engineering design equipments, where the time to recover from failure can be neglected and the failure remains constant with respect to time. It is simply said as failure in the inverse of the MTBF. Failure rates can be expressed using any measure of time but hours is the most common unit in practice.

II. Literature review

Ravindra Prasad etal [1] used a numerical method is presented for calculating the temperature fields in a semi-adiabatic diesel engine piston having a cooling oil canal. The crown face of the piston is coated by a 2 mm thick oxide based ceramic insulating material. The non-ideal thermal contacts between the piston circumference and cylinder wall are also considered. A detailed analysis has been given for estimating the boundary conditions of the cylinder-piston assembly of an internal combustion engine. The isothermic distribution in the piston body and the heat flow rate through the different cooling media at four different engine loads have been depicted both for the cases with and without insulation coating. The results indicate a reduction (12–30%) in heat loss through the piston by use of an insulation coating at the piston crown face, assuming that both the heat transfer process from and the temperature of the combustion products remain unchanged.

D.J. Pickens [2] in this paper describes the theory and use of a method for estimating the service life of an internal combustion (I.C.) engine based on experimental evidence and the law of adhesive wear. A simple computer program is described, which predicts the overall life of an I.C. engine from its design data and a typical sample of its particular running conditions. The use of the program for an engine generator set operating on biogas at a farm site is given as an example. We are thoroughly implementing the maintenance, inspection, and operation of diesel engines in order to maintain them in optimum working condition. However, despite the remarkable progress in technology, the number of failures in newly built diesel engine has been increasing. Judging from a number of instances, they seem due to design defects, material defects, and manufacturing faults. Once a diesel engine failure occurs, a ship owner not only loses profits, but can also encounter other major problems, such as the loss of life and environmental damage. Over a period of several years (to make clear the actual conditions) we have attempted to gather and accumulate data on failures and on abnormalities in regard to newly built diesel engines from 15 Japanese ship owners/managers. Our investigation shows that most of these failures are attributable to poor engineering design and poor quality control. Because we (ship owners/operators/managers) want to help improve the reliability of these high-powered diesel engines, we are willing to work with engine designers and builders. We will, therefore, based upon our analysis results, make constructive and positive proposals to engine designers and builders to help them eliminate these problems.

V.Macian [3] concluded combustion failure diagnosis techniques for reciprocating internal combustion engines have been developed over the last few years. Nowadays the most usual techniques are based on the crankshaft instantaneous speed or on engine vibrations. These methods, although successfully in use, may be applied only to maintenance tasks or to low and moderate engine speeds. In this paper, a controller for the correction of injection failures is presented. The aim of the algorithm is to ensure that the same quantity of fuel is injected into each one of the cylinders. This governor can be applied to the full operating range of the engine. The injection failure detection and identification technique is based on the measurement of the turbocharger instantaneous speed and its treatment in the frequency domain. The simulation of the controller shows an effective reduction in the dispersion between cylinders to a level below 2 per cent.

An expert system solves problems using a process that is very similar to the methods used by the human expert. An Expert System is a computer program designed to model the problem solving ability of a human expert (Durkin, 1994) [2]. When compared to a mechanic, an Expert system would present the following advantages: It is always available and anywhere; it is replaceable; it is not perishable; it is consistent in performance and speed; and its cost is affordable. Currently, there are Expert Systems and computerized tools for diagnosing and troubleshooting car faults in which engine faults can also be diagnosed. Some heavy duty vehicles have On Board Diagnostics (OBD). OBD was developed to provide improved, information - rich visibility to complex operation and control mechanisms that many service technicians still treat as black boxes(Barkai, 2001) [3]. When a simple correlation exists between the OBD malfunction data and its root cause, OBD is a useful troubleshooting tool but it provides little assistance in diagnosing more complex situations such as multiple fault codes or inconsistent information (Barkai, 2001) [3].

The mean time between the failures of the Crank case, Connecting rod, Bearing, Cylinder head, Timing gear IC engine components are collected and they are as follows.

S.no	Crank case (Hrs)	Conn-ecting rod (Hrs)	Beari ng (Hrs)	Cylinder head (Hrs)	Timing gear (Hrs)
1)	20.2	20.13	20.1	20.131	21.231
2)	25.31	25.21	25.3	25.243	47.738
3)	30.54	31.33	30.5	30.335	72.363
4)	35.23	36.41	35.7	35.44	101.94
5)	41.62	41.52	40.9	40.556	130.63
6)	46.84	46.63	46.1	45.634	26.342
7)	52.00	51.74	51.3	50.738	51.844
8)	57.12	57.12	56.5	55.846	78.863
9)	62.45	62.93	61.8	60.95	106.13
10)	67.38	68.13	66.9	65.134	135.72
11)	72.14	73.14	72.1	70.24	31.433
12)	78.02	80.25	77.3	75.331	56.936
13)	83.14	86.31	82.5	80.424	84.632
14)	88.33	95.51	87.7	85.533	111.24
15)	93.60	103.7	93.9	90.64	140.86
16)	98.75	110.8	98.1	95.755	36.521
17)	103.9	116.9	104	100.86	62.14
18)	109.1	121.2	110	105.97	90.743
19)	114.5	127.1	116.4	110.18	117.35
20)	125.8	135.4	123.6	115.16	145.9
21)	130.9	140.5	130.7	120.27	40.83
22)	136.0	155.8	139.9	125.38	66.51
23)	143.2	145.6	148.2	130.42	95.83
24)	152.6	150.7	166.3	135.536	123.46
25)	160.7	160.9	180.5	140.74	150.16

The mean times between the failures of the Crank shaft, valve, camshaft, piston, Cam shaft gear of IC engine components are collected and they are as follows.

These tabulation are done for chi square test, this is done for testing the null hypothesis which states that there is no significant difference between the expected and observed result. Test is done for following IC engine components.

- Crankcase
- Connecting rod
- Bearing
- Cylinder head
- Timing gear
- Crankshaft
- Valve
- Camshaft
- Piston
- Camshaft gear
- Piston
- Camshaft gear

s.no	Crank shaft (Hrs)	Valve (Hrs)	Cam shaft (Hrs)	Piston (Hrs)	Cam shaft gear (Hrs)
1)	20.12	20.133	25.345	32.331	20.131
2)	45.653	26.242	52.954	25.248	25.248
3)	70.263	31.336	78.681	32.331	30.361
4)	95.745	36.45	111.484	36.462	35.481
5)	120.463	41.531	142.231	42.634	40.593
6)	25.232	46.542	25.345	53.234	45.684
7)	50.748	52.743	52.954	60.963	50.736
8)	75.381	57.856	78.681	60.963	55.881
9)	100.854	62.931	111.484	65.148	60.994
10)	125.578	66.14	142.231	70.334	65.16
11)	30.345	71.25	30.453	85.774	70.271
12)	55.859	76.364	57.133	92.834	75.384
13)	80.493	82.431	85.734	92.834	80.496
14)	105.948	87.543	117.563	97.965	85.584
15)	130.683	93.634	148.481	103.136	90.676
16)	35.432	98.743	35.564	116.463	95.781
17)	60.963	103.863	62.288	121.574	100.891
18)	85.584	109.943	92.145	121.574	105.941
19)	110.234	115.245	123.641	126.683	110.136
20)	135.791	121.363	155.563	131.743	115.241
21)	40.548	125.474	41.671	141.948	120.374
22)	65.148	132.694	67.361	147.154	125.483
23)	90.631	138.785	98.268	147.154	130.594
24)	115.348	145.836	130.937	153.236	135.684
25)	140.848	150.945	160.648	160.341	140.731

METHODOLOGY CHI SQUARE TEST

From the life time of all the IC engine components shown in the tabulation the chi square test has been conducted to estimate the mean life time of IC engine components. Chi square test is a statistical test commonly used to compare observed data with data we would expect to obtain according to a specific hypothesis. The chi square test is always testing the null hypothesis which states that there is no significant difference between the expected and observed result. Chi square is the sum of the squared difference between observed (o) and the expected (e) data (or the deviation, d), divided by the expected data in all possible categories. The degrees of freedom are determined by calculating as the number of components. A relative standard is determined as the basis for accepting or rejecting the hypothesis. The relatively standard commonly used is p>0.05 where p is the probability. Chi square should not be calculated if the expected value in any category is less than 5.

Chi square test is given by,

[2T/ψ²2n, 1-α/2; 2T/ψ²2n, α/2]

Where T= Total time,

α=confidence level,

n= number of components,

III. CALCULATION

1. Crankcase:

The confidence level α is taken as 95%.T is the total mean time of IC engine components from the data's collected.

[2T/ψ²2n,1-α/2;2T/ψ²2n,α/2]
[2*2392.12/ψ²54, 0.975;2*2392.12/ψ²54, 0.025]
[4784.24/ψ²54, 0.975;4784.24/ψ²54, 0.025]
[4784.24/68.3, 0.0975;4784.24/73.6, 0.025]
[68.3; 73.6]
[1/68.3;1/73.6]
[0.0146; 0.0135]

The failure range of the crankcase is from 0.0135 to 0.0146 months.

2. Connecting rod:

The confidence level α is taken as 95%.T is the total mean time.

[2T/ψ²2n, 1-α/2; 2T/ψ²2n, α/2]
[5639.14/ψ²60, 0.975;5639.14/ψ²60, 0.025]
[5639.14/76.2, 0.975;5639.14/83.3, 0.025]
[76.2; 83.3]
[1/76.2;1/83.3]
[0.0131; 0.0120]

The failure range of the connecting rod is from 0.0120.to 0.0131 months.

3. Bearing:

The confidence level is taken as 95%.T is the total mean time.

[2T/ψ²2n, 1-α/2; 2T/ψ²2n, α/2]
[2*2624.65/ψ²54, 0.975;2*2624.65/ψ²54, 0.025]
[5249.30/ψ²54.975;5249.3./ψ²54.025]
[5249.30/73.4, 0.975;5249.3/81.5, 0.025]
[73.4, 81.5]
[1/73.4;1/81.5]
[0.0136; 0.0122]

The failure range of the bearing is from 0.0122.to 0.0136 months

4. Cylinder head:

The confidence level α is taken as 95%.T is the total mean time.

[2T/ψ²2n, 1-α/2; 2T/ψ²2n, α/2]
[2*2012.43/ψ²50, 0.975;2*2012.43/ψ²50, 0.025]
[4024.87/ψ²50, 0.975;4024.87/ψ²50, 0.025]
[4024.87/63.3, 0.975;4024.87/71.4, 0.025]
[63.3; 71.4]
[1/63.3;1/71.4]
[0.0157; 0.0140]

The failure range of the cylinder is from 0.0140 to 0.0157 months

5. Timing gear:

The confidence level α is taken as 95%.T is the total mean time.

2T/ψ²2n, 1-α/2; 2T/ψ²2n, α/2]
[2*2309.64/ψ²54, 0.975;2*2309.64/ψ²54, 0.025]
[4619.28/ψ²54, 0.975;4619.28/ψ²54, 0.025]
[4619.28/68.3, 0.975;4619.28/75.6, 0.025]
[68.3, 75.6]
[1/68.3, 1/75.6]
[0.0146, 0.0132]

The failure range of the timing gear is from 0.0132 to 0.0146 months.

6. Crankshaft:

The confidence level α is taken as 95%.T is the total mean time.

[2T/ψ²2n, 1-α/2; 2T/ψ²2n, α/2]
[2*2013.89/ψ²50, 0.975;2*2013.89/ψ²50, 0.025]
[4027.78/ψ²50, 0.975;4027.78/ψ²50, 0.025]
[4027.78/63.3, 0.975;4027.78/71.4, 0.025]
[63.3; 71.4]
[1/63.3;1/71.4]
[0.0157; 0.0140]

The failure range of the crankshaft is from 0.0140 to 0.015 months.

7. Valve:

The confidence level α is taken as 95%.T is the total mean time.

2T/ψ²2n, 1-α/2; 2T/ψ²2n, α/2]
[2*2309.83/ψ²54, 0.975;2*2309.83/ψ²54, 0.025]
[4619.66/ψ²54, 0.975;4619.66/ψ²54, 0.025]
[4619.66/68.3, 0.975;4619.66/75.6, 0.025]
[68.3; 75.6]
[1/68.3;1/75.6]
[0.0146; 0.0132]

The failure range of the valve is from 0.0132 to 0.0146 months.

8. Camshaft:

The confidence level α is taken as 95%.T is the total mean time.

[2T/ψ²2n, 1-α/2; 2T/ψ²2n, α/2]
[2*2624.76/ψ²58, 0.975;2*2624.76/ψ²58, 0.025]
[5249.52/ψ²58, 0.975;5249.52/ψ²58, 0.025]
[5249.52/73.4, 0.975;5249.52/81.5, 0.025]
[73.4; 81.5]
[1/73.4;1/81.5]
[0.0136; 0.0122]

The failure range of the camshaft is from 0.0122 to 0.0136 months.

9. Piston:

The confidence level α is taken as 95%.T is the total mean time.

2T/ψ²2n, 1-α/2; 2T/ψ²2n, α/2]
[2*2625.30/ψ²58, 0.975;2*2625.30/ψ²58, 0.025]
[5250.60/ψ²58, 0.975;5250.60/ψ²58, 0.025]

[5250.60/74.4, 0.975;5250.60/82.6, 0.025]
[74.4; 82.6]
[1/74.4;1/82.6]
[0.0134; 0.0121]

The failure range of the piston is from 0.0121 to 0.0134 months.

10. Camshaft gear:

The confidence level α is taken as 95%.T is the total mean time.

[$2T/\psi^2 2n$, $1-\alpha/2$; $2T/\psi^2 2n$, $\alpha/2$]
[$2*2013.53/\psi^2 50$, 0.975;$2*2013.53/\psi^2 50$, 0.025]
[$4027.06/\psi^2 50$, 0.975;$4027.06/\psi^2 50$, 0.025]
[4027.06/73.4, 0.975;4027.06/81.5, 0.025]
[73.4; 81.5]
[1/73.4;1/81.5]
[0.0136; 0.0122]

The failure range of the piston is from 0.0122 to 0.0134 months.

From these entire test conducted the failure rate of the IC engine components are tabulated as follows.

S.no	Component	occurrence	description	Potential failure range	Rank
1	Crankcase	High	Repeated failures	0.0135 to 0.0146	3
2	Connecting rod	Moderate	Occasional failures	0.0120. to 0.0131.	8
3	Bearing	High	Repeated failures	0.0122.to 0.0136	3
4	Cylinder head	High	Repeated failures	0.0140 to 0.0157	1
5	Timing gear	Moderate	Occasional failures	0.0132 to 0.0146.	4
6	Crank shaft	High	Repeated failures	0.0140 to 0.0157	1
7	Valve	High	Repeated failures	0.0132 to 0.0146.	4
8	Cam shaft	Moderate	Occasional failures	0.0122 to 0.0136.	6
9	Piston	High	Repeated failures	0.0121 to 0.0134.	7
10	Camshaft gear	moderate	Occasional failures	0.0122 to 0.0134.	4

IV. FAILURE MODE AND EFFECTS ANALYSIS

FMEA (Failure Modes and Effects Analysis) is used to identify potential failure modes, determine their effects on the operation of the product, and identify actions to mitigate the failures. Design FMEA is methodology for analyzing potential reliability problems early in the design phase where it is possible to take actions to reduce design defects by modification. It is a product design verification activity that can help avoid a large percentage of product design problems before the design is finalized. While anticipating every failure mode is not possible, the development team should formulate a list of potential failure modes as extensively as possible.

A failure mode is the manner by which an equipment or machine failure is observed. It generally describes the way the failure occurs. In FMEA, occurrence is ranked according to the failure probability, which represents the number of failures anticipated during the design life of an item. The range of values and the linguistic terms used to describe the frequency of the failure mode occurrence Failure modes can be observed and represented by occurrence and failure modes can be considered as defects representations of the subsystem (assembly or components). In this paper, we try to find the relationship between occurrence and defects number to estimate the value of k. The aim is to obtain creditable reliability prediction through making good use of design FMEA result, to reduce the time for gathering valid reliability information, and to increase the prediction efficiency.

V. RELIABILITY PREDICTION USING DESIGN SIMILARITY METHOD

New diesel engines are always developed on the basis of existing ones, a great deal of similarities exist between them although there are some variations. Design similarity method utilizes fault rates of existing components to predict fault rates of new products. The failure rate of an existing component can be obtained from sources such as company warranty records, customer maintenance records, component suppliers, or expert elicitation from design or field service engineers. Defects in a component are imperfections that cause inadequacy or failure. The imperfections are always caused in the design and manufacture process. The relationship between failure rate and defect number is expressed as follows:

$\lambda_0 = m*d_0$ (1)

Where λo is the failure rate of existing similar components, do denotes the total number of known defects, and m is a coefficient.

The failure rate of the new component is calculated as follows:

$\lambda_n = m*d_n$ (2)

Where λn is the failure rate of the new component, dn is the total

Defects number of the new design:

$d_o = d_o + d_i - d_e$ (3)

Where d_n is the total number of new defects caused by design modification, de is the total number of eliminated defects by design modification.

According to Eq (1), Eq (2) and Eq (3), the failure rate of the new component can be calculated as:

$\lambda_n = \lambda_o(d_o+d_i-d_e/d_o)$ (4)

The difference between the failure rates of the new and existing products is defined as Δλ, then:

$\Delta\lambda = \lambda_o-\lambda_o = k\lambda_o$ (5)

Where k represents the coefficient considering the reliability improvement

Because of design modification, then:

$\lambda_n = \lambda_o-\Delta\lambda = \lambda_o(1-k)$ (6)

and Eq. (4) can be rewritten as:

$\lambda_n = \lambda_o(1-d_e-d_i/d_o)$ (7)

By comparing Eq. (6) and Eq. (7), the relationship between k and defects number is given as follows:

$k = d_e-d_i/d_o$ (8)

After determining the values of d_o, d_e and d_i the coefficient k can be obtained.

Then the failure rate of the new subsystem/ component can be calculated according to Eq. (7).

After predicting the reliability value of each component, the reliability of the diesel engine system can be estimated on the basis of the reliability block diagram model, which is expressed in Eq. (9):

$\lambda_s^* = \Sigma\lambda_i^*$

where λ_s^* refers to reliability prediction value of the engine system and λ_i^* refers to the reliability value of the its component.

When using design similar method. It is often difficult to obtain defects number exactly in engineering practice. This motivates us to find a relatively feasible method to estimate the defects number.

VI. ESTIMATION k ON THE BASIS OF FMEA:

FMEA (Failure Modes and Effects Analysis) is used to identify potential failure modes, determine their effects on the operation of the product, and identify actions to mitigate the failures. Design FMEA is methodology for analyzing potential reliability problems early in the design phase where it is possible to take actions to reduce design defects by modification. It is a product design verification activity that can help avoid a large percentage of product design problems before the design is finalized. While anticipating every failure mode is not possible, the development team should formulate a list of potential failure modes as extensively as possible. Failure modes can be observed and represented by occurrence, and failure modes can be considered as defects representations of the subsystem (assembly or components). In this work, the relationship between occurrence and defects number to estimate the value of k has been done. The aim is to obtain creditable reliability prediction through making good use of design FMEA result, to reduce the time for gathering valid reliability information, and to increase the prediction efficiency. According to table 1, there exists a nonlinear relationship between failure rate and occurrence rank. It is not possible to produce a linear function of occurrence rank. By multiplying the failure rate by eight, the relationship can be transformed to linear. The transformed scale of failure rate is also shown in table 1. The defects number of existing items is estimated by:

$d_o = \Sigma d_j$ (9)

Where d_j is the transformed scale of failure mode occurrence in design FMEA. After design modification, the total number of new defects is given as:

$d_i = \Sigma d_t$ (10)Where dt is the transformed scale of the ith new failure mode in design FMEA. The eliminated defects number is given as

$d_e = \Sigma d_k$ (11)

Where d_k is the transformed scale of kth failure mode in design FMEA. Then the factor k can be calculated.

Case study

A cylinder head gasket is a gasket that sits between the cylinder block and cylinder head in a diesel engine. It is an integral component of the engine and the most critical sealing application in any engine. The cylinder head gasket must maintain the seal around the combustion chamber at peak operating temperature and pressure. The gasket must seal against air, coolants, combustion and engine oil at their respective peak operating temperature and pressure. The materials used and design employed must be thermally and chemically resistant to the products of combustion and the various chemicals, coolants and oils used in the engine.

In the design process of a new type of diesel engine on the basis of previously used ones, suppose that design modification is made by increasing the flange of cylinder block. The aim is to decrease the occurrence of "Gas leakage" and to reduce the performance degradation probability subsequently. However, the design modification causes a new potential failure mode.

The steps are shown as follows:

(1) Calculate the sum of transformed scales of five failure modes in the previously designed diesel engine:

d_o=0.004+0.004+0.00005+0.00005+0.004=0.0121

(2) Calculate the sum of transformed scales of potential failure modes in the new design:

d_i = 0.00005

(3) Calculate the sum of transformed scales of eliminated failure modes in the new design:

d_e = 0.004

Then the factor k can be obtained according to Eq. (8):$K=d_e-d_i/d_o$=0.004- 0.00005/0.0121= 0.3264

From the failure range obtained from the chi-square test for each component in the IC engines the transformed scale for each component is listed as follows.

This tabulation is done by considering occurrence in nature.

- Very low
- Low
- Moderate
- High
- Very high

Rank	occurrence	Description	Potential failure rate	Transformed scale
1	Very low	Failure is unlikely	<1/15xE 5	0.000005
2 3	Low	Relatively few Failures	About1/15xE4 About 1/15xE3	0.00005 0.0005
4 5 6	Moderate	Occasional failures	About 1/2xE3 About1/4 xE2 About 1/80	0.004 0.02 0.1
7 8	High	Repeated failures	About 1/20 About 1/8	0.4 1.0
9 10	Very High	Failure is almost Inevitable	About 1/3 >1/2	2.7 4.0

Calculation of failure rate of old component and new component:

$\lambda 0 = m.d0$
$0.1156 = m*0.0121$
$m = 0.1156/0.0121$
$= 9.553$
$d_n = d_o + d_i + d_e$
$= 0.0121 + 0.00005 - 0.004$
$= 0.00815$

Where,

d_i =total number of new defects caused by design modification

d_e =total number of eliminated defects by design modification

$\lambda_n = m.d_n$

Where,

λ_n= failure rate of new component

d_n= total number of defects in the new design

$\lambda_n = m.d_n$
$= 9.553*0.00815$
$= 0.0778$
$\lambda = \lambda_o(d_o + d_i - d_e/d_o)$
$= 0.1156(0.0121 + 0.00005 - 0.004/0.0121)$
$= 0.0778$
$\Delta\lambda = \lambda_o - \lambda_n$
$= k\lambda_o$
$= 0.3264*0.1156$
$= 0.0377$

Where $\Delta\lambda$=difference between the failure rates of the new and existing products.

MARKOV CHAIN

A markov chain is an order series of states connected by an appropriate transition matrix, a rectangular array in which the elements are transition probabilities which are such that the probability of an event in time period n+1 depends only on the state of the system in time period n.

The purpose of using a markov chain is to obtain the failure probabilities for the future.

There is a finite set of states numbered 1, 2... n. The process can be in one, and only one, of these states at a given time are the so-called transition probability P_y, the probability of a transition from state i to state j, is given for every possible combination of i nd j, including i=j. These transition probabilities are assumed to be stationary (unchanging) over the time period of interest and independent of how state i was reached. Either the initial state in which the process begins is known, or probability distribution of initial states is specified. The transition probabilities P_y can be arranged in the form of what is termed a one-stage stationary transition probability matrix P:

	To		
From	1	2	3 …. n
1	p11	p12	p13 ….p1n
2	p21	p22	p23 ….p2n
3	p31	p32	p33….p3n
n	pn1	pn2	pn3….pnn

P is a square matrix with non-negative elements and row elements that sum to unity. Such a matrix is called a stochastic matrix. Any stochastic matrix can serve as a matrix of transition probabilities; together with an initial probability distribution of states, it completely defines a markov chain.

MARKOV ANALYSIS ALGORITHM

Before we start analyzing a markov process, a problem is presented in which the states of activities are brands of products and transition probabilities represent the likelihood of customers moving from one brand to another. The various steps involved may be summarized as follows:

1. Determine the retention probabilities (groups of customers that do not switch) by dividing the no of failure components retained for the period under review by the total no components of at the beginning of the period.
2. Determine the probabilities associated with the component failures.

(i)Probabilities of component failures can be calculated by dividing the number of components that fail at each period by the number of components manufactured during the period.

(ii)For component failure probabilities, divide the number of has lost by the original number of customers it served.

3. Devolop state transition matrix by listing retention probabilities (as calculated in step1) along the main diagonal (upper left to lower right) whereas loss probabilities (calculated in step2) become row values and gain probalities become column values.
4. Determine the expected future market shares for any period m-1 as shown below:

[Failure possibilities of period 1][State-transition matrix = [Expected component failures in period 2]

[Expected component failures in period 2][State-transition matrix] = [Expected component failures in period 3]

[Expected component failures in period k-1][state transition matrix]

= [Expected component failures in period m]

5. Obtain the steady-state or equilibirium conditions for the current problems by the use of matrix algebra and the solution of a set of simultaneous equations obtained above

VII. CALCULATION

[Expected component failures in period k-1] *[state transition matrix]

= [Expected component failures in period m]

40/500	60/500	75/500	65/500	30/500	40/500	40/500	50/500	70/500	30/500
60/750	75/750	55/750	40/750	80/750	90/750	85/750	80/750	100/750	85/750
30/350	20/350	25/350	35/350	30/350	40/350	50/350	40/350	30/350	50/350
40/400	35/400	25/400	30/400	60/400	25/400	30/400	50/400	60/400	45/400
60/500	75/500	65/500	30/500	40/500	40/500	50/500	40/500	70/500	30/500
60/600	70/600	50/600	45/600	55/600	50/600	80/600	50/600	65/600	75/600
40/400	35/400	25/400	60/400	25/400	30/400	30/400	50/400	60/400	45/400
70/700	60/700	75/700	65/700	50/700	90/700	80/700	80/700	60/700	70/700
80/650	70/650	40/650	60/650	55/650	65/650	70/650	80/650	35/650	95/650
30/350	20/350	25/350	35/350	30/350	50/350	40/350	30/350	50/350	40/350

0.15
0.05
0.1
0.1
0.15
0.1
0.05
0.15
0.1
0.05

The product of these two matrix provides the upcoming failures of ten components in the IC engines. The following table summarizes the expected failure probabilities for the year 2008 to 2011

VIII. SENSITIVITY ANALYSIS USING LINEAR PROGRAMMING

Sensitivity Analysis for linear Programming model is important, but it is not the only information available. There is a tremendous amount of sensitivity information, or about what happens when data values are changed. We recalled that in order to formulate a problem as a linear program, we had to invoke a certainty Assumption: we had to know what value the data took on, and we made decisions based on that data. Often this assumption is somewhat dubious: the data might be unknown, or guessed.Sensitivity analysis (also called post-optimality analysis) is the study of the behavior of the optimal solution with respect to changes in the input parameters of the original optimization problem. It is often as important solving the original problem itself, partly because in real life applications, the parameters are not always precise and are subject to some source of error. For the LP case, sensitivity analysis based on the optimal basis matrix has been well studied.

Terms used in the sensitivity analysis are as follows:

X1 no. of failures of crankcase (CS)
X2 no. of failures of connecting rod (CR)
X3 no. of failures of bearing (BG)
X4 no. of failures of Cylinder head (CH)
X5 no. of failures of timing gear (TG)
X6 no. of failures of crank shaft (CSH)
X7 no. of failures of valve (VE)
X8 no. of failures of camshaft (CMT)
X9 no. of failures of piston (PN)
X10 no. of failures of camshaft gear (CG)

θ= T/R.
θ= MTBF
T = total time
R = number of failures

by using this relation of all the IC engine components are calculated by the sensitivity analysis conducted on the linear program developed .the sensitivity is conducted by changing the values on the left hand side and also on the right hand side values and also by changing the constraints.

The model linear program is generated from the above relation,

Min $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10}$
ST
MTBF1*x_1 + MTBF2*x_2 + MTBF3*x_3>∑ of the total life time of the components of CS, CR, BG.
MTBF1*x_1 + MTBF3*x_3 + MTBF4*x_4>∑ of the total life time of the components of CS, CR, CH.
MTBF3*x_3 + MTBF5* x_5 + MTBF6*x_6>∑ of the total life time of the components of CR,TG,CSH.

No.	2008 failure probabilities of 10 IC engine components	2009 failure probabilities of 10 IC engine components	2010 failure probabilities of 10 IC engine components	2011 failure probabilities of 10 IC engine components
1.	0.09905	0.10514	0.0982	0.142
2.	0.10215	0.0984	0.1241	0.0841
3	0.0961	0.1236	0.1091	0.0942
4	0.0915	0.1012	0.0843	0.1041
5	0.085325	0.1082	0.0962	0.0832
6	0.0957	0.1142	0.1241	0.1904
7	0.1213	0.0902	0.1312	0.1014
8	0.10412	0.0854	0.8412	0.0922
9	0.1156	0.1055	0.0804	0.1214
10	0.2594	0.12816	0.0942	0.0734

x_7>712(total life time of the component of VE)
x_8>812(total life time of the component of CMT)
MTBF7*x_7 + MTBF8*x_8 + MTBF*x_9>∑ of the total life time of the components of VE, CMT,PN.
MTBF6*x_6 + MTBF7*x_7 + MTBF8*x_8 + MTBF9*x_9 + MTBF10*x_{10}>∑ of the total life time of the components of CSH, VE, CMT, PN, CG.

Min $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10}$
ST
$40x_1 + 32x_2 + 52x_3 > 2024$
$40x_1 + 52 x_3 + 20x_4 > 76024$

$52x_3 + 20x_5 + 23.2x_6 > 1536$
$x_7 > 512$
$x_8 > 512$
$32x_7 + 46x_8 + 56x_9 > 1536$
$23.2x_6 + 32x_7 + 46x_8 + 56x_9 + 24x_{10} > 2048$ the above framed LP is solved by LINDO and their results are as follows.

OBJECTIVE FUNCTION VALUE

By sensitivity analysis conducted on various IC engine components from X1 to X10 variable cost reductions by comparison is given below. Standard objective functional value is

1) 2486.000

Variable cost	value	Reduced cost
X1	0.000000	0.230769
X2	0.000000	1.000000
X3	1462.000000	0.000000
X4	0.000000	0.615385
X5	0.000000	1.000000
X6	0.000000	1.000000
X7	512.000000	0.000000
X8	512.000000	0.000000
X9	0.000000	1.000000
X10	0.000000	1.000000

Right hand side changes

Min $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10}$
ST
$40x_1 + 32x_2 + 52x_3 > 2124$
$40x_1 + 52x_3 + 20x_4 > 76324$
$52x_3 + 20x_5 + 23.2x_6 > 1936$
$x_7 > 712$
$x_8 > 812$
$32x_7 + 46x_8 + 56x_9 > 2036$
$23.2x_6 + 32x_7 + 46x_8 + 56x_9 + 24x_{10} > 2448$
END

IX. Results

OBJECTIVE FUNCTION VALUE

1) 1995.467

Left-hand side changes

variable	value	reduced cost
X1	13.62	0.00
X2	0.00	0.72
X3	77.18	0.00
X4	0.00	1.00
X5	44.66	0.00
X6	0.00	0.68
X7	450	0.00
X8	760	0.00
X9	650	0.00
X10	0.00	0.00

Min $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10}$
ST
$45x_1 + 37x_2 + 57x_3 > 2124$
$35x_1 + 47x_3 + 15x_4 > 76324$
$55x_3 + 23x_5 + 26.2x_6 > 1936$
$6x_7 > 712$
$8x_8 > 812$
$42x_7 + 56x_8 + 66x_9 > 2036$
$13.2x_6 + 22x_7 + 36x_8 + 46x_9 + 14x_{10} > 2448$
END

LP OPTIMUM FOUND AT STEP 0

OBJECTIVE FUNCTION VALUE

1) 1844.082

Changing the constraints

variable	value	reduced cost
X1	0.000000	0.255319
X2	0.000000	1.000000
X3	1623.914917	0.000000
X4	0.000000	0.680851
X5	0.000000	1.000000
X6	0.000000	1.000000
X7	118.666664	0.000000
X8	101.500000	0.000000
X9	0.000000	1.000000
X10	0.000000	1.00000

Max $x1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10}$
ST
$40x_1 + 32x_2 + 52x_3 < 2024$
$40x_1 + 52x_3 + 20x_4 < 76024$
$52x_3 + 20x_5 + 23.2x_6 < 1536$
$x_7 < 512$
$x_8 < 512$
$32x_7 + 46x_8 + 56x_9 < 1536$
$23.2x_6 + 32x_7 + 46x_8 + 56x_9 + 24x_{10} < 2048$
END

LP OPTIMUM FOUND AT STEP 4

OBJECTIVE FUNCTION VALUE

1)4026.583

From the sensitivity analysis conducted on the linear program developed from the data's collected from the IC engine it has been concluded that when the total life time of the components on the right hand side ,MTBF(mean time between the failure) on the left hand side and the inequality constraints are subjected to sensitivity the number of failures becomes minimized by changing the left hand side values compared to changing the values on the values on the right hand side i.e. the total life time of the components .

variable	value	reduced cost
X1	0.000000	2.250000
X2	63.250000	0.000000
X3	0.000000	5.825000
X4	3801.19995	0.000000
X5	76.800003	0.000000
X6	0.000000	1.126667
X7	0.000000	0.333333
X8	0.000000	0.916667
X9	0.000000	1.33333
X10	85.333336	1.000000

X. Conclusion

In this paper from the mean time between the failures of the IC engine components, various failure analyses have been conducted to verify whether the failure rate and failure of the IC engine components are uniform. By the time it is easy to determine the failure range of the IC engine components using chi-square test. In this paper the usage of the markov chain gives the exact failure probabilities of all IC engine components has been determined. The failure mode and effect analysis (FMEA) and cause and effect diagram gives the exact failure reasons, all the design modification problems and finally it prioritizes the IC engines critical components according to their potential failure rate. Finally the sensitivity based optimization is carried out to minimize the total number of failures of the IC engine components.

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