OMAINTEC CONFERENCE EXHIBITION 2017

15th INTERNATIONAL OPERATIONS & MAINTENANCE CONFERENCE IN THE ARAB COUNTRIES
UNDER THE THEME: **“SMART MAINTENANCE”** CONICIDE WITH THE 15TH ARAB MAINTENANCE EXHIBITION

Smart condition based maintenance Decision by use of Fuzzy logic method

TRINATH SAHOO

Indian Oil Corporation Ltd

MAINTENANCE METHODOLOGIES

There are four universally recognized maintenance methodologies in use today.

Breakdown/ Failure based → Preventive → Predictive → Proactive

Breakdown/ Failure based	Preventive	Predictive	Proactive
-Equipment is allowed to run till it fails. (+) -Breakdown maint. is allowed for small, non critical rotating machines.(+) - sometimes failure may be catastrophic.(-) - machine require more extensive repair.(-)	- A programme of periodic disassembly, inspection and replacement of worn parts.(+) - periodic inspection interval difficult to predict.(-) - periodic insp. of critical machine is difficult.(-)	- Involves trending and analysis of machine parameters.(+) - problems can be detected early.(+) - repair can be scheduled for a convenient time.(+)	-focus on failure mode and its prevention. - Root cause failure Analysis.(+) - equipment upgrade and redesign.(+) - Material upgrade and standardization.(+)

CHANGE IN MAINTENANCE PHILOSOPHY OVER YEARS (NASA report)

FAILURE RATE

Corrective Maintenance
"Run-to-failure maintenance"

Breakdown maintenance

-High risk of secondary failure
-High production downtime
-High cost of spares parts
-Overtime labor
-Safety hazardous

+ Machines are not over maintained
+ No condition monitoring related costs

Predetermined Maintenance
"Fix it before it breaks"

Planned maintenance Historical maint. Calendar based maint.

-Machines are repaired where there is no faults
-Repair often causes more harm than good
-There are still "unscheduled" breakdowns
+Maintenance is performed in controlled manner
+Fewer catastrophic failures
+Greater control over stored parts and costs
+Unexpected machinery failure should be reduced

Predictive Maintenance
"If it ain't broke, don't fix it"

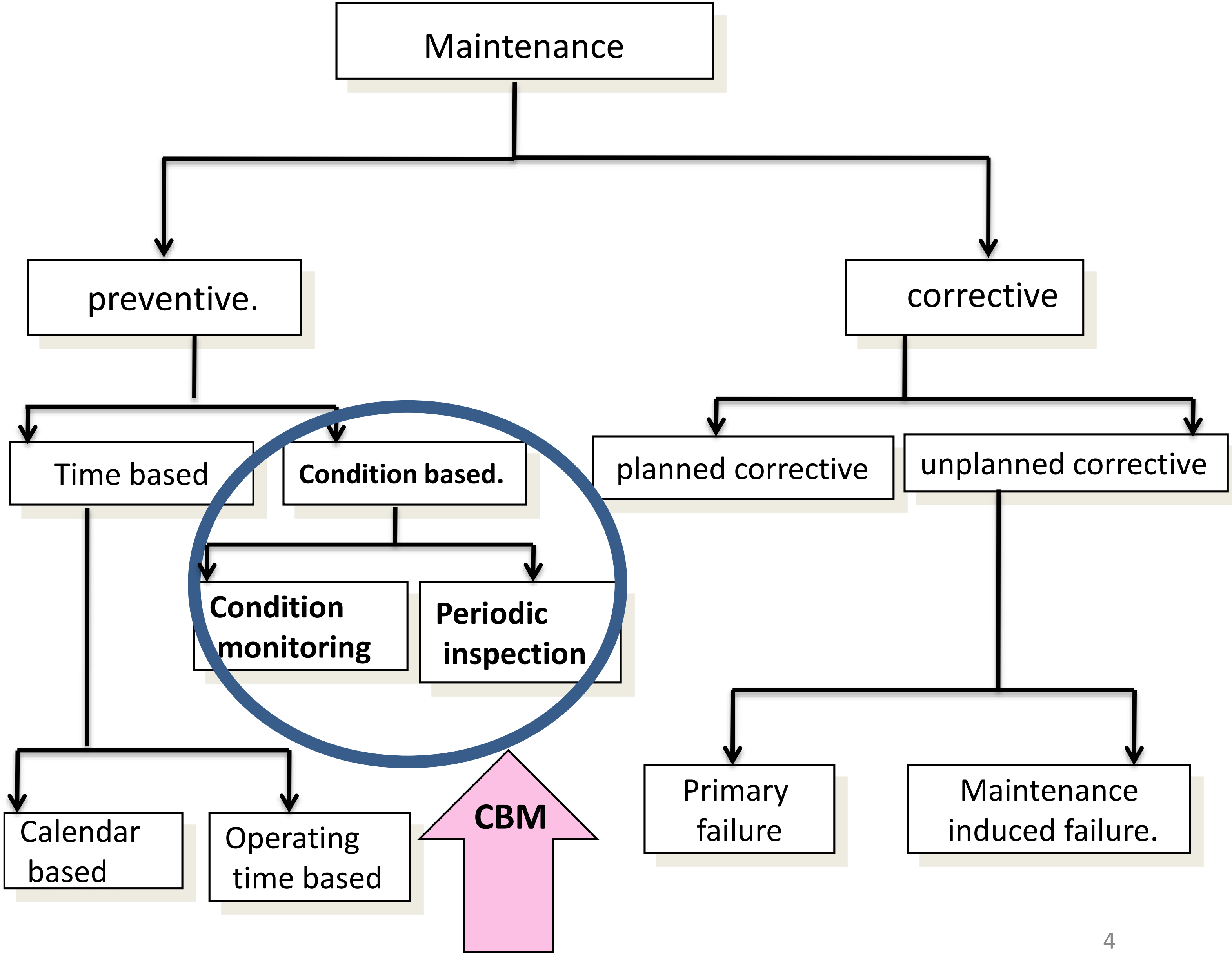
Condition based maintenance

-High investment cost
-Additional skills required

+Unexpected breakdown is reduced.
+Parts are ordered when needed
+Maintenance is performed when convenient
+Equipment life is extended

CHANGE IN MAINTENANCE PHILOSOPHY

CBM approach and the process.

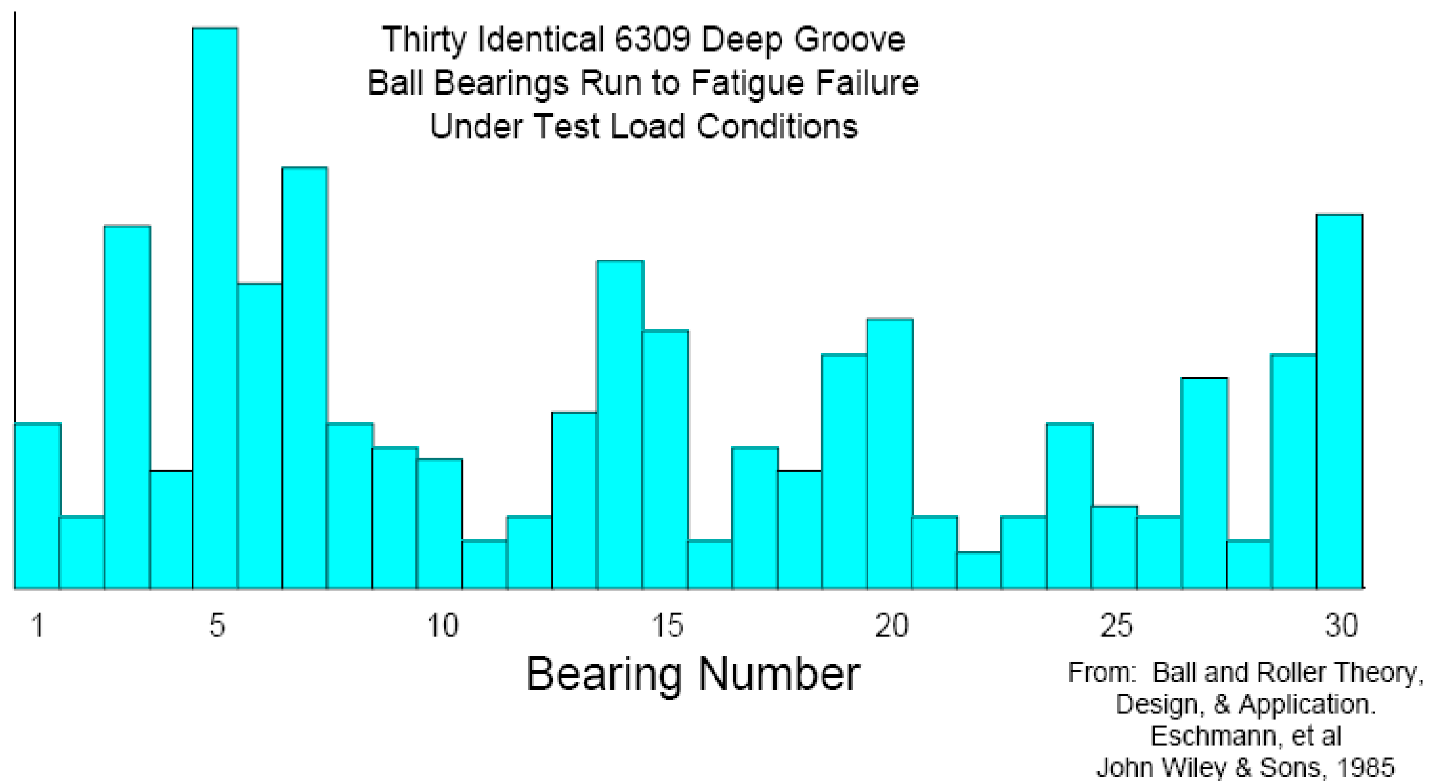


Replacement decision

Replacement decisions based on age often removes workable components, which could have run substantially longer without the risk of failure.

Most of literature applies statistical methods for prediction of remaining useful life. Such conservative approach often limits much of component’s useful life .

Equipment Failure Pattern (Eschmann,1985) Bearing life scatter.



Equipment Failure Pattern (Eschmann,1985)

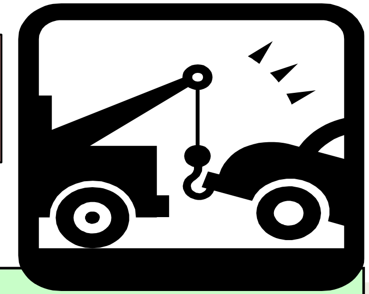
The failure pattern shows that many failures are not time dependent.

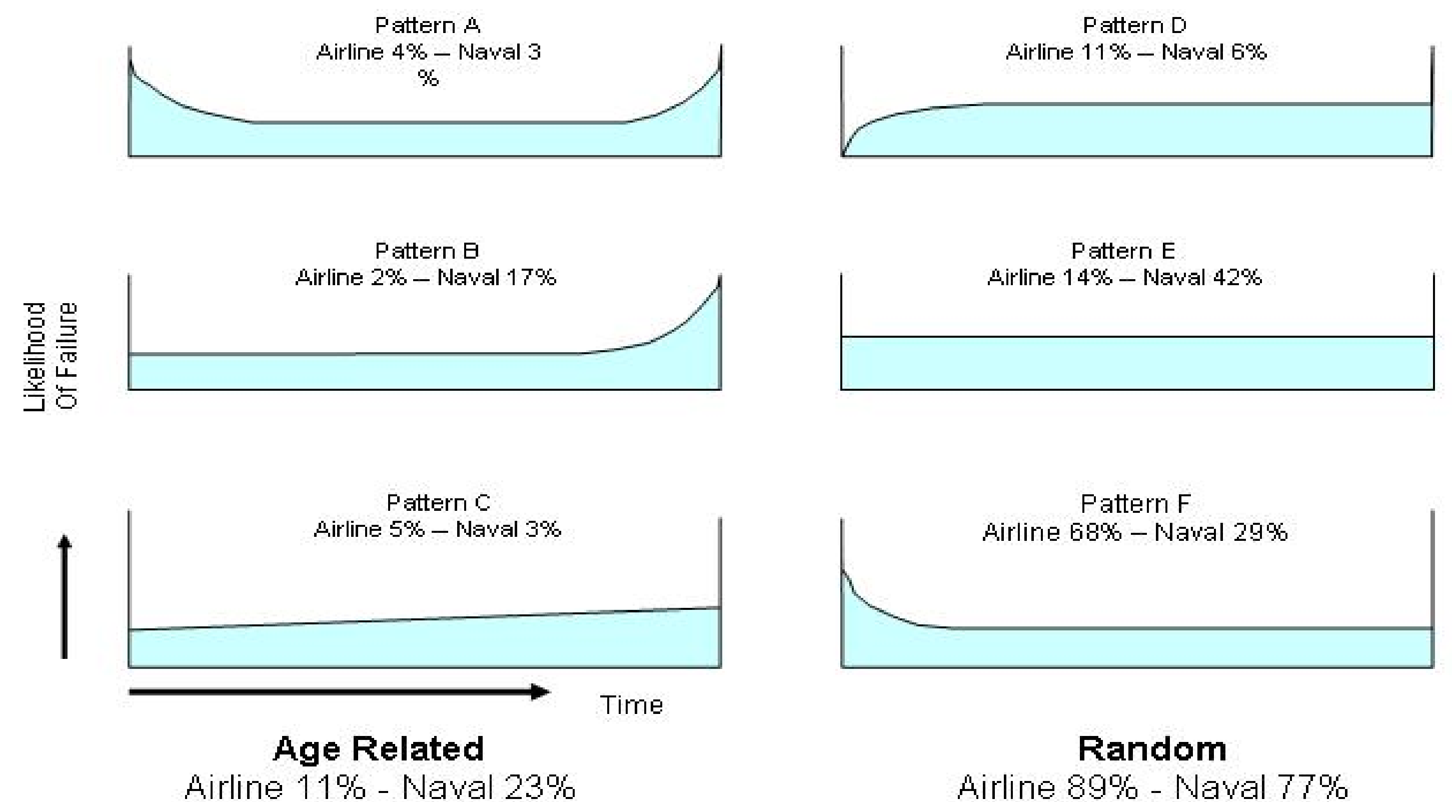
Most equipment failure have no relationship to length of time in Service. (Only 15-20 % are age dependent).

Most of the failures are totally time random events (about 80%).

Detecting a future failure helps in handling it more cost effectively before it becomes a breakdown.

NASA -Equipment Failure Pattern





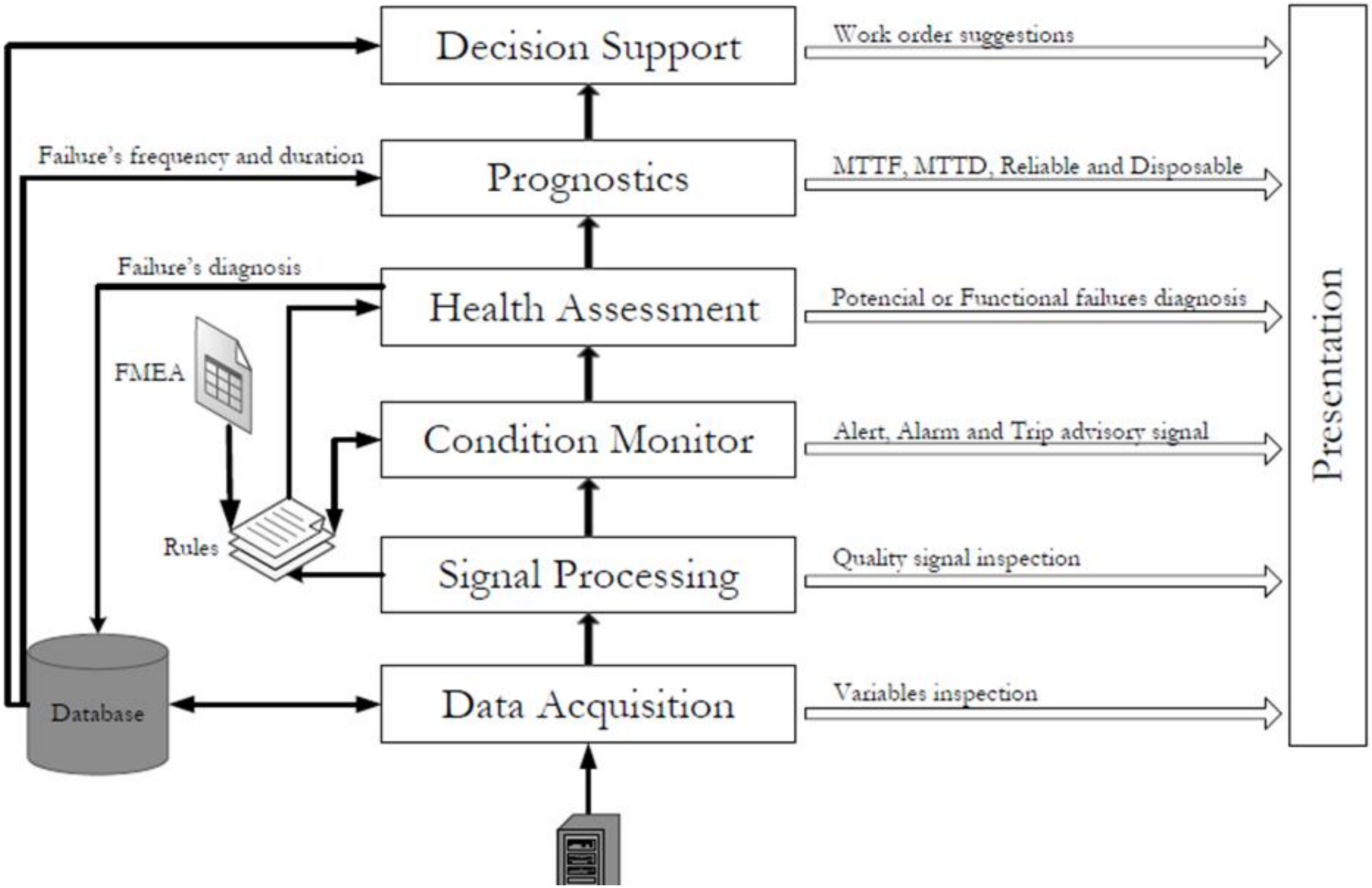
CBM AND PROGNOSTICS

A recent study of maintenance management practices shows that there are three major problems facing many modern engineering plants .

1. How to pre-plan and pre-schedule maintenance work for sophisticated equipment under a complex operating environment?
2. How to reduce the high inventory cost for spare parts?
3. How to avoid the risk of catastrophic failure and eliminate unplanned forced outage of equipment or systems?

Consequently the question arises how long can the item be operated safely before it is necessary to perform maintenance in order to prevent a breakdown? To answer this question diagnostics approach fails and Prognostics gives a proper solution. By application of CBM indicative prognostic parameters can be detected and used to quantify possible failure of equipment before it actually occurs

Condition based maintenance architecture



This model was used by Amaya et al., Thurston and Lebed et al

Condition based maintenance architecture

Data Acquisition – In this layer information is collected from sensor, transmitter or another data source to capture the dynamic effect caused by the incipient failure

Signal processing - The purpose of signal processing in diagnostic applications involve (i) removal of distortions and restoration of the signal to its original shape,

(ii) remove sensor data that is not relevant for diagnostics,

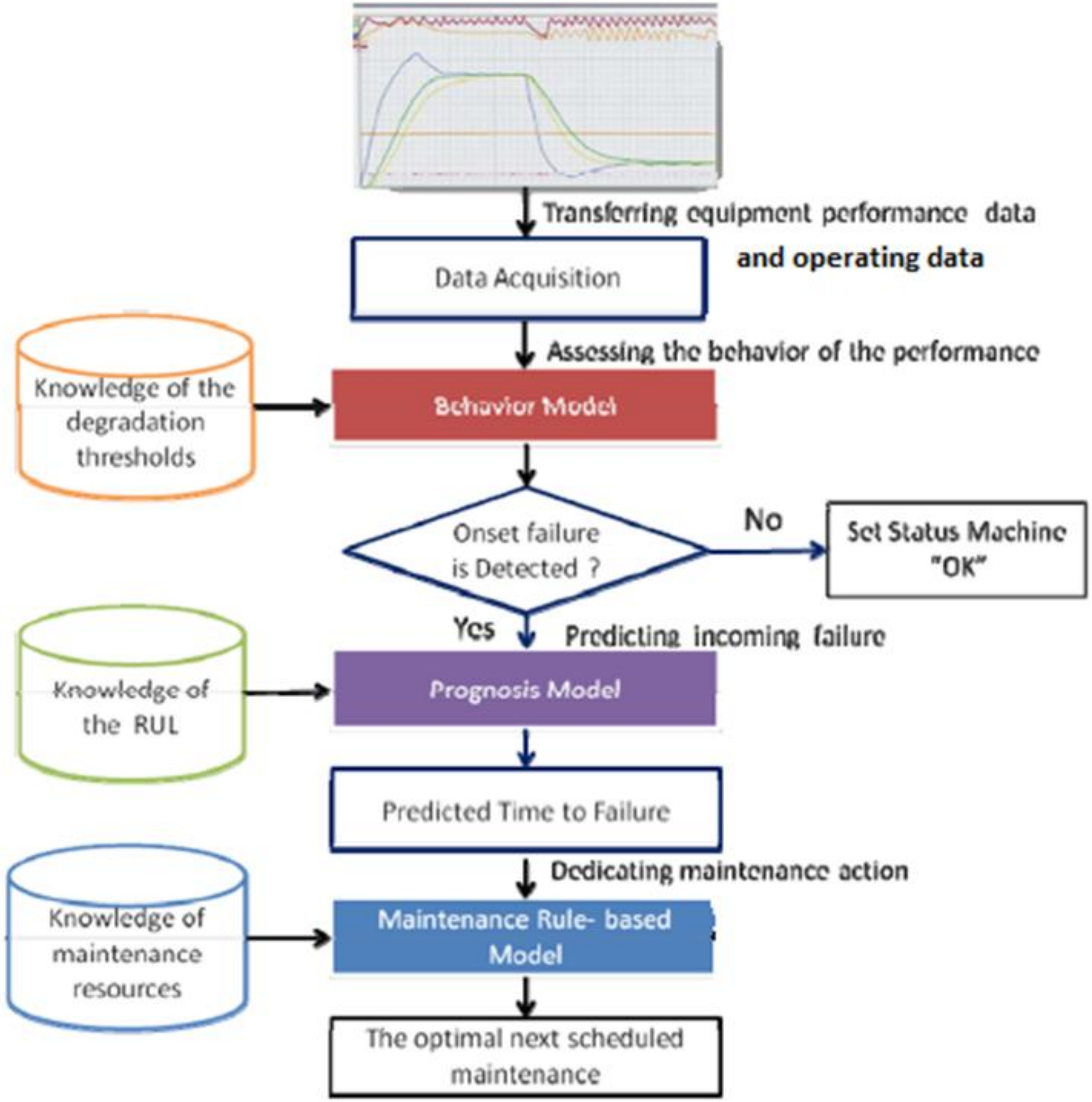
Condition Monitor - This layer compares on-line data with its expected values.

Health Assessment - Here the health of the monitored item is checked for its degraded level

Prognostics - This layer require data from the previous layers to calculate the future health of an asset

Decision Support - The primary function of decision support is to provide recommended maintenance actions

MODEL DEVELOPED



Problem formulation

Nobody has looked into the maintenance problem when the condition monitoring data and operating context are taken together which involve imprecision judgment.

This become our objective of investigation.

The intelligent predictive decision support system (IPDSS) for condition-based maintenance integrates the following aspects.

i) Equipment condition data/ last inspection data
ii) Operating contexts
iii) Intelligent fault prognosis

Problem statement

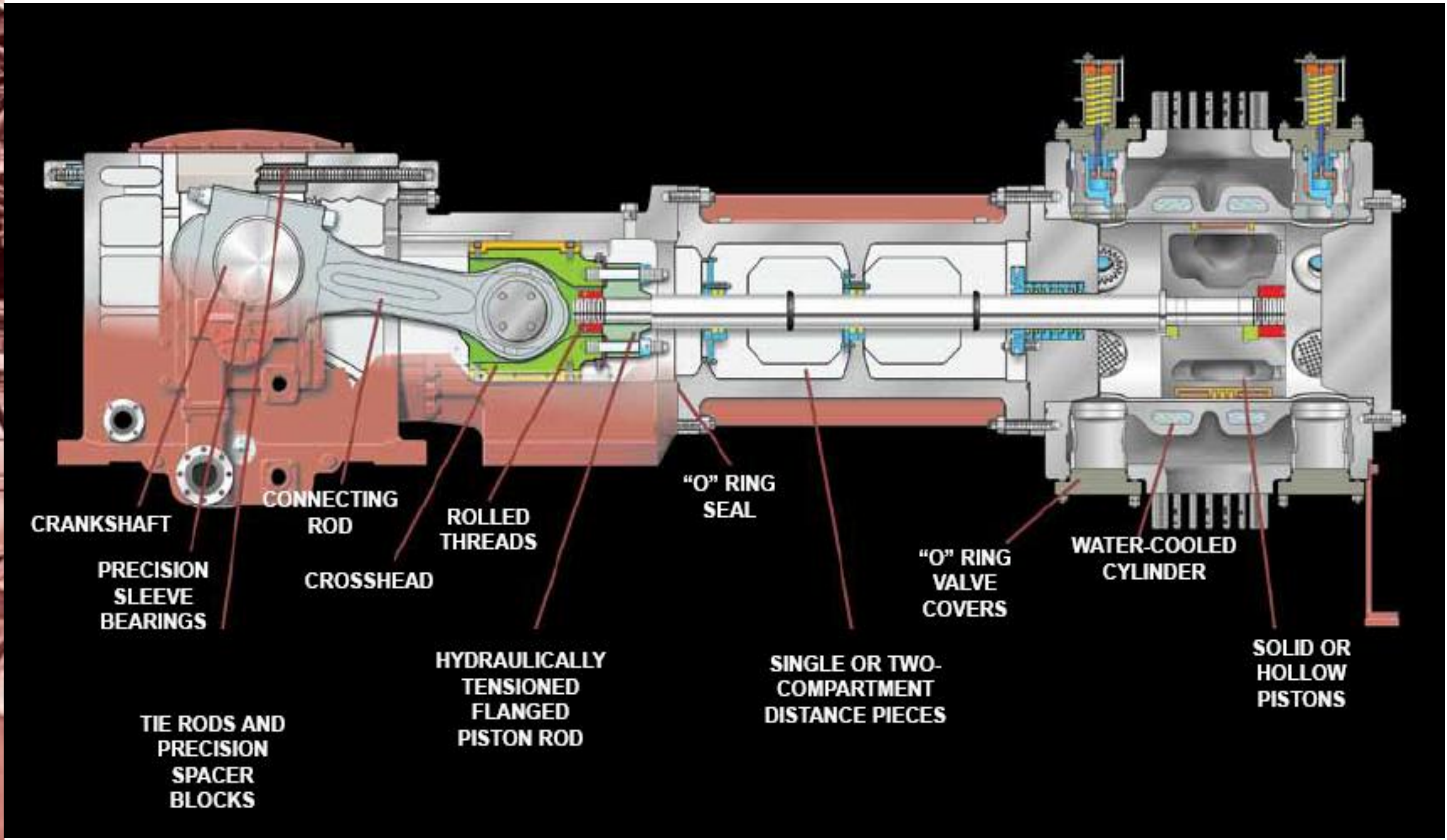
•The refinery industry essentially have a compressor unit that works as it's life line. It consist of many components that has relative motion.

•It is there fore very pertinent to look in to a systematic scientific methodology to establish a better maintenance strategy to increase the unit health.

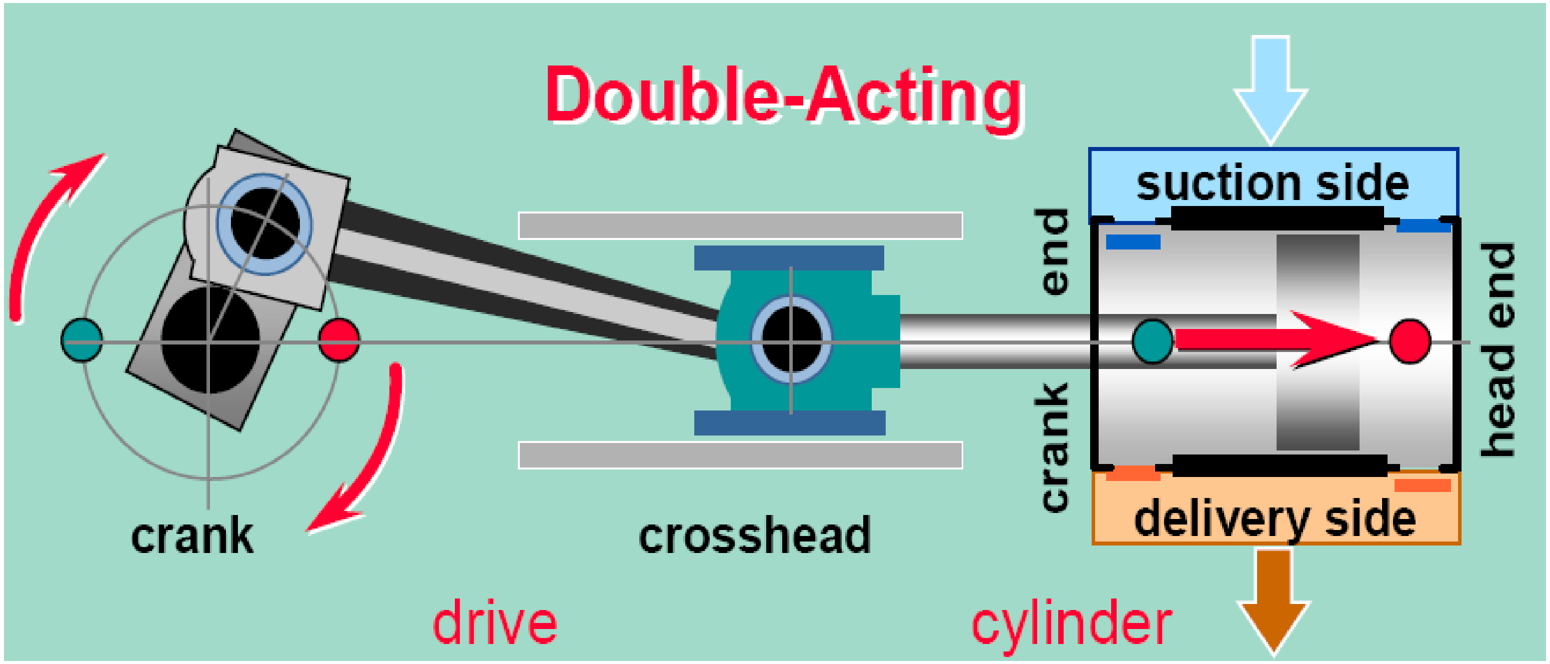
•It is observed that with the development of maintenance philosophy to reduce the failure rate though much work is already being developed , though literature on correlation between failure rate and operating context is scanty.

•In this view in the present work a fuzzy logic based maintenance strategy is attempted . The adaptation has yielded significant improvement on the maintenance cost and there by increase availability of the unit.

System of interest/ H.P. compressor unit

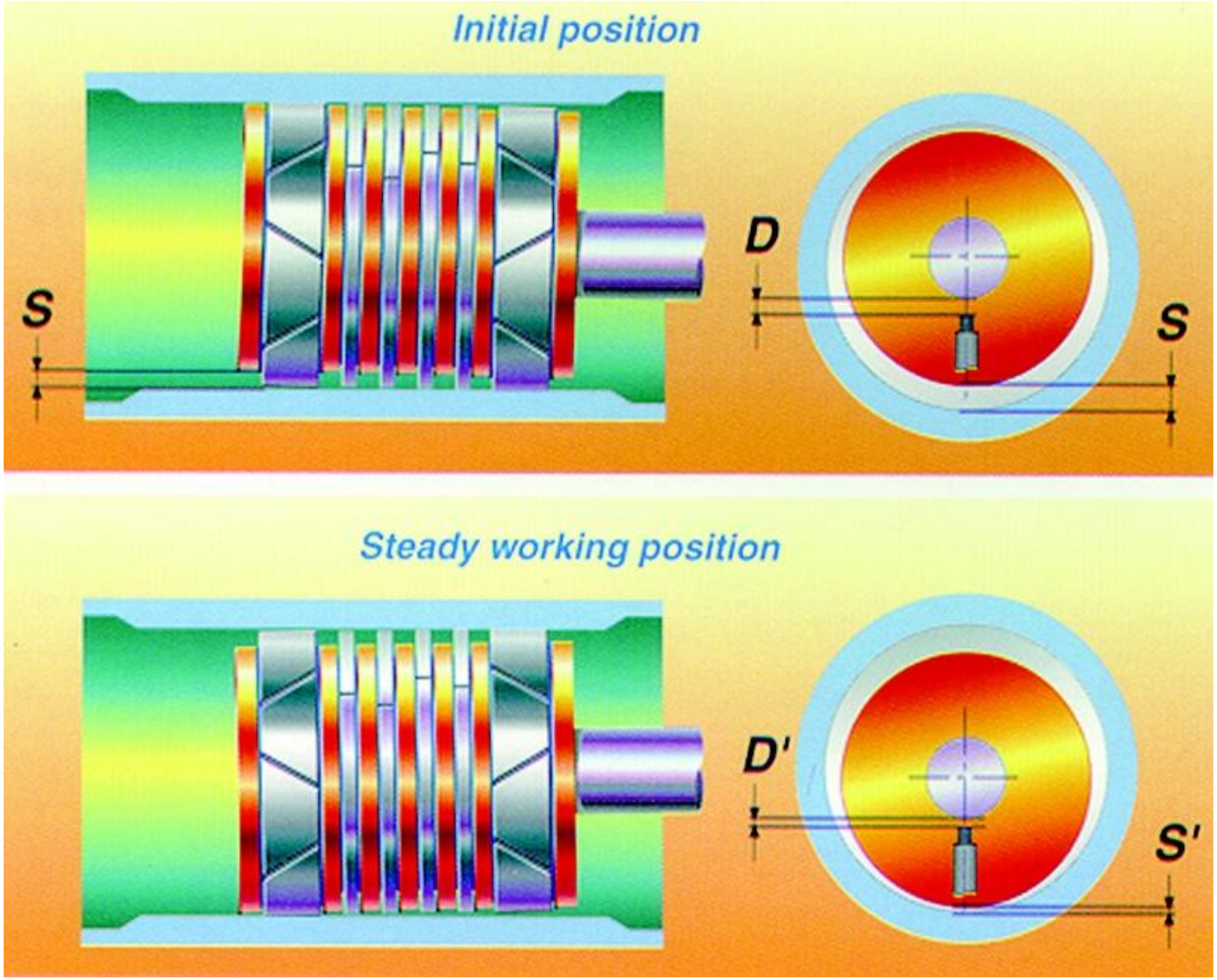


Double Acting Compressor



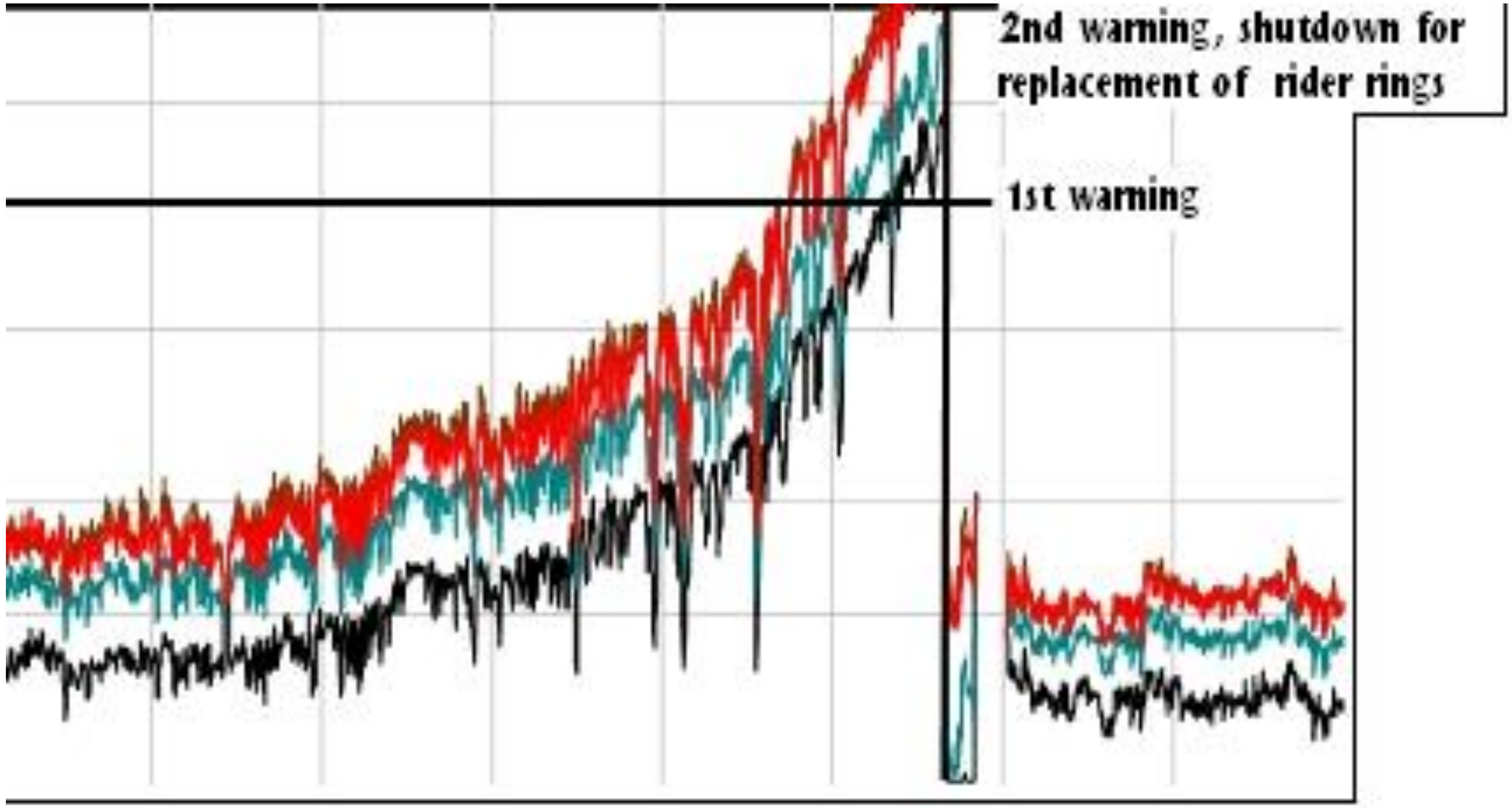
ROD DROP MONITORING

- The piston rod assembly drops during operation due to normal rider band wear .
- Sometimes due to high temperature of the the gas stream , cylinder valve problem, insufficient lubrication for prolonged period can cause drastic reduction in rider band life.
- Replacement of rider bands solely an hours of operation is not the most efficient method



PISTON ROD DROP BY RIDER RING WEAR

BROKEN RIDER RING



Rod drop values prior to the shutdown for replacement of the worn rider rings

Fuzzy

A key difference between crisp and fuzzy sets is their membership function; a crisp set has a unique membership function, whereas a fuzzy set can have an infinite number of membership functions to represent it. For fuzzy sets, the uniqueness is sacrificed, but flexibility is gained because the membership function can be adjusted to maximize the utility for a particular application.

Fuzzy

The idea is best explained by using an example. Suppose that Boolean logic is used to identify whether a room temperature is “hot” or “cold”. Most people would agree that 40oC is a “hot” room temperature and 10oC is a “cold” room temperature. However, if the room temperature falls to 25oC, it becomes much harder to classify the temperature as

“hot” or “cold”.

The concept in reality allows imprecision to be expressed in a quantitative fashion. This is done by introducing a set membership function, represented by μ (x), which maps A

element x to real values between 0 and 1; the value indicates the degree to which an element belongs to set A. A membership value of 0 (μ (x) = 0) indicates the element x is A entirely outside the set, whereas a μ (x) = 1 indicates the element x lies entirely inside the A given set A.

Consider then the previous example: if fuzzy logic is used to represent the “hotness” of a room, 40 oC would have a membership value of 1 and 10 oC would have a membership value of 0. 25 on the other hand, would have a “hotness” membership value of, say, 0.6 and a “coldness” membership value of, say, 0.3.

Fuzzy

The most common representations of condition monitoring data are the triangular membership functions . Figure below shows an example of a triangular membership function, which is expressed by (a1, a2, a3).

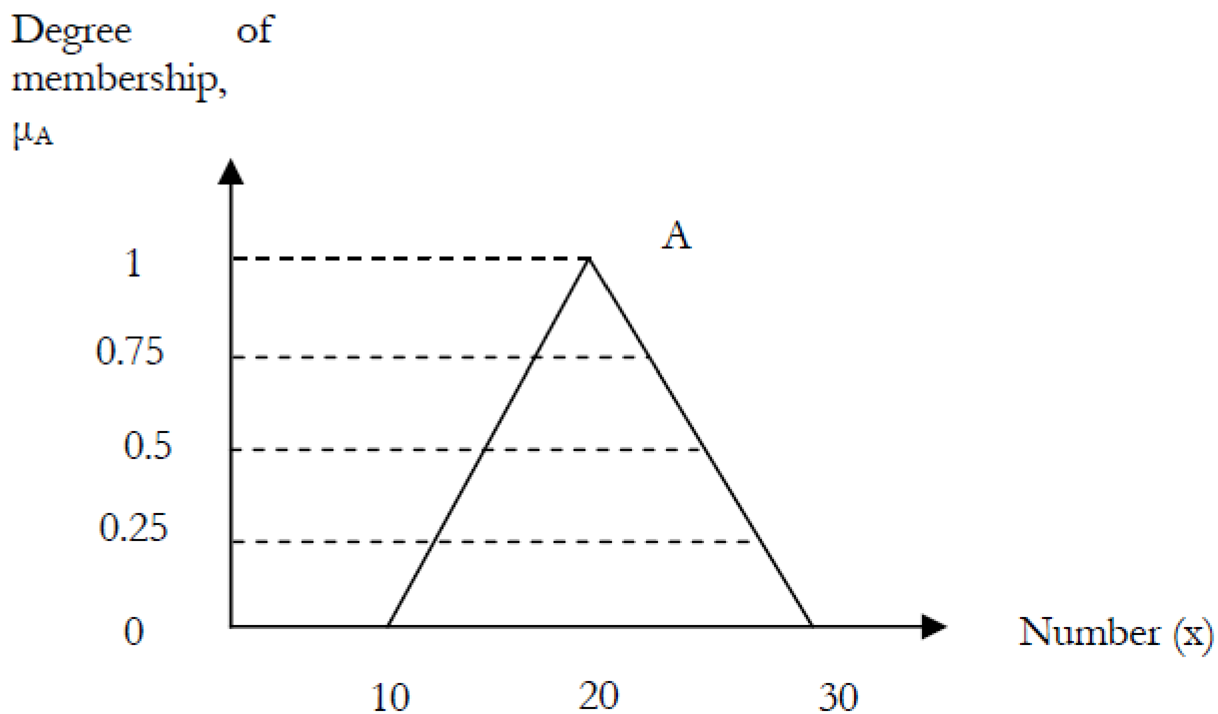


Figure : Triangular membership function (10, 20, 30)

Fuzzy

To account for all values of the numbers between 10 and 30, the membership function above can be represented mathematically by Eq. below

$$\mu_A(x) = \begin{cases} 0, & \text{for } x \le 10 \\ (x-10)/10, & \text{for } 10 \le x \le 20 \\ (30-x)/10, & \text{for } 20 \le x \le 30 \\ 0, & \text{for } x > 30 \end{cases}$$

Fuzzy

It was indicated that there are inherent uncertainties in the data collected by condition monitoring method which are due in part to the inspectors' knowledge.

Hence a tool is needed to reduce these underlying uncertainties associated with condition monitoring result of components. Such a tool should be able to process information based on natural language descriptions which is used by inspectors when making defect assessments.

Fuzzy logic was introduced in the 1960's to deal with such fuzziness of human perception and decision making. The application of fuzzy logic in real world utilization is represented in knowledge-based fuzzy inference systems.

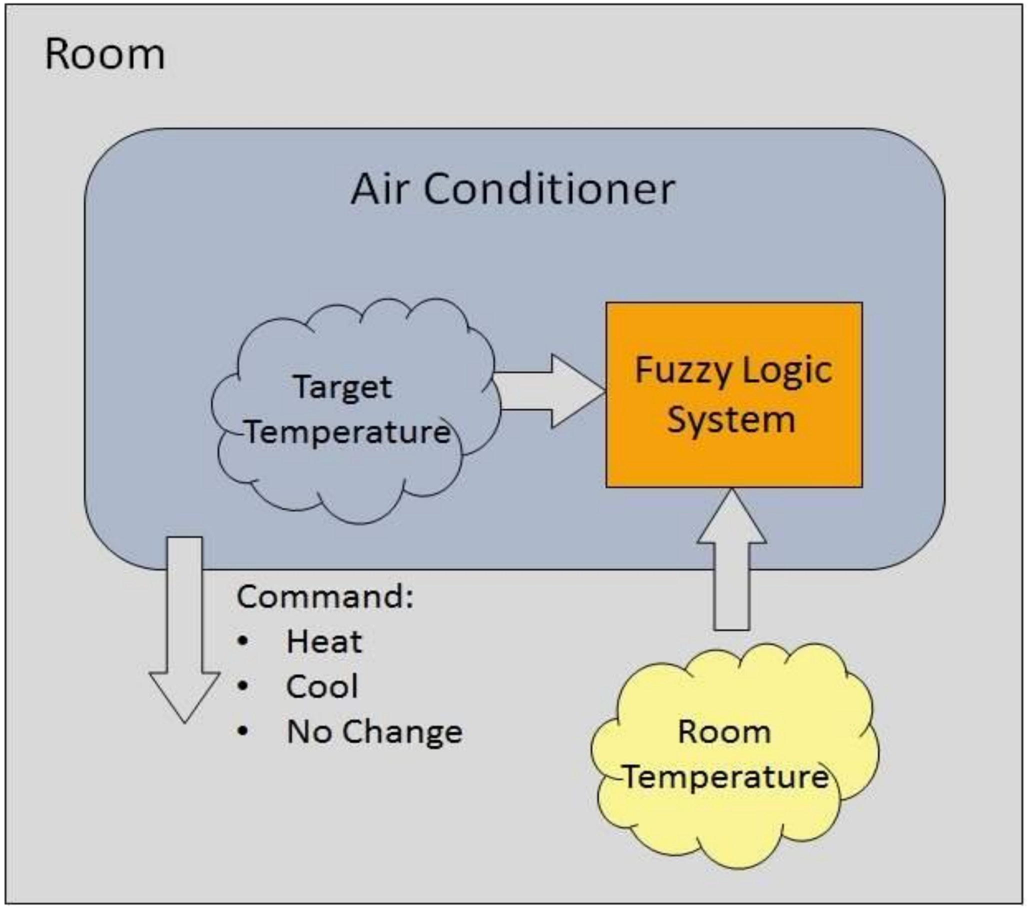
Fuzzy

The concept of fuzzy logic was developed by Lotfi Zadeh, a professor at University of California, Berkeley, in the mid 1960’s as a way of processing data based on linguistic descriptions . Unlike Boolean logic or classical logic, which assumes that every fact is either entirely true or false, fuzzy logic extends Boolean logic to handle vague and imprecise expressions. According to Zadeh , the essential characteristics of fuzzy logic are:

- Exact reasoning is viewed as a limiting case of approximate reasoning
- Everything is a matter of degree
- Any logic system can be fuzzified
- Knowledge is interpreted as a collection of equivalent and fuzzy constraints on a collection of variables
- Inference is viewed as a process of propagation of fuzzy constraints

Example of a Fuzzy Logic System

Let us consider an air conditioning system with 5-level fuzzy logic system. This system adjusts the temperature of air conditioner by comparing the room temperature and the target temperature value



Construct knowledge base rules

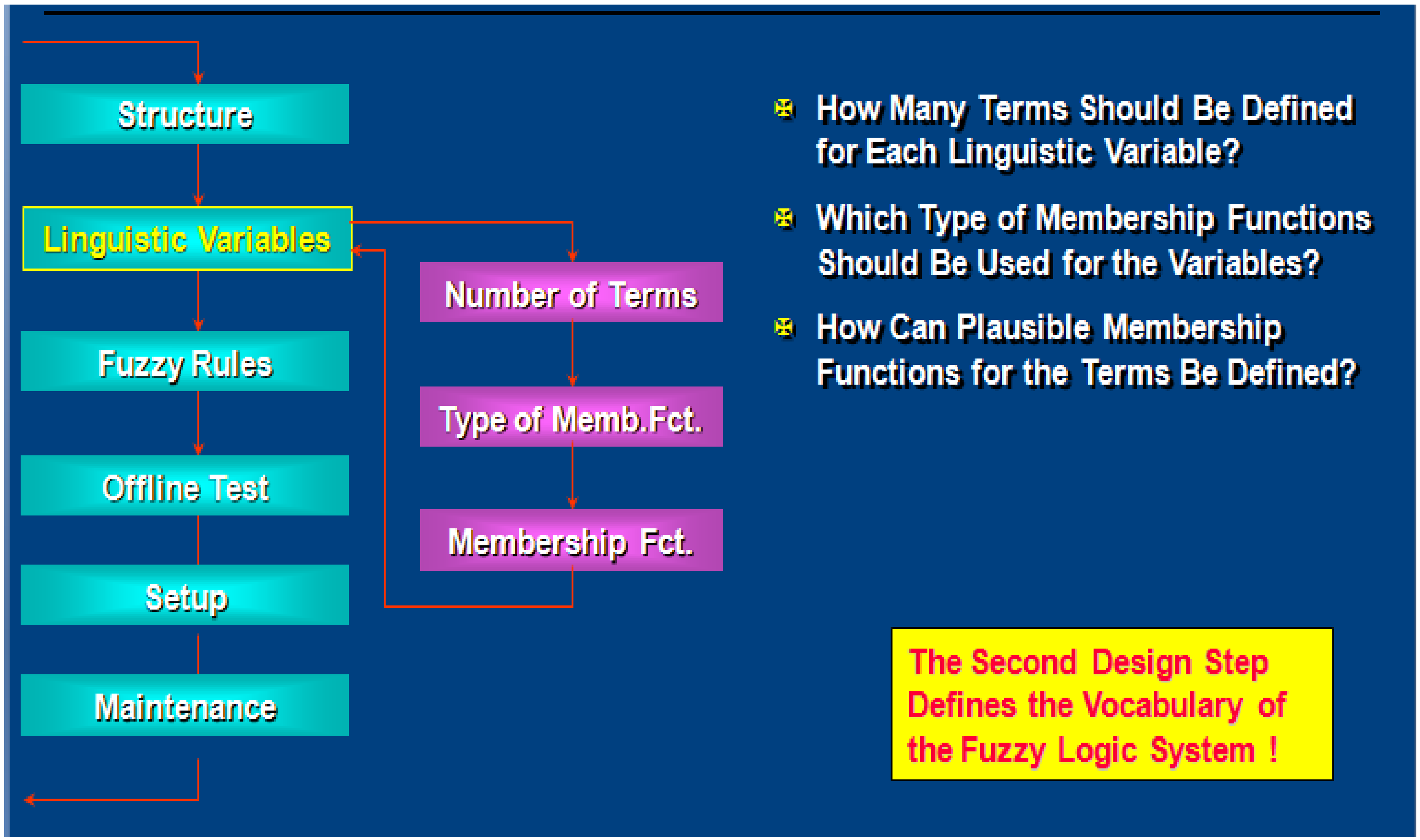
Create a matrix of room temperature values versus target temperature values that an air conditioning system is expected to provide

RoomTemp. /Target	**VeryCold**	**Cold**	**Warm**	**Hot**	**VeryHot**
Very Cold	No Change	Heat	Heat	Heat	Heat
Cold	Cool	No Change	Heat	Heat	Heat
Warm	Cool	Cool	No Change	Heat	Heat
Hot	Cool	Cool	Cool	No Change	Heat
Very Hot	Cool	Cool	Cool	Cool	No Change

IF-THEN-rule structures

Build a set of rules into the knowledge base in the form of IF-THEN structures

Sr. No.	Condition	Action
1	IF temperature=(Cold OR Very_Cold) AND target=Warm THEN	Heat
2	IF temperature=(Hot OR Very_Hot) AND target=Warm THEN	Cool
3	IF (temperature=Warm) AND (target=Warm) THEN	No Change



Structure
Linguistic Variables
Fuzzy Rules
Offline Test
Setup
Maintenance
Number of Terms
Type of Memb.Fct.
Membership Fct.
How Many Terms Should Be Defined for Each Linguistic Variable?
Which Type of Membership Functions Should Be Used for the Variables?
How Can Plausible Membership Functions for the Terms Be Defined?
The Second Design Step Defines the Vocabulary of the Fuzzy Logic System !

Number of Terms

Type of Memb.Fct.

Membership Fct.

A "Typical Value" May Also Be an Interval !

Definition in Four Easy Steps:

1. For Each Term, Define a Typical Value/Interval
2. Define μ=1 for This Value/Interval
3. Define μ=0 from Which the Next Neighbor is μ=1
4. Join Points With Linear / Cubic Spline Functions

Example of Linguistic Variable "Error":

Table 1- RIDER RING CONDITIONS- input variable 1

Set	Vriable	Description	Range
1	Extremely high deficiency level	Major mission degradation which can affect other components also	3-4 mm
2	high deficiency level	Major mission degradation or major system damage	4-6 mm
3	average deficiency level	Minor mission degradation, or minor system damage	5-8 mm
4	low deficiency level	Less than minor mission degradation, or minor system damage	8-10 mm

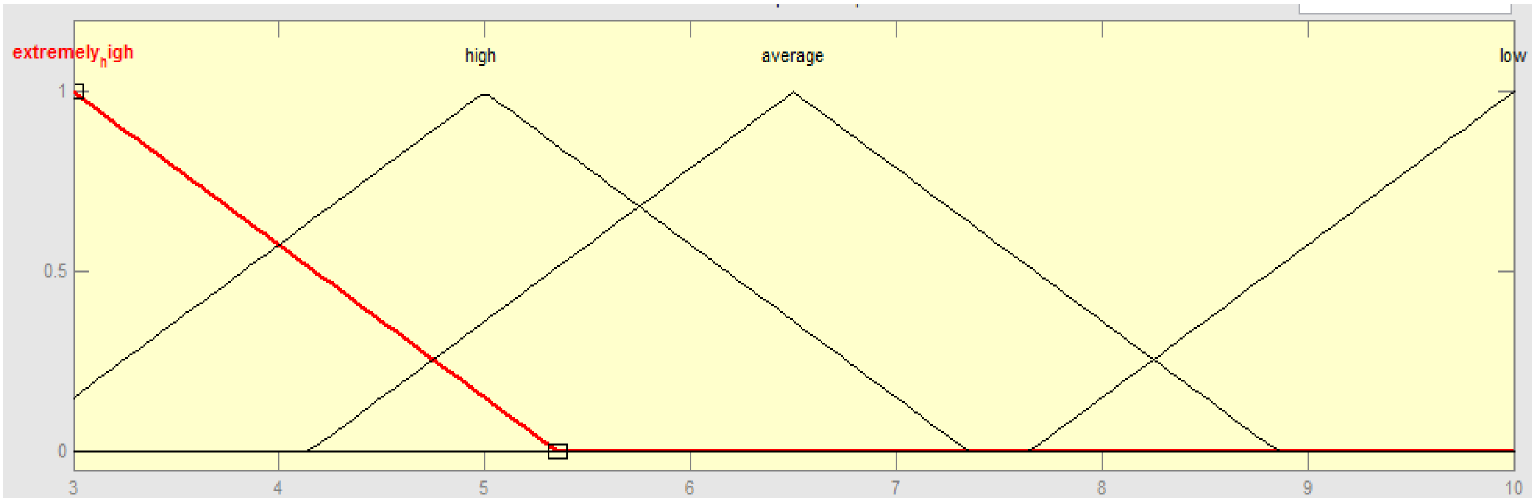
Table -2 - OPERATING TEMPERATURE CONDITIONS- input variable 2

Set	Vriable	Description	Range
1	strong deviation	Strong deviation fom normal condition	140-150
2	slightly deviation	slight deviation fom normal condition	135-140
3	less severe operation,	Less deviation fom normal condition	130-135
4	no change	No change fom normal condition	110-130

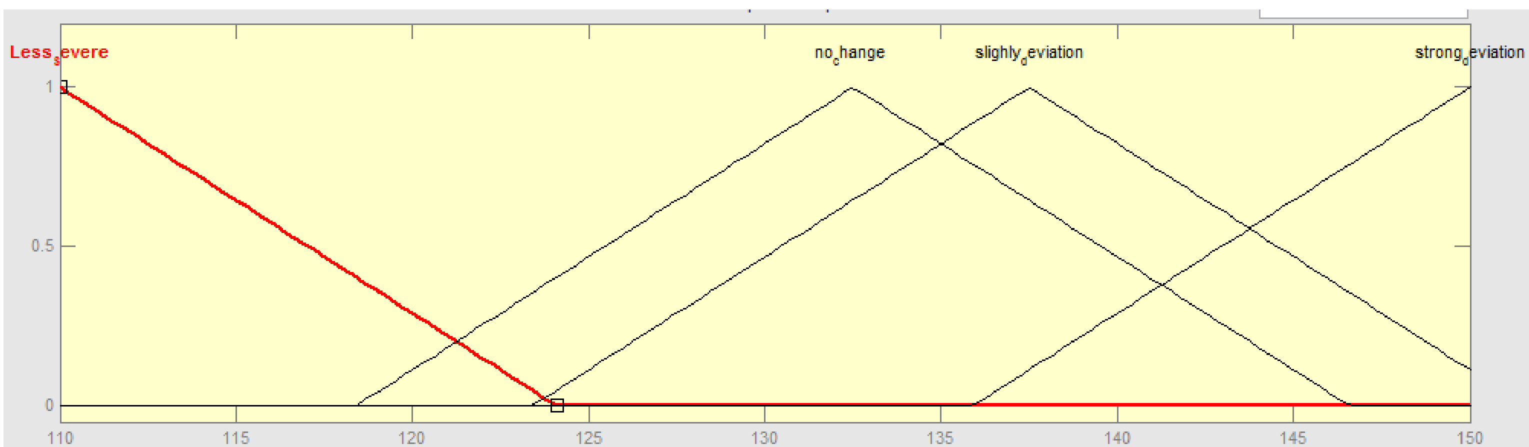
Fuzzy inference systems

The steps performed by fuzzy inference systems when processing inputs are:

1. Compare the input variables with the membership functions of the premise part to obtain the membership values of each linguistic terms this step is called fuzzification
2. Combine the membership values of the premise part to deduce firing strength of each rule using the selected operator
3. Generate the consequence or results of each rule
4. Aggregate the results or consequences to produce a crisp output – this step is called defuzzification



Input Membership Function for Rider Ring condition

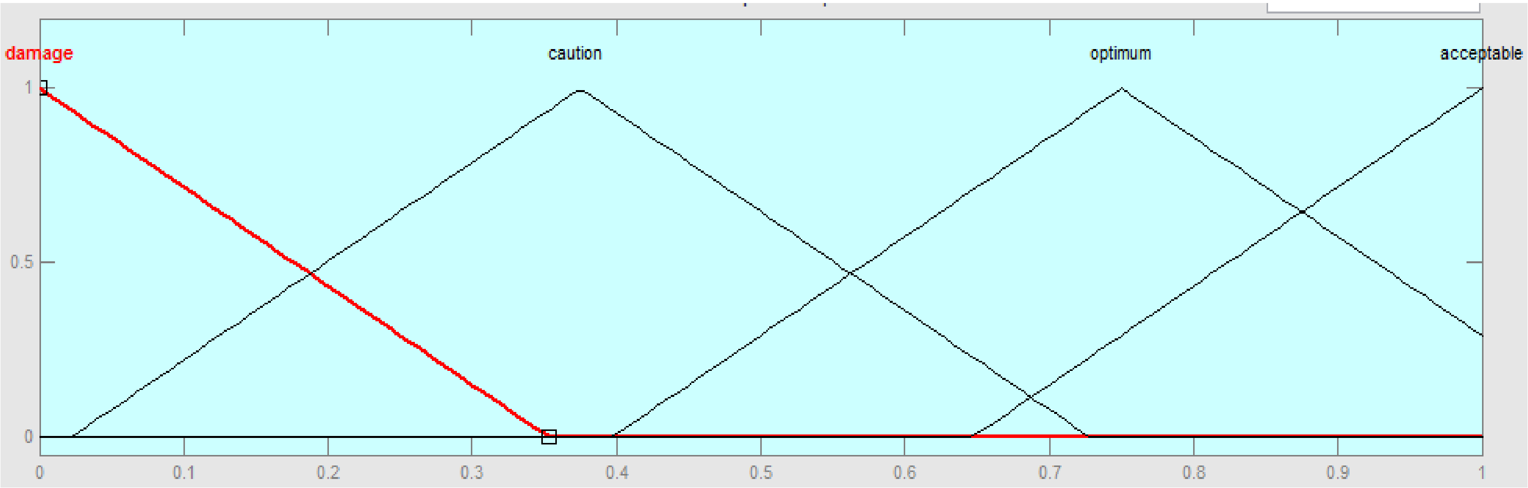


Input Membership Function for Operating Temperature condition

Table -4 - output variable - Suggested compressor maintenance decision

Set	Membership function	Description	Range
1	Damage	Immediately replace the component	0-0.25
2	Caution	Replace in the next opportunity maintenance schedule Before next inspection- less than one year	0.25 - 0.5
3	Optimum	Can run till next inspection – more than one year	0.5-1
4	Acceptable	Can run further – more than two years	1

Output Membership

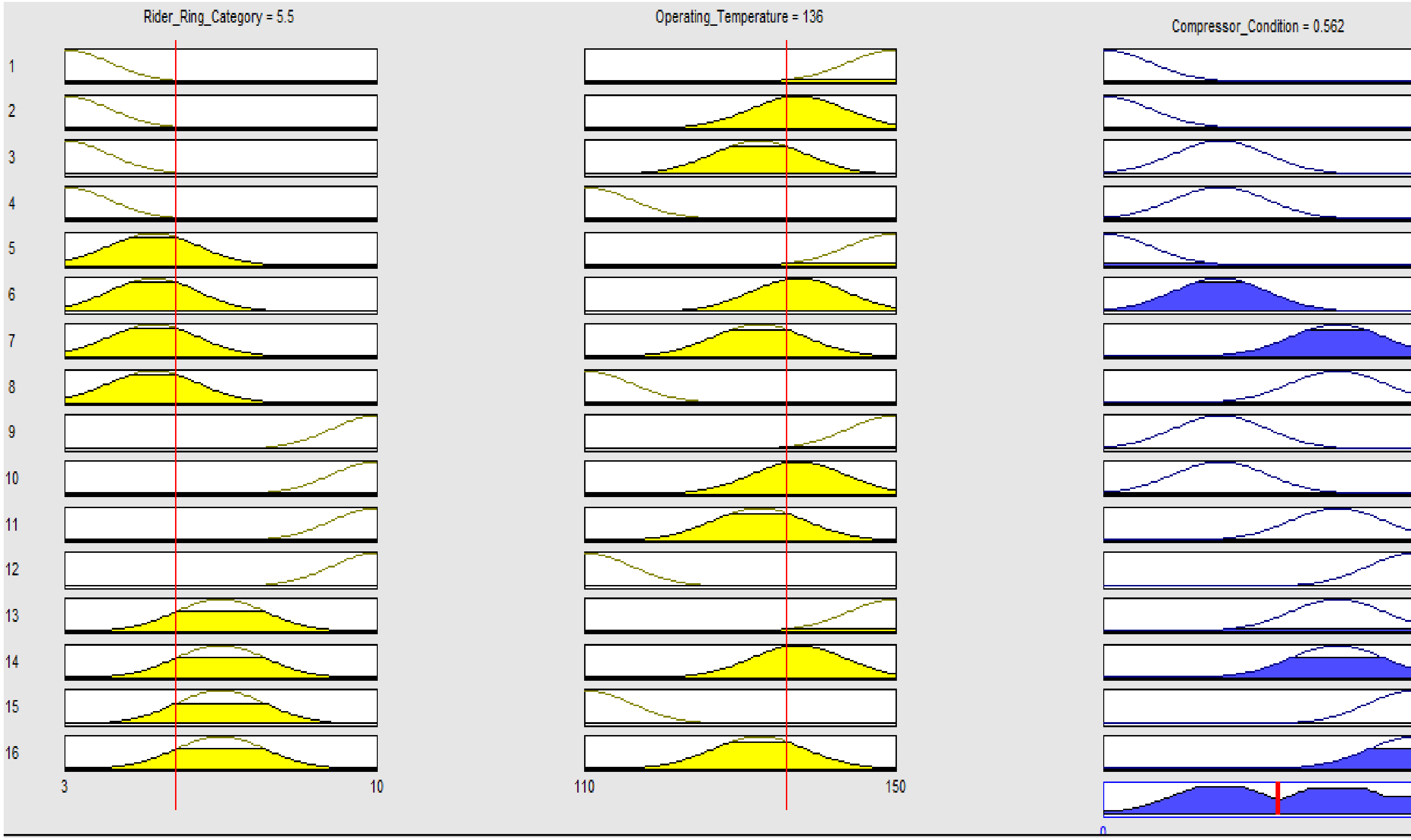


Output Membership Functions for Compressor Condition

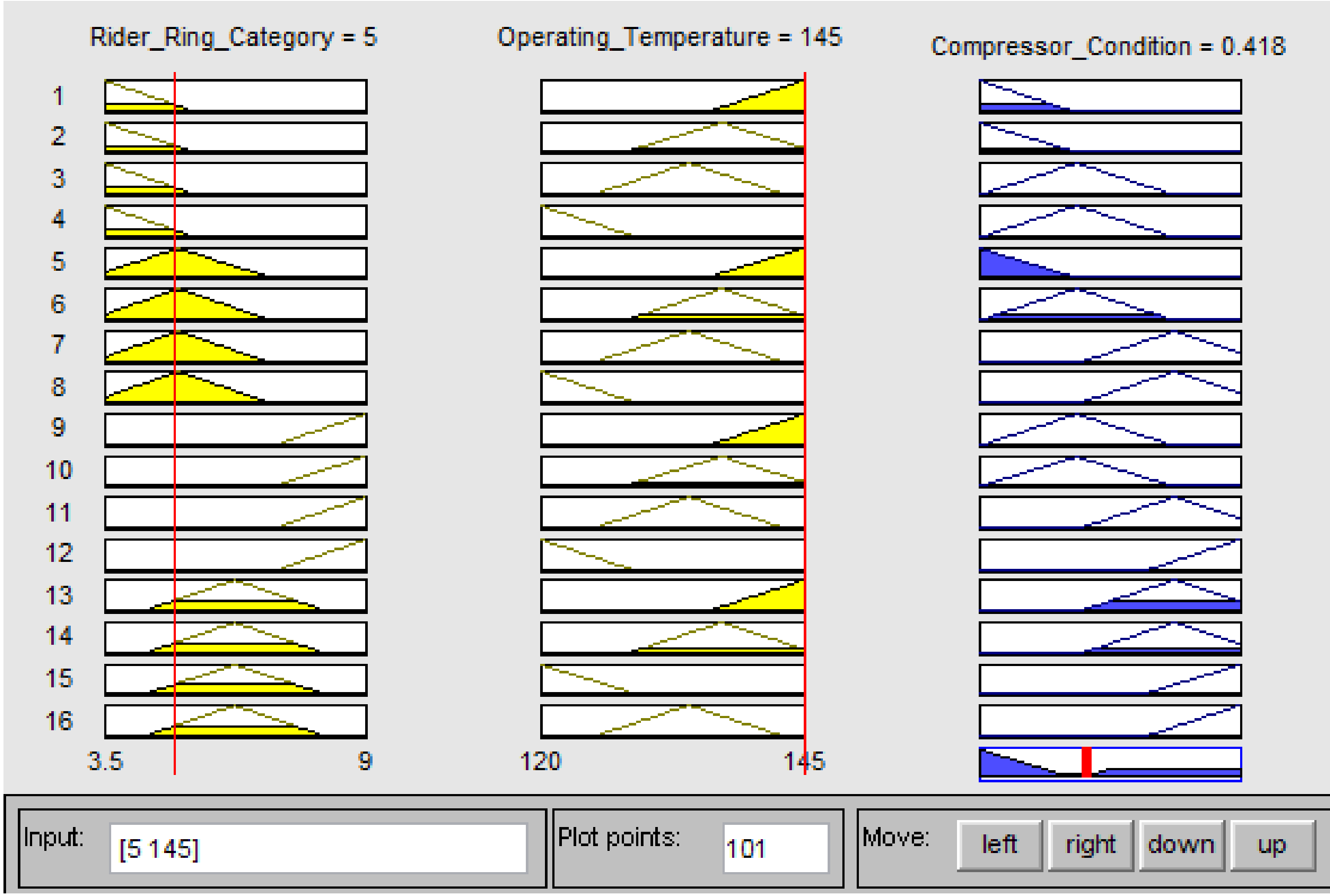
IF-THEN Rules - fuzzy inference system

Rule	IF	Last inspect result	AND	Operating Condition	THEN	Maintenance practice
1		low		strong deviation		optimum
2		low		slightly deviation		acceptable
3		low		no change		acceptable
4		low		less severe operation		acceptable
5		average		strong deviation		optimum
6		average		slightly deviation		acceptable
7		average		no change		acceptable
8		average		less severe operation		acceptable
9		high		strong deviation		damage
10		high		slightly deviation		optimum
11		high		no change		acceptable
12		high		less severe operation		acceptable
13		Extremely high		strong deviation		damage
14		Extremely high		slightly deviation		damage
15		Extremely high		no change		caution
16		Extremely high		less severe operation		caution

SAMPLE 1- Rider Ring Thickness- 5.5mm   Temperature- 136C

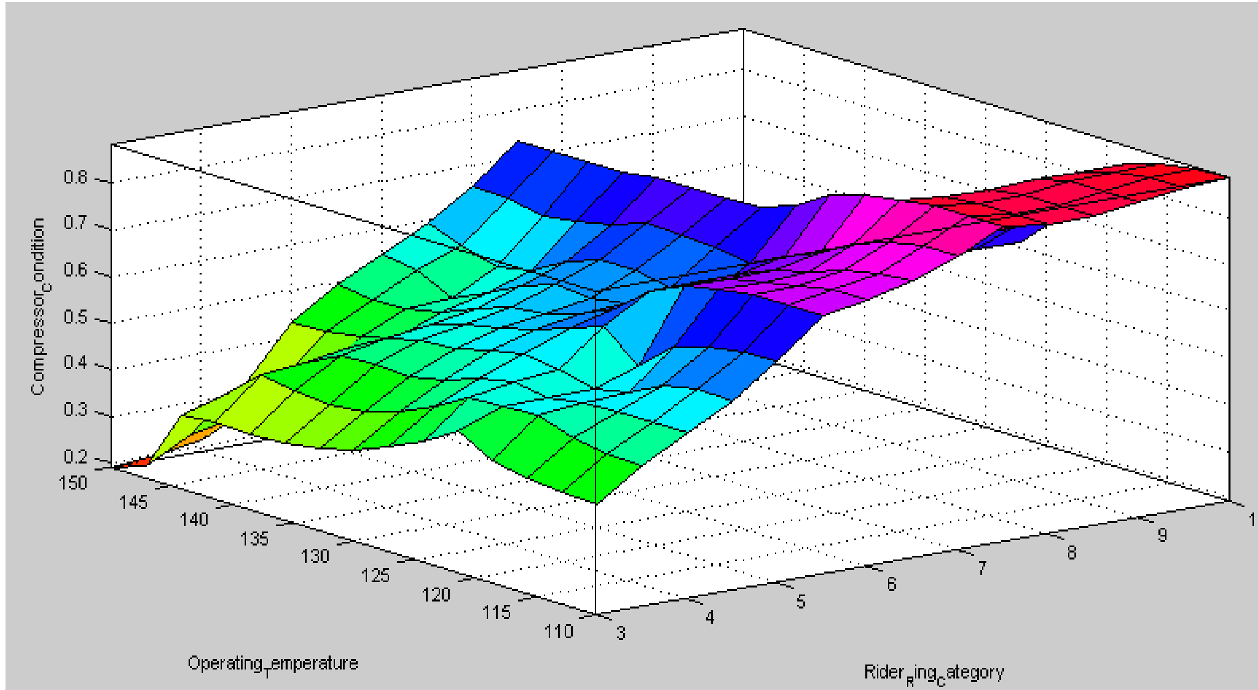


A sample case is taken when the rider ring thickness is 5.5 mm and the operating temperature is 136 deg C ,the compressor Condition in MATLAB tool box output comes out to be 0.562 which means maintenance decision taken should be optimum and compressor can run till next inspection. Hence no maintenance action need to be taken for one year



In this case the rider ring thickness is 5 mm and the operating temperature is 145 deg C ,the compressor Condition in MATLAB tool box output comes out to be 0.418 which means maintenance decision is caution. Replace in the next opportunity maintenance schedule before next inspection-(one year)

Surface Viewer



A surface viewer is created in MATLAB , Upon opening it , you see a three-dimensional curve that represents the mapping input and output . Because this curve represents a two-input one-output, you can see the entire mapping in one plot. It helps to view the dependency of one of the outputs on any one or two of the inputs (Fuzzy user guide 2012). If we provide arbitrarily two values of the variables of ring thickness and temperature , just by placing the cursor in the 3D plot we will be able to predict the severity and take maintenance decision.