Webinar 01/2023

DYNAMIC TRANSITION TO CONDITION BASED MAINTENANCE PHILOSOPHY : A PROSPECTIVE ANALYSIS

Organised by:
Marine, Hull, Chemical and Process Engineering,
Material Science and Naval Architecture
Sectional Committee

SCHEME

Introduction to CBM

CBM Evolution in SLN

CBM Techniques

Integrated CBM Techniques

Prospective Analysis of CBM against PPM

INTRODUCTION

SLN followed Planned Preventive Maintenance (PPM) over last years for all ship borne & shore based machinery

PPM of SLN needed an urgent review

Aged procedures to be revised based on the findings from an own comprehensive data base

Transition from PPM to widely practiced Condition Based Maintenance (CBM)

Balancing cost reduction & efficiency improvement targets are vital needs

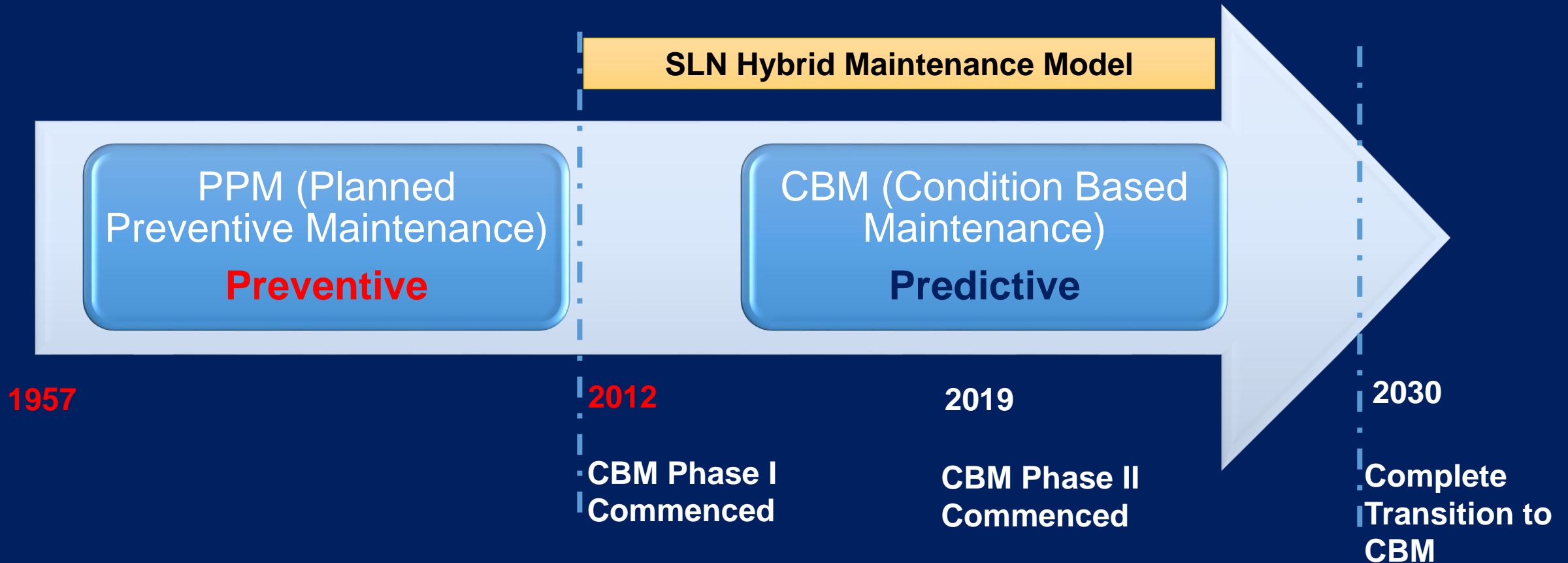Machinery Testing & Trials Unit (MTTU)

CONDITION BASED MAINTENANCE (CBM)

CBM or **Predictive Maintenance (PdM**) is a strategy that drives to identify incipient faults before they become critical which enables more accurate planning.

Source : K Mobley (2002)

SLN MAINTENANCE PHILOSOPHY

THE PARADIGM TRANSITION

SLN Hybrid Maintenance Model

PPM (Planned Preventive Maintenance)
Preventive

CBM (Condition Based Maintenance)
Predictive

1957

2012

CBM Phase I Commenced

2019

CBM Phase II Commenced

2030

Complete Transition to CBM

CBM CAPABILITY OF MTTU

TECHNIQUE	AVAILABILITY
Vibration Analysis	✓
Ultrasonic noise analysis	✓
Oil Wear Down Analysis	✓
Oil testing	✓
Thermography	✓
Non Destructive Testing	✓

A Total CBM Solution

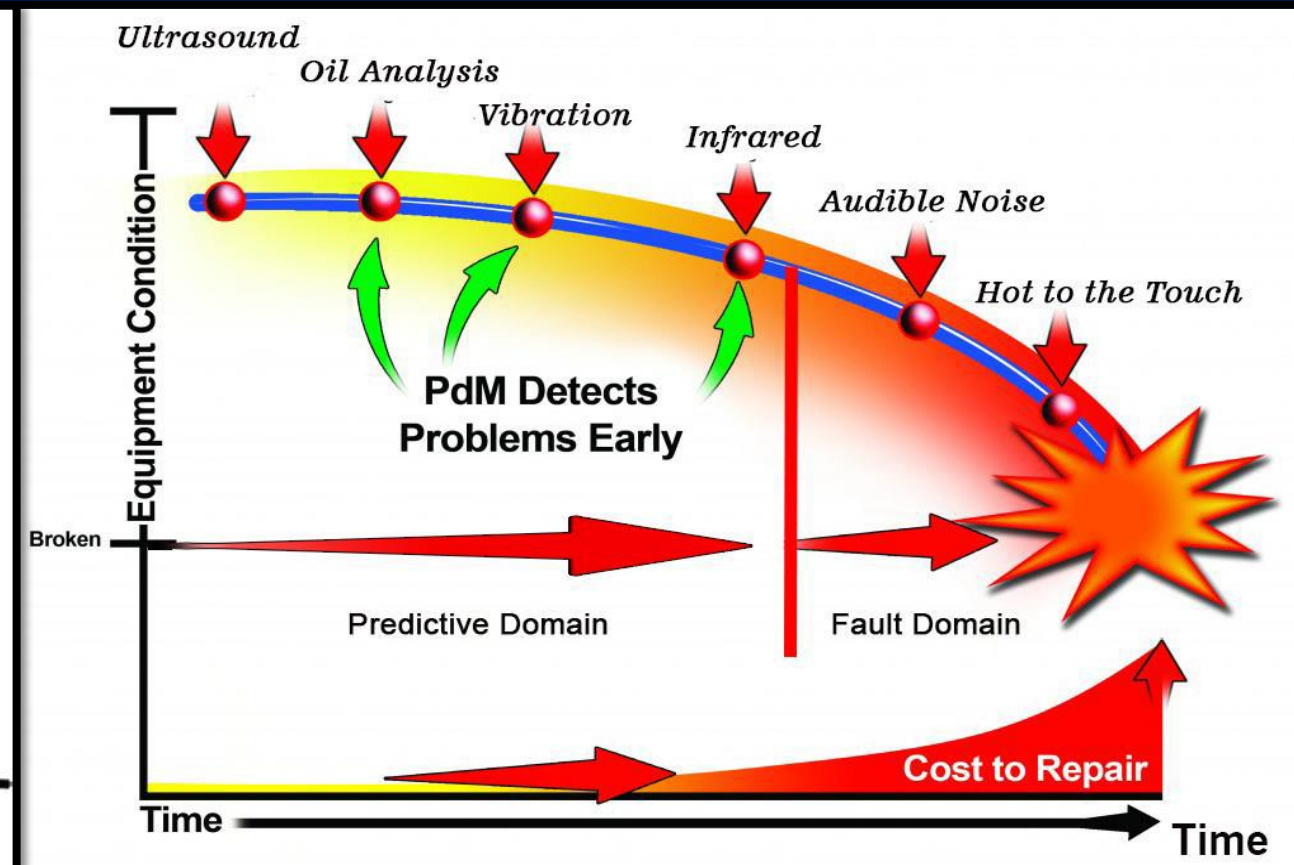*Source : SLN BR 31 (2021)*

P-F CURVE & CBM APPLICATIONS
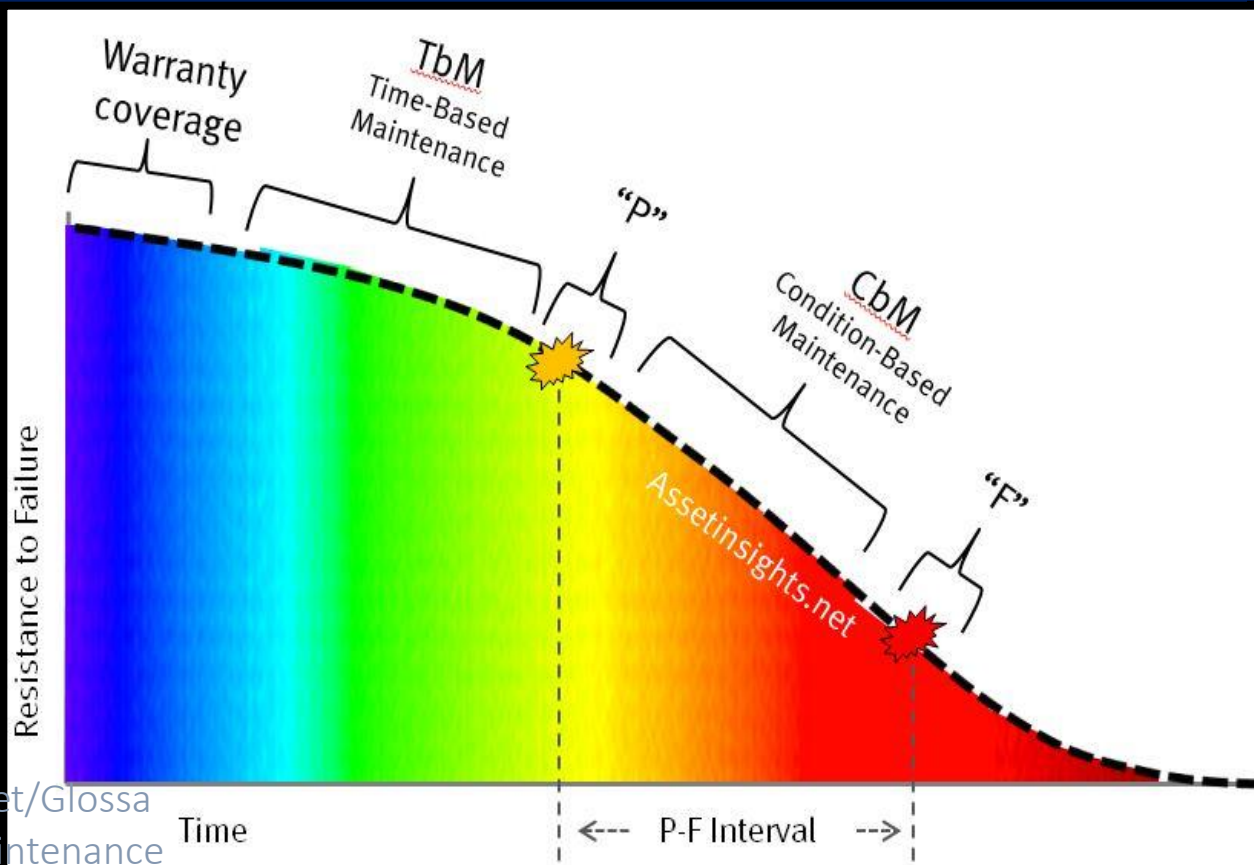
Source : www.assetinsights.net (2021)

Source : Reliability web (2022)

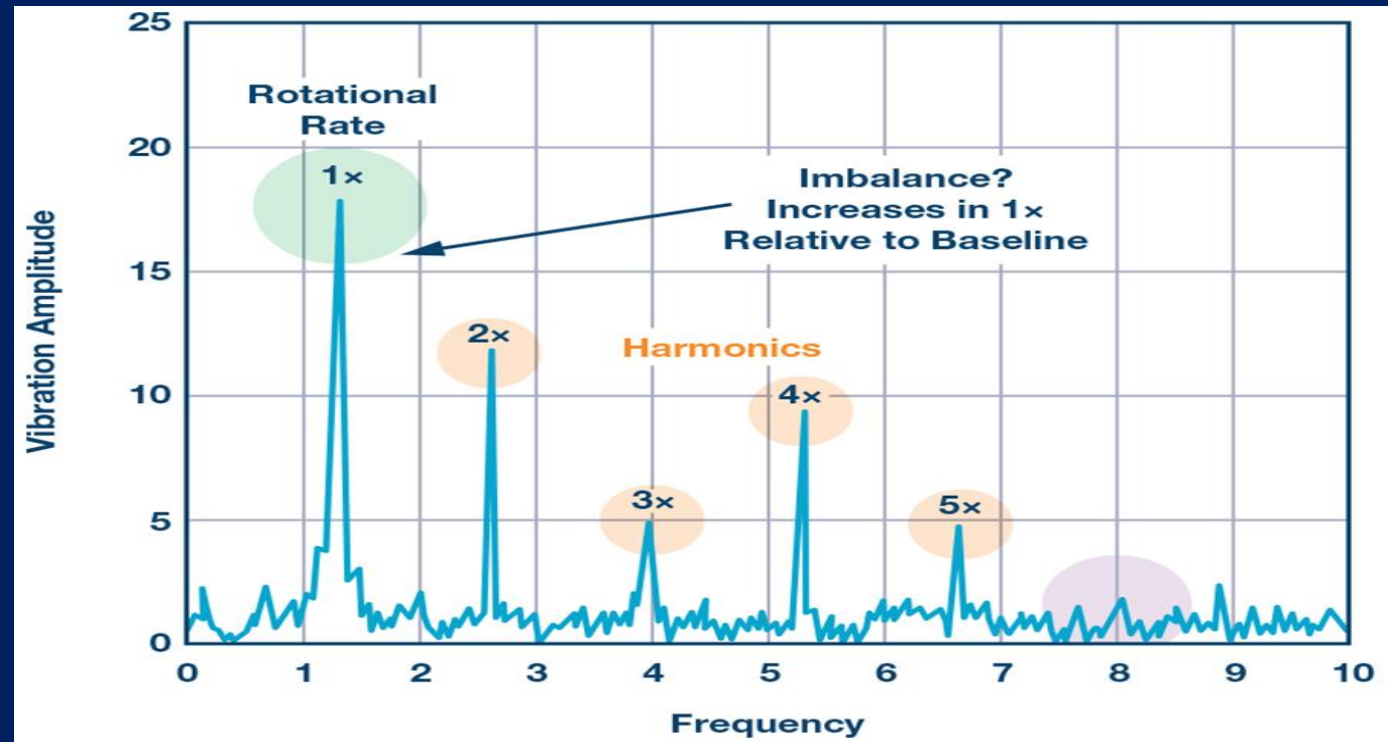# CBM TECHNIQUES

VIBRATION ANALYSIS

"VIBRATION IS THE MOTION OF A BODY ABOUT A REFERENCE POINT CAUSED BY AN UNDESIRABLE MECHANICAL FORCE"

Applications

- Rolling element defects
- Mass unbalance
- Misalignment
- Mechanical looseness
- Defects with gears

VIBRATION ANALYSIS
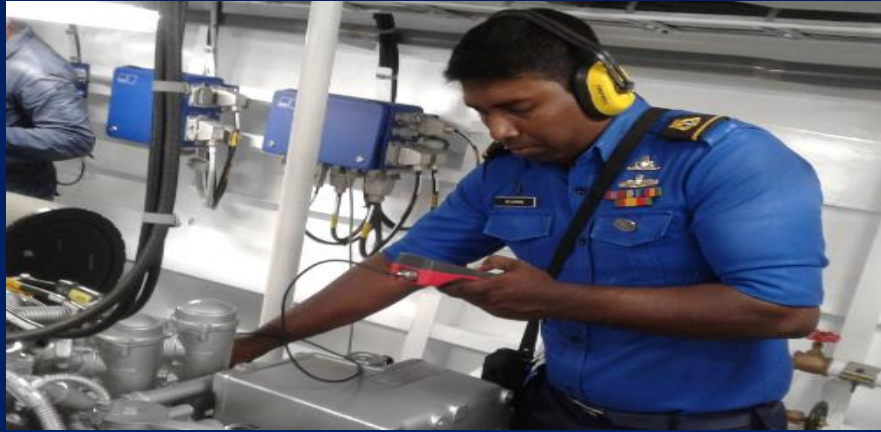
VIBRATION ANALYSIS

➤ **Vibration Analysers**

VIBRATION ANALYSIS

➢ Trend Analysis
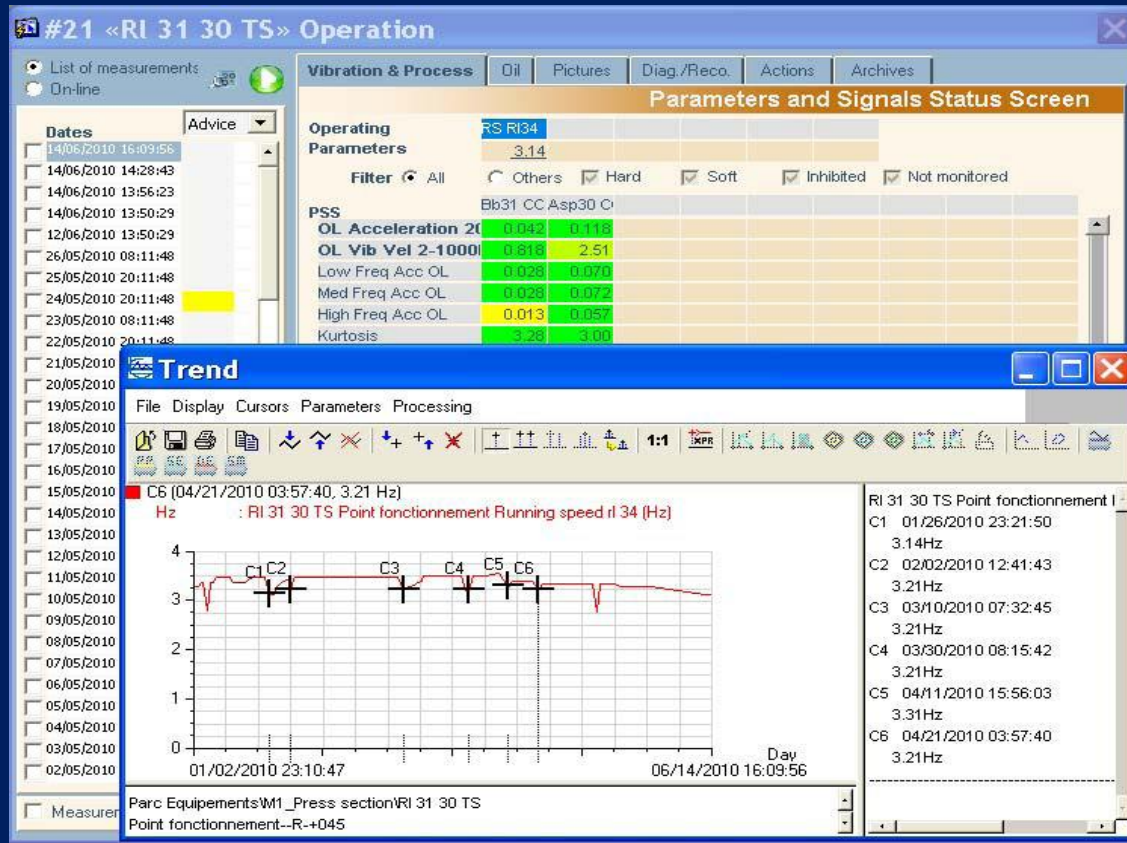
➢ Spectrum Analysis
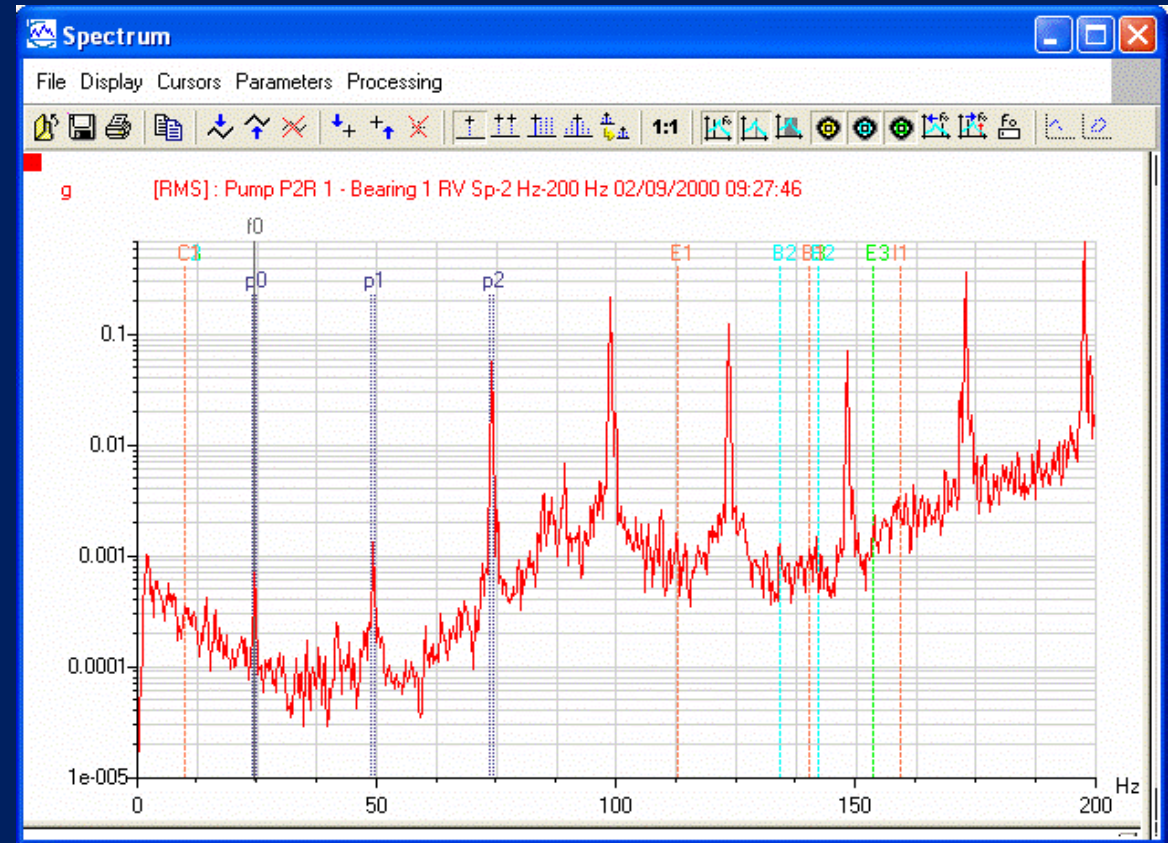
VIBRATION ANALYSIS

Comparison of Vibration spectrums Gearbox Free Ends

2017 (past records) to **2020 (Defect stage)**
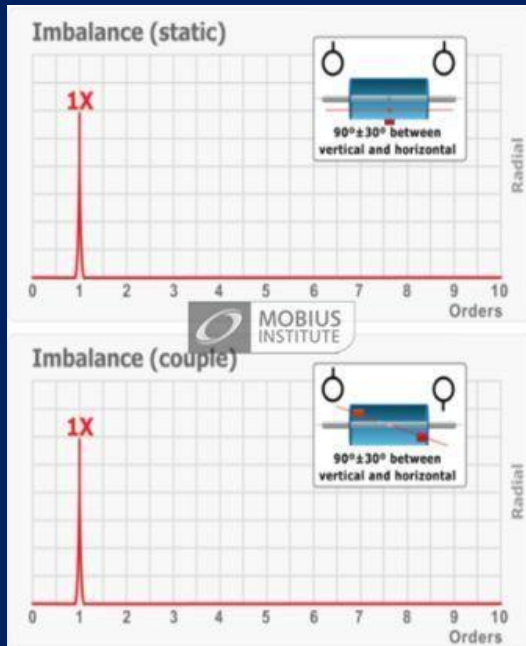
Standard Spectrum Plot for Imbalance

Port G/B F/E

Stbd G/B F/E

VIBRATION ANALYSIS

Observations upon Dismantling

- Port Coupling sheared off

- Stbd Coupling needs dynamic balancing

Rubber delamination & shear

Port Coupling

Stbd Coupling

SAFE OPERATIONAL CRITERIA FOR SLN

All	400 rpm		770 rpm		1050 rpm	
	Average	Alarm	Average	Alarm	Average	Alarm
Gear Box	0.20	1	0.92	2	1.61	3
Main Engine	1.66	4	5.12	8	9.20	16
P/block	0.10	1	0.38	2	0.54	4
Shaft seal	0.08	0.5	0.32	1	0.47	2
Stern tube	0.11	0.5	0.78	1	1.67	2
A Bracket	0.35	1	0.72	1	0.78	2
Rudder top	0.24	1	0.86	2	1.45	3

Category 1 - Advanced Off Shore Patrol Vessel (AOPV)

OIL ANALYSIS

➤ **BASIC OIL ANALYSIS**

Health assessment of oil

➤ **WEAR DOWN ANALYSIS**

Health assessment of machinery

OIL ANALYSIS

➢ **Oil Wear Down Analysis (WDA)**

iCAP 7200 ICP-OES Radial
Oil Spectrometer, USA

OIL ANALYSIS

	Fresh Oil Sample	Port Main Engine			Stbd Main Engine		
Oil Running Hrs	-	372.40	28.30	87.00	372.40	28.30	99.00
Total Running Hrs of Machinery	-	20368.30	20397.00	20455.30	20368.05	20396.35	20467.05
Element	**Max. Permissible Limit**						
Fe	80	< 1.000	8.026	2.925	7.278	9.407	2.294	8.974
Cr	10	< 1.000	1.243	< 1.000	< 1.000	1.044	< 1.000	< 1.000
Si	15	< 1.000	< 1.000	< 1.000	4.918	< 1.000	< 1.000	6.215
Al	20	< 1.000	< 1.000	< 1.000	2.746	< 1.000	< 1.000	3.521
Pb	20	< 1.000	< 1.000	< 1.000	< 1.000	4.569	1.059	1.504
Cu	25	< 1.000	58.069	15.901	32.860	95.370	16.343	55.159
Sn	10	< 1.000	< 1.000	1.001	1.916	< 1.000	1.548	2.896
Ni	10	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000	< 1.000

Elemental Concentration as per ASTM D 5185 (ppm)
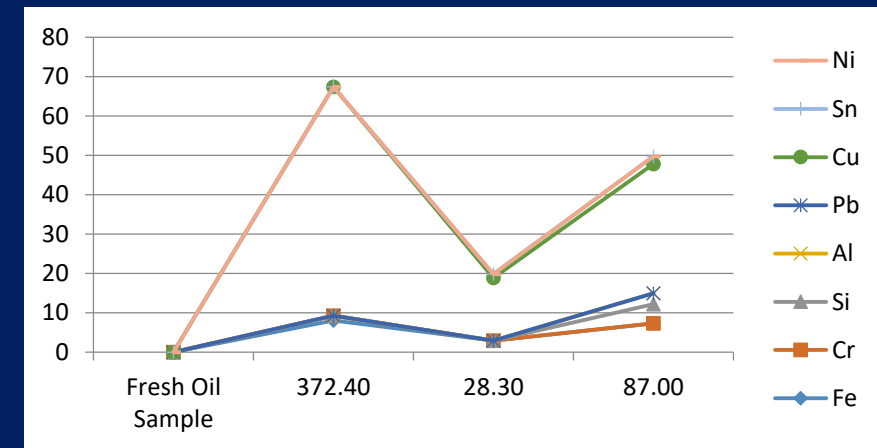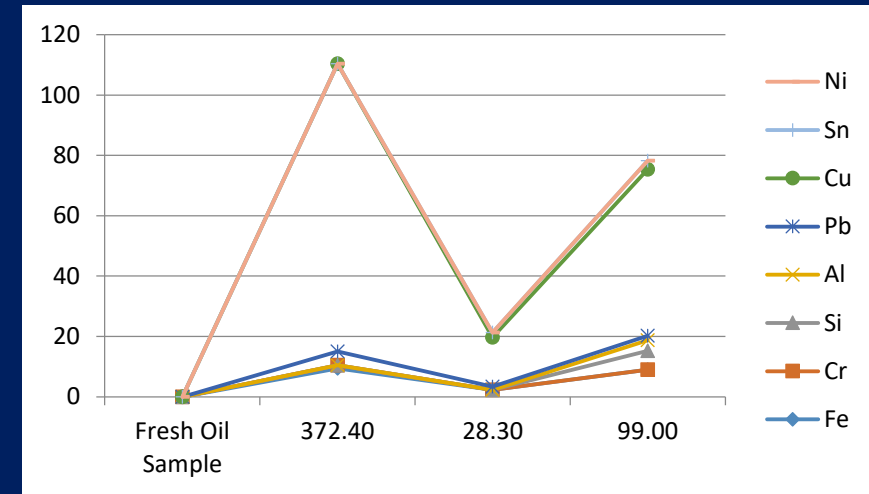
OIL ANALYSIS

Observations after Dismantling

a. Metal particles in lub oil sumps.
b. Port crankshaft inner stop ring (thrust ring) worn out and cracked.
c. Stbd crank shaft inner stop ring worn out.
d. All main bearings of both M/Es slightly scrapped and edges sharpened.
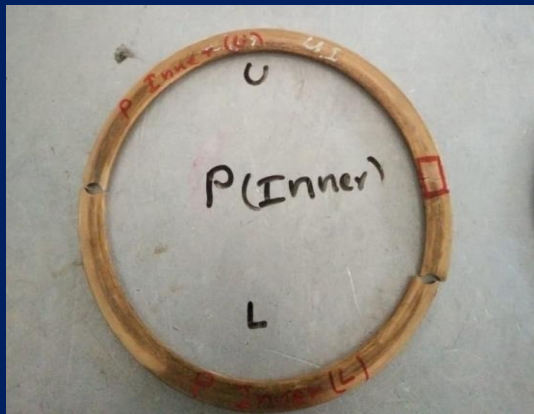
OIL ANALYSIS

➢ **Basic Oil Acceptance Testing**

- Kinematic Viscosity – ASTM D 445
- Water Content – ASTM D 95
- TAN/ TBN Test – ASTM D 2896/ D 4379
- Drop Test (Blotter Paper) – ASTM D 7899
- Flash Point – ASTM D 92
- Insolubles – ASTM D 893

OIL ANALYSIS

Kinematic Viscosity Testing
as per - ASTM D 445

Total Base Number Testing
as per - ASTM D 2896/4739

Drop Test (Blotter Paper) as per
 - ASTM D 7899

OIL ANALYSIS

Flash Point Tester
As per – ASTM D 92

Insoluble Testing Centrifuge
As per – ASTM D 893

Water Content Tester
As per – ASTM D 95

INFRARED THERMAL ANALYSIS

"INFRARED RADIATION (IR) IS NOT DETECTABLE BY THE HUMAN EYE, AN IR CAMERA CAN CONVERT IT TO A VISUAL IMAGE THAT DEPICTS THERMAL VARIATIONS ACROSS AN OBJECT OR SCENE"
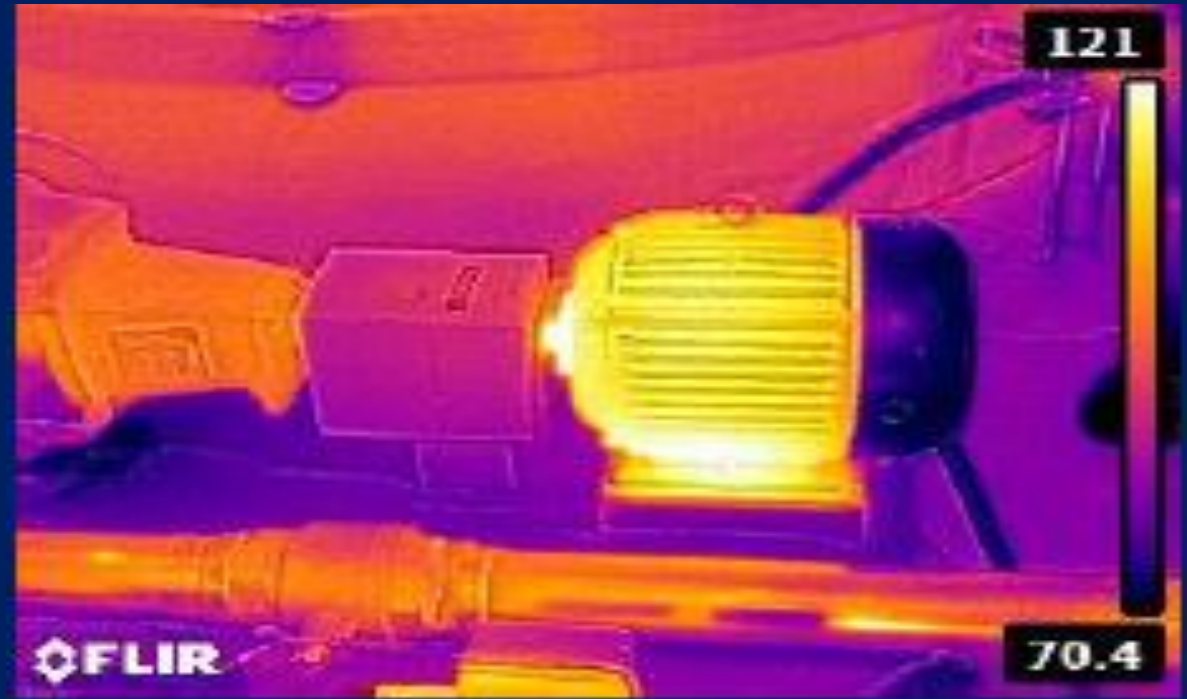
INFRARED THERMAL ANALYSIS

➢ **Applications**
   Mechanical Inspection
   Electrical Inspection

INFRARED THERMAL ANALYSIS
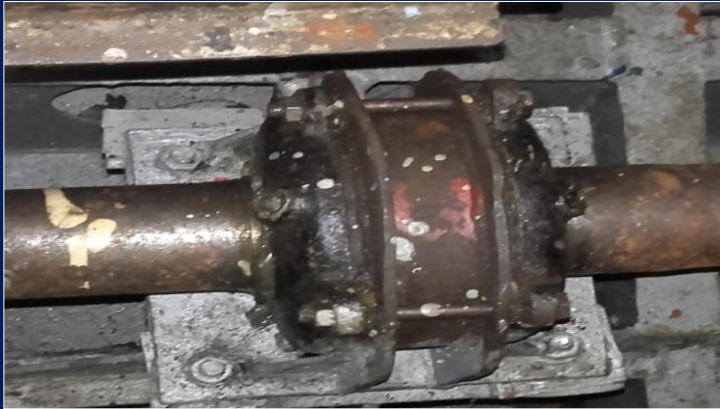
VISIBLE LIGHT IMAGE OF SHAFT BEARING

THERMAL IMAGE OF SHAFT BEARING

VISIBLE LIGHT IMAGE OF MARINE GEAR BOX

THERMAL IMAGE OF MARINE GEAR BOX

INFRARED THERMAL ANALYSIS
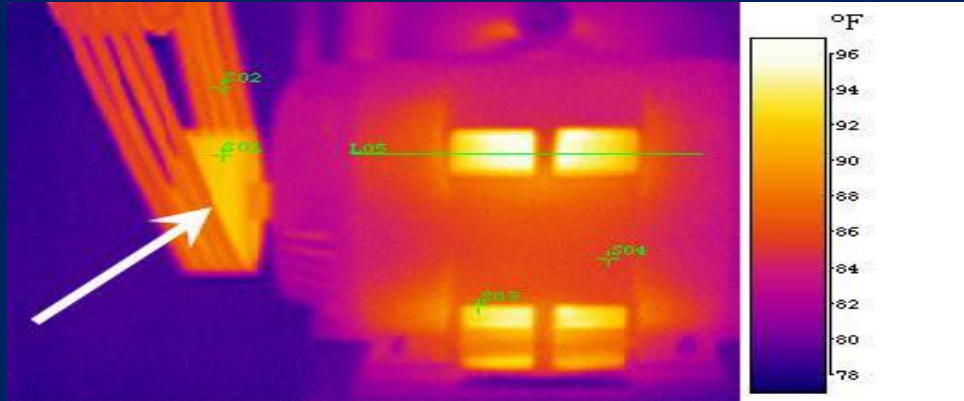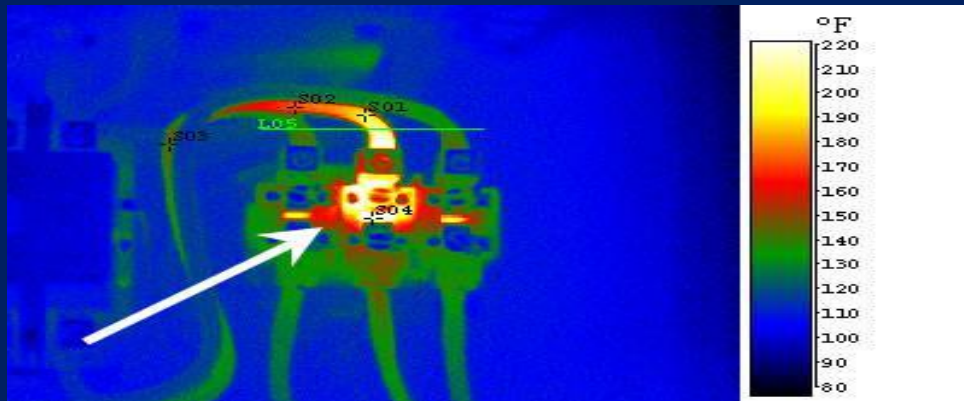
INFRARED THERMAL IMAGE

VISIBLE LIGHT IMAGE

INFRARED THERMAL IMAGE
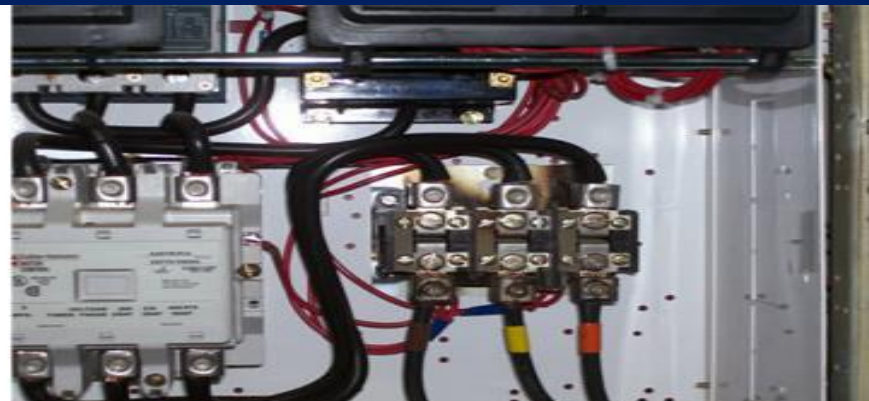
VISIBLE LIGHT IMAGE

INFRARED THERMAL ANALYSIS

INFRARED THERMAL IMAGE

VISIBLE LIGHT IMAGE
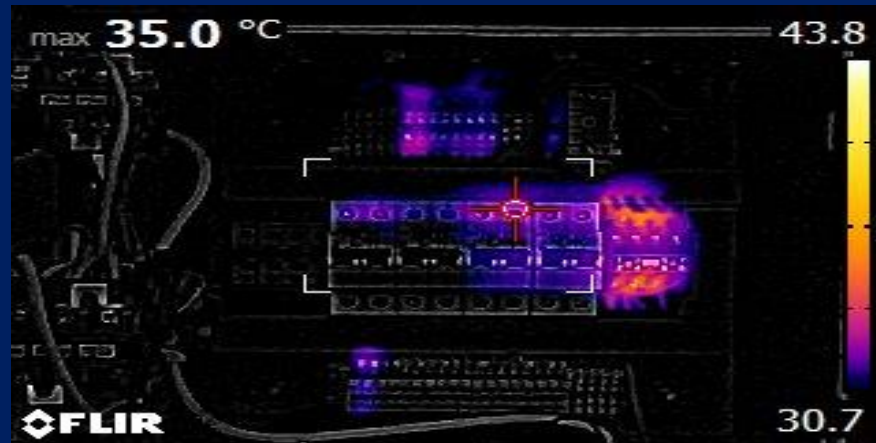
INFRARED THERMAL IMAGE

VISIBLE LIGHT IMAGE

ENGINE DYNAMIC TESTING

- ➢ **Amplitude demodulation**
- ➢ **Constant bandwidth analysis**
- ➢ **Octave band analysis**
- ➢ **Peak value (peak value) analysis**
- ➢ **Proximity analysis**
- ➢ **Spike energy**
- ➢ **Time synchronous averaging analysis**

ULTRASOUNDS DETECTION

"ULTRASONIC ANALYSIS HELPS DETECT CHANGES IN SOUND PATTERNS CAUSED BY PROBLEMS SUCH AS WEAR, FATIGUE AND DETERIORATION IN MOVING PARTS"

ULTRASOUNDS DETECTION

➤ **Some of applications**

Bearing inspection

Steam traps inspection

Electrical inspections

Leakages inspection

Valves inspection

Defective Bearing
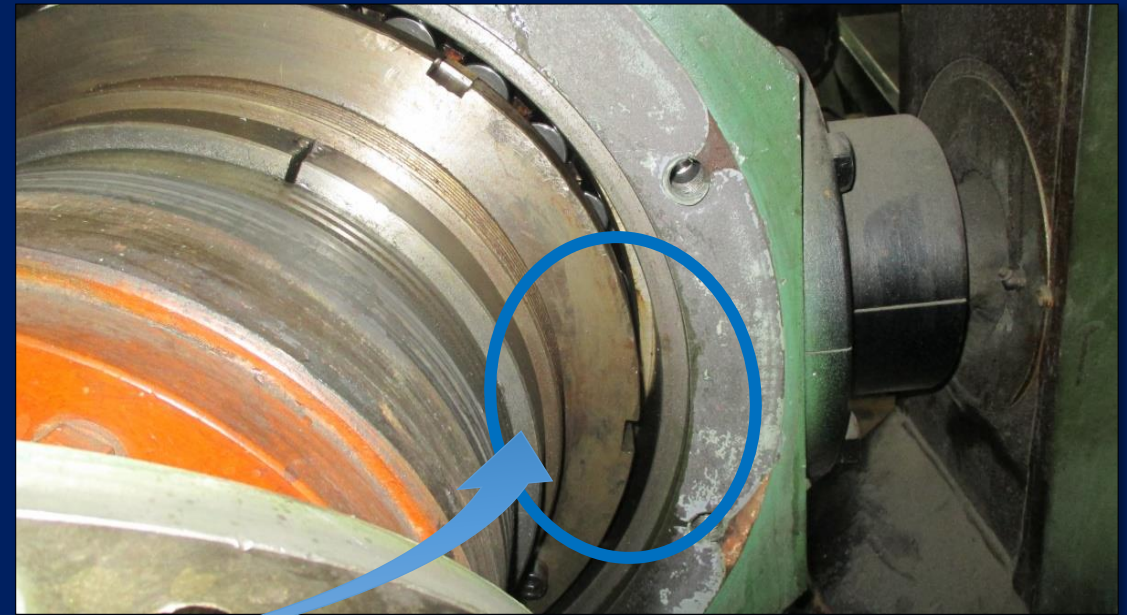
Actual Defect (Outer Ring Fractured)

ULTRASOUNDS DETECTION
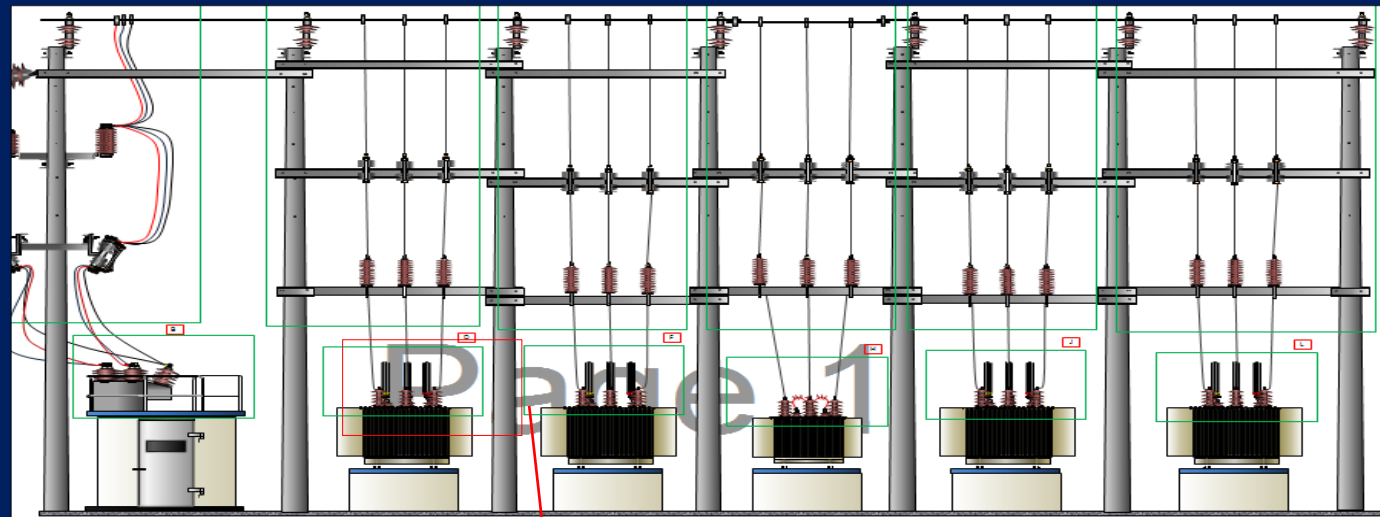
Defected Insulator

INTEGRATED CBM TECHNIQUES

➢ **Laser Alignment**

➢ **Dynamic Balancing**

➢ **Non Destructive Testing**

INTEGRATED CBM TECHNIQUES

> ## Laser Alignment

Diagnosis of a Misalignment
Through Vibration analysis
&
Integrate using Alignment

1X, High2X, 3X and harmonics
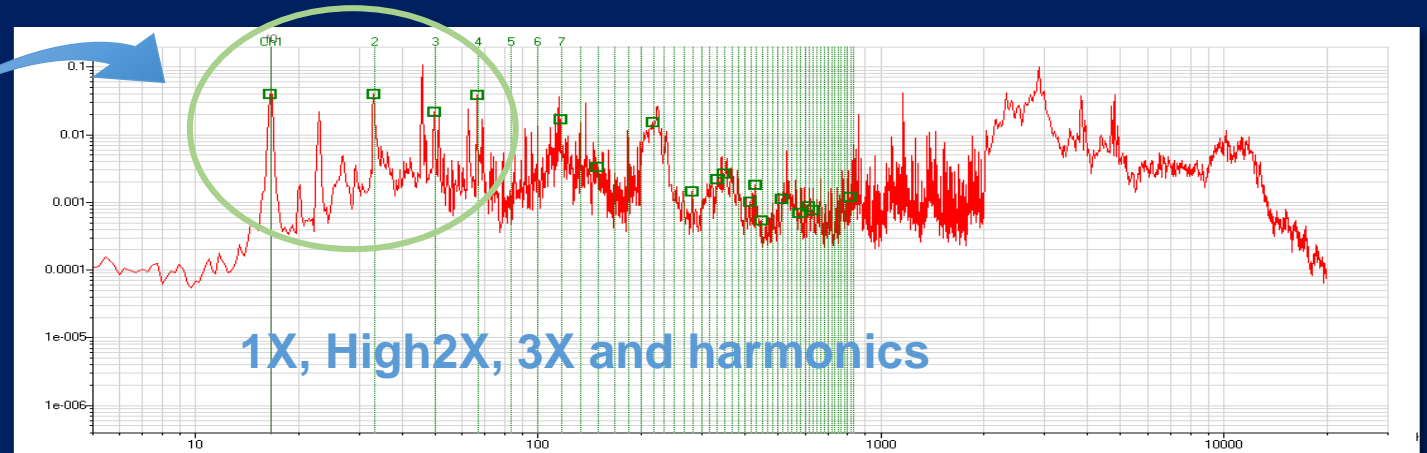
INTEGRATED CBM TECHNIQUES
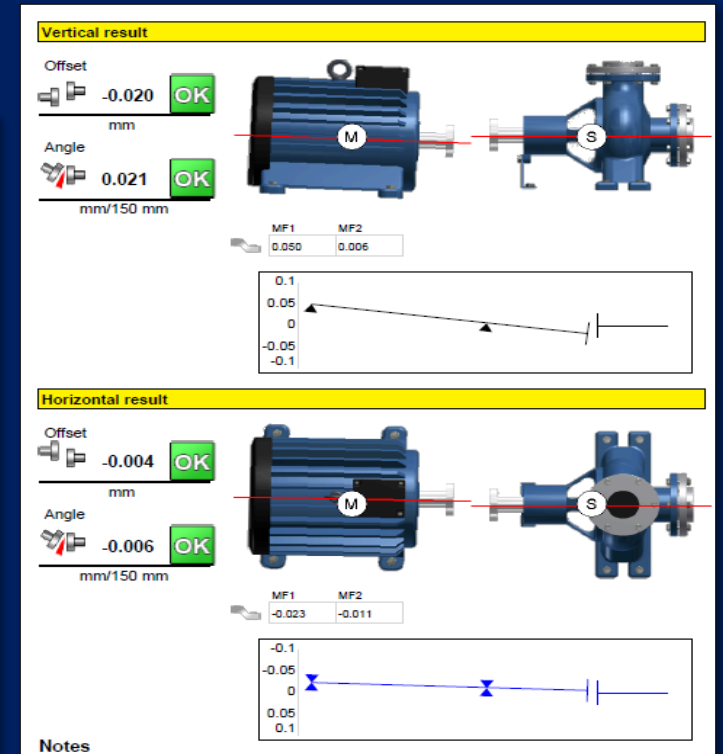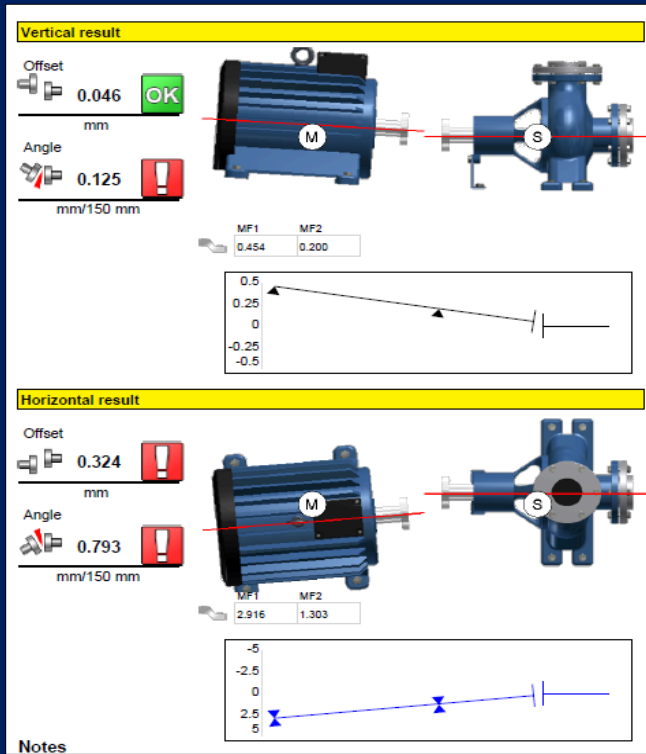
Before Alignment

After Alignment
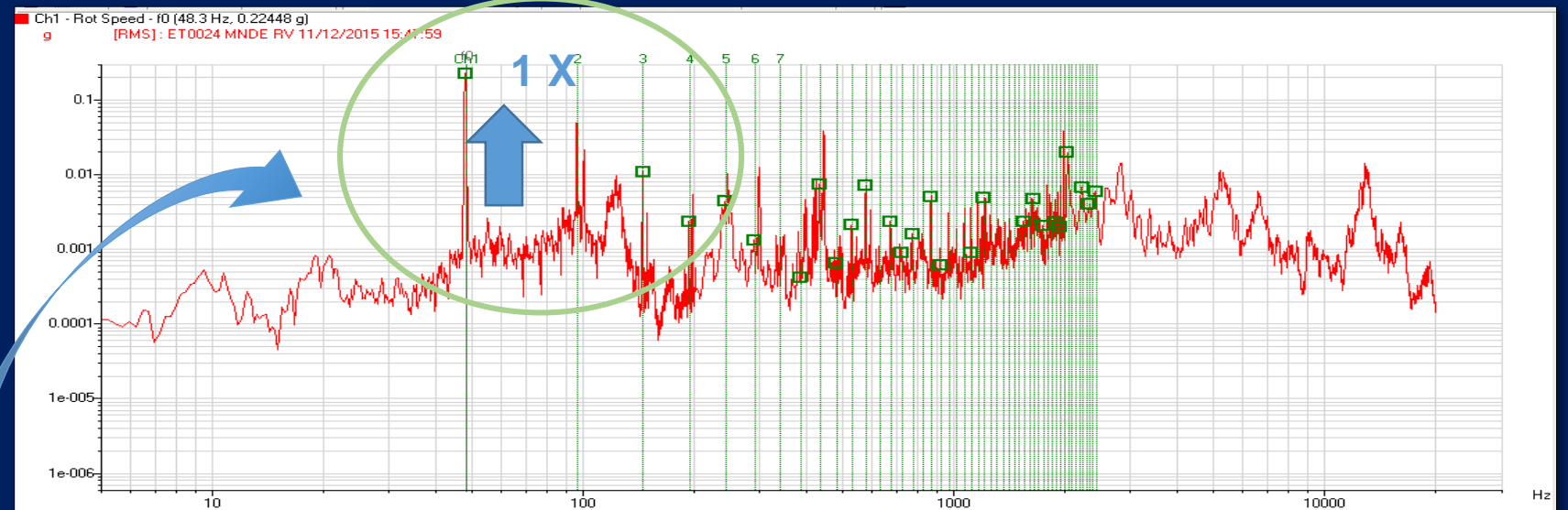
➤ **Dynamic Balancing**

Diagnosis of Rotor Unbalance
through Vibration Analysis
&
Use integrated Balancer Module

INTEGRATED CBM TECHNIQUES

Vibration(mm/s)
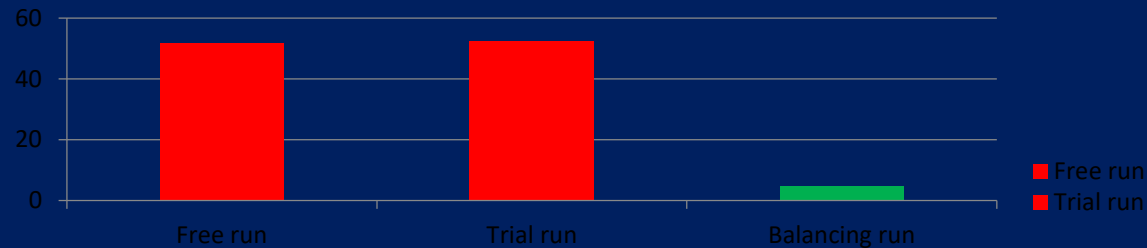
Vibration values are decreased on after dynamic balancing

Before Balancing — **51.72 mm/s**
After Balancing — **4.61 mm/s**

INTEGRATED CBM TECHNIQUES

➢ **Non Destructive Testing**

- Visual testing
- Liquid penetrant testing
- Magnetic particle testing
- Ultrasonic testing
- Eddy current testing
- Radiography testing

INTEGRATED CBM TECHNIQUES

MPT

UT

INTEGRATED CBM TECHNIQUES

LPT

ET

PROSPECTIVE ANALYSIS OF CBM TECHNIQUES

COST EFFECTIVENESS OF CBM

Direct (traditional) maintenance costs

Indirect (hidden) Maintenance costs = Up to 5x direct costs

The "Iceberg" Model

Labor, Materials, Contracts, Overheads

Lower quality

Higher energy

Over maintained

Late deliveries

Reduced asset life

Lost production

Wasted resources

Safety risks

Environmental issues
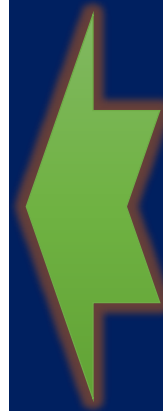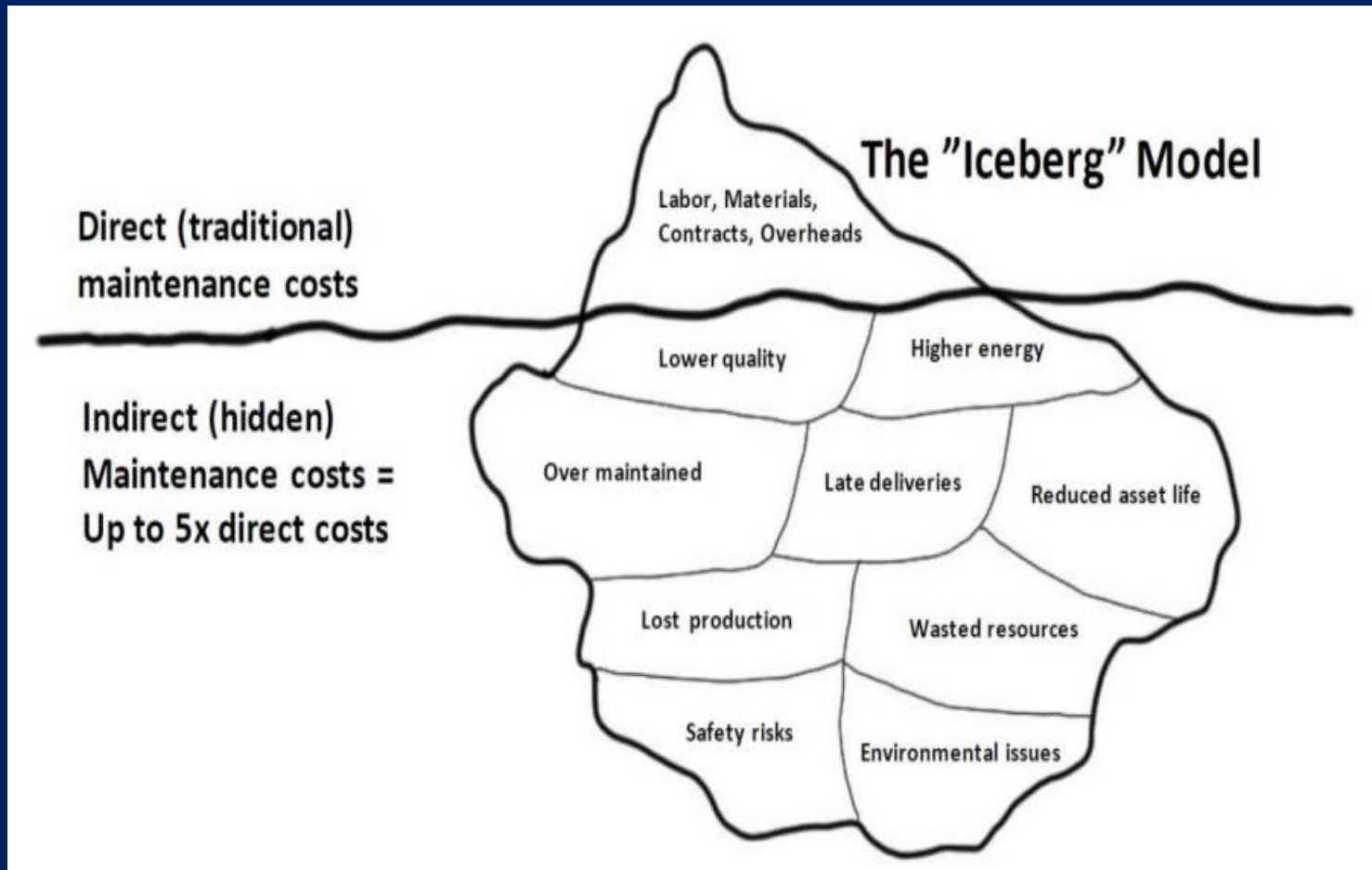
CBM Address them all

Source : M Wienker (2016)

EFFECTIVENESS OF CBM

Maintenance costs reduced by 50%

Unexpected failures reduced by 55%

Repair and overhaul time reduced by 50%

Source : CBM DoD Guidebook USN, (2008)

Spare parts inventory reduced by 30%

Mean Time Between Failures (MTBF) increased by 30%

Machinery availability increased by 30%

REGRESSION ANALYSIS METHOD

Financial Effectiveness Analysis (FEA)

Physical Effectiveness Analysis (PEA)

Subject Matter Experts' (SME) Opinion

FINANCIAL EFFECTIVENESS ANALYSIS (FEA)

QUANTITATIVE ANALYSIS
Cost & ROIs of CBM Programme – VA Section

	YEAR 2018	YEAR 2019	YEAR 2020	YEAR 2021
Capital cost	39,834,257.35	39,972,198.82	39,161,617.74	17,798,388.81
Annual cost saving	1,000,000.00	212,289,900.00	68,100,000.00	25,400,000.00
Total ROI	1,000,000.00	213,289,900.00	281,389,900.00	306,789,900.00

Source : SLN Records
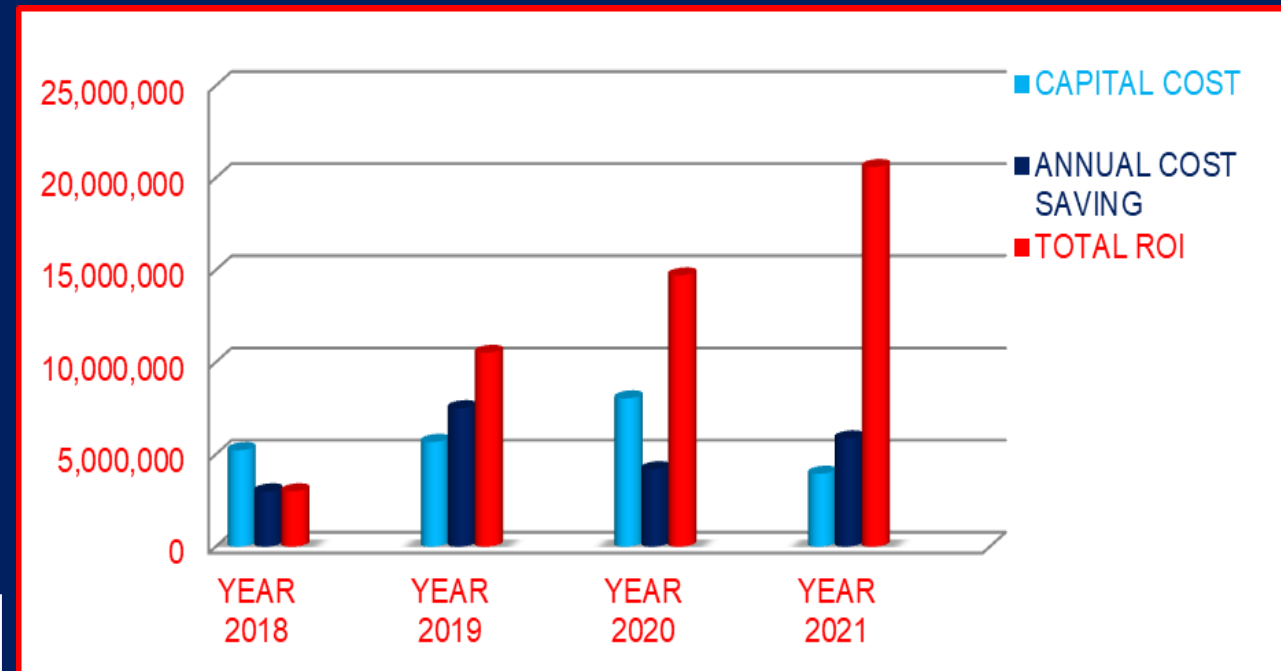
FINANCIAL EFFECTIVENESS ANALYSIS (FEA)

QUANTITATIVE ANALYSIS
Cost & ROIs of CBM Programme – Oil Section

	YEAR 2018	YEAR 2019	YEAR 2020	YEAR 2021
Capital cost	5,233,786.33	5,682,008.59	8,046,256.40	3,958,873.13
Annual cost saving	3,000,000.00	7,515,000.00	4,200,000.00	5,875,000.00
Total ROI	3,000,000.00	10,515,000.00	14,715,000.00	20,590,000.00
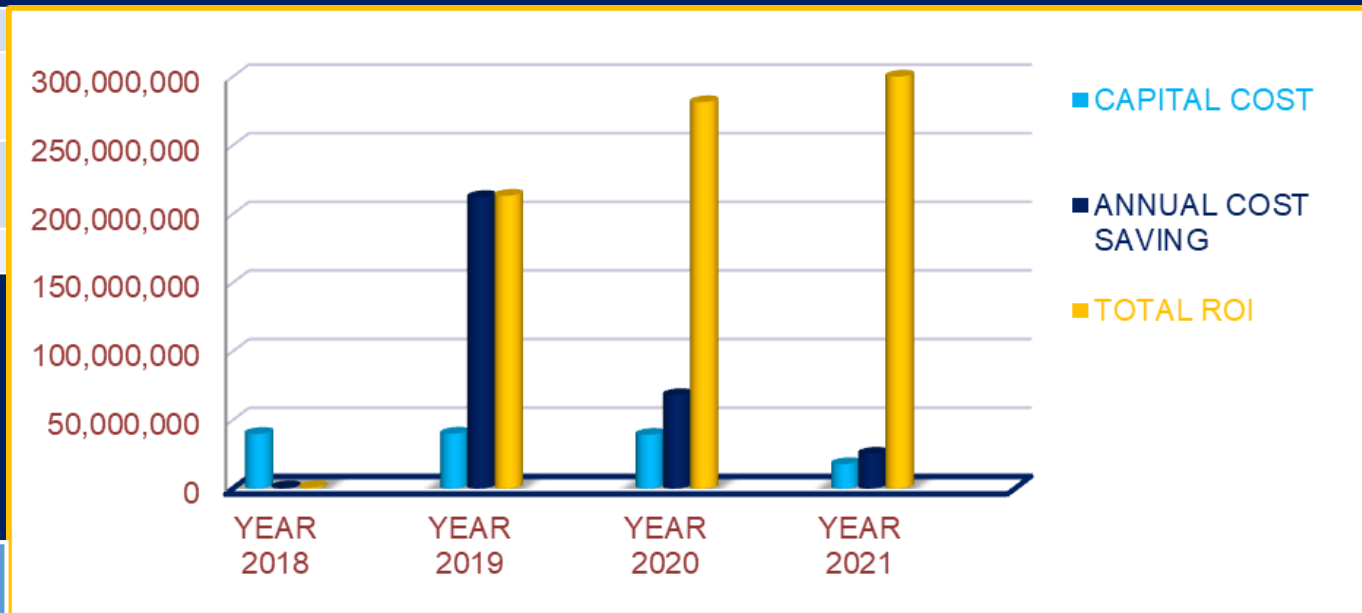
Source : SLN Records

FINANCIAL EFFECTIVENESS ANALYSIS (FEA)

QUANTITATIVE ANALYSIS
Cost & ROIs of CBM Programme – NDT Section

	YEAR 2018	YEAR 2019	YEAR 2020	YEAR 2021
Capital cost	3,212,327.63	2,584,841.38	1,529,116.35	721,005.58
Annual cost saving	1,473,000.00	3,698,000.00	4,060,000.00	9,520,000.00
Total ROI	1,473,000.00	5,171,000.00	9,231,000.00	18,751,000.00
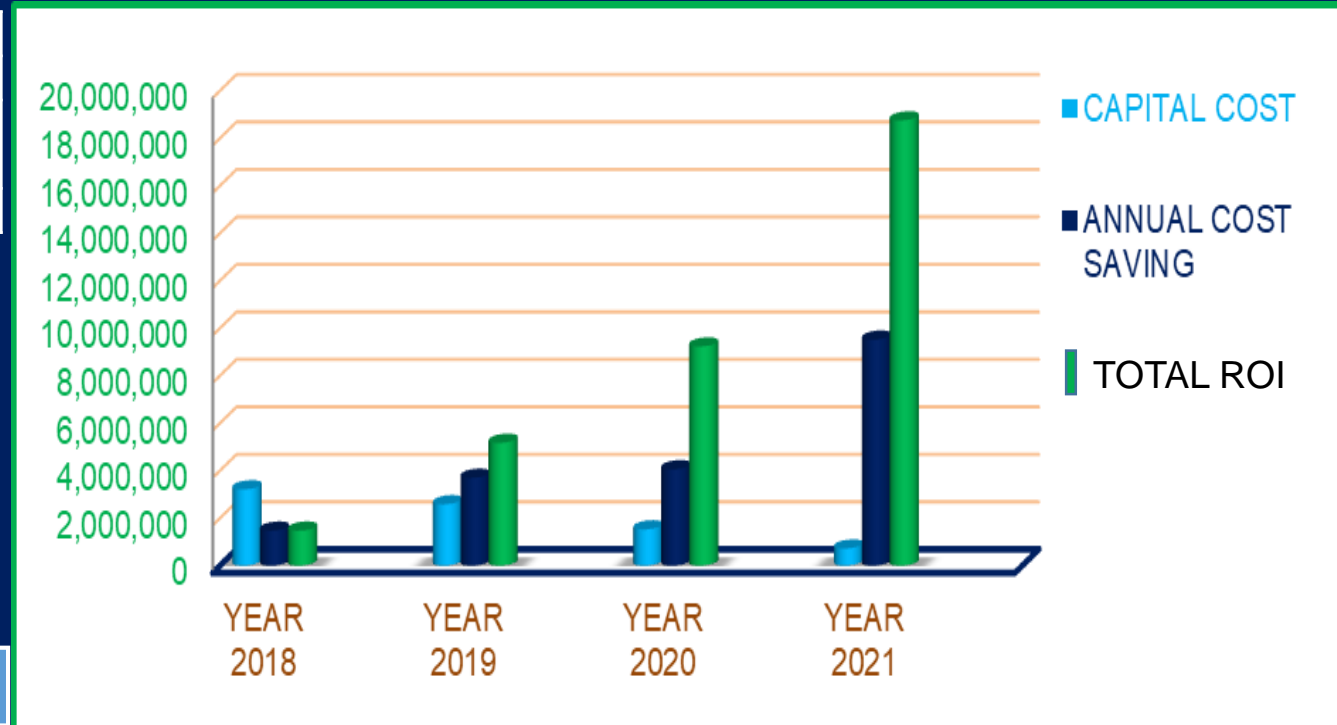
Source : SLN Records

FINANCIAL EFFECTIVENESS ANALYSIS (FEA)

QUANTITATIVE ANALYSIS
Cost & ROIs of CBM Programme – Combined solutions

	YEAR 2018	YEAR 2019	YEAR 2020	YEAR 2021
Training Cost (Staff)	80,000.00*	800,000.00*	2,400,000.00*	50,000.00*
Total Training Cost	3,330,000.00*			
Total ROI	-	-	725,000.00	9,883,000.00

*- Approximate value

FINANCIAL EFFECTIVENESS ANALYSIS (FEA)

COST BENEFIT ANALYSIS (CBA)

- CBA is a policy assessment method that quantifies in monetary terms the value of all consequences of a policy to all members of society.

NET BENEFIT DECISION RULE

- It is the thumb rule to adopt all sub policies (projects) that have positive net benefits.

FINANCIAL EFFECTIVENESS ANALYSIS (FEA)

Sub CBM Programmes	Initial Cost Involvement	Return On Investment	Net Benefit	Benefit/ Cost
VA Programme	39,834,257.35	306,789,900.00	266,955,642.65	6.702
OA Programme	5,233,786.33	20,590,000.00	15,356,213.67	2.934
NDT Programme	3,212,327.63	18,751,000.00	15,538,672.37	4.837
Total CBM Programme	3,330,000.00	9,883,000.00	6,553,000.00	1.968
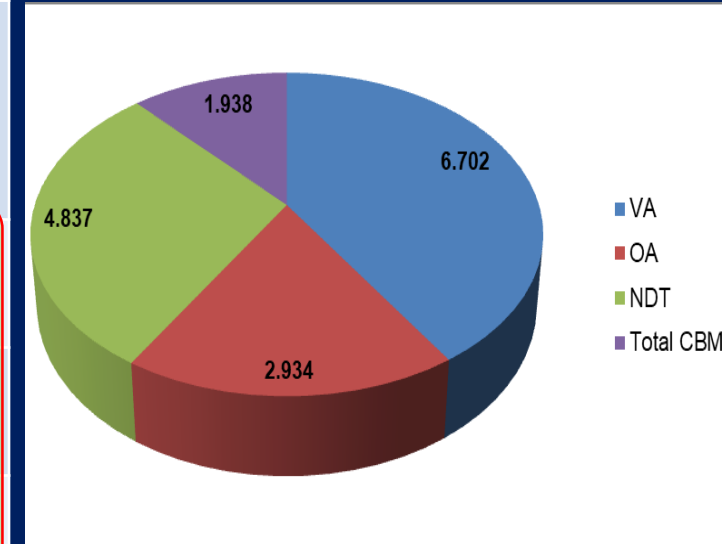
Benefit Distribution Share

Choosing Efficient Projects & Use of Net Benefits versus Benefit/ Cost

Source : D Weimer (2017)

PHYSICAL EFFECTIVENESS ANALYSIS (PEA)

PARETO EFFICIENCY

- As a distinction among maintenance theories (here between PPM & CBM) Pareto efficiency (or Pareto optimality), is used to evaluate or compare different allocations of resources.

- Pareto says a system can not be improved without disturbing the other.

Source : M Salish (2020)

PHYSICAL EFFECTIVENESS ANALYSIS (PEA)

QUALITATIVE ANALYSIS

Survey using Google Forms – 144 Personnel
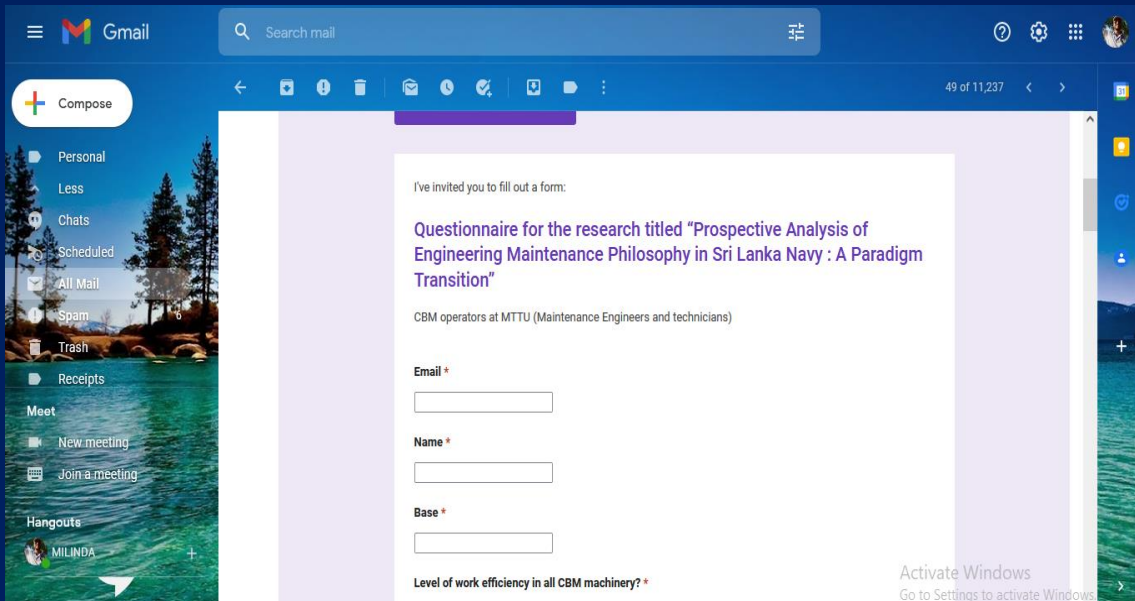
Google forms

Target group	Sample
Top Management	16
CBM operators	25
End users	103

Sample weightage

PHYSICAL EFFECTIVENESS ANALYSIS (PEA)

THREE QUESTIONNAIRES (SURVEY)

Top Management

CBM Operators

End Users

Physical effectiveness (Infrastructure)

Physical effectiveness (Job satisfaction)

Physical effectiveness (knowledge transfer)

Physical effectiveness (Financial - by individual perception)

PHYSICAL EFFECTIVENESS ANALYSIS (PEA)

WEIGHTED MATRIX

Ex : Q7	Effectiveness in implementation of CBM in phases?				
	a. Excellent	b. Good	c. Average	d. Need improvement	e. Poor
Weightage	CBM 4	CBM 3	CBM 2 PPM 1	CBM 1 PPM 3	 PPM 4

Source : S Hanley (1993)

Top Management

Sample

16

Timestamp	Name	Level of implementation	Your perception on the a	The level of SLN staff re	Present level of defect d	Rate of meeting deadline	Cost benefit projection a	Effectiveness in impleme	Rate of knowledge trans	Rate of technology tran
2/8/2022 21:20:12	Cmde Joseph	c. Average	b. Good	c. Average	b. Good	d. Need improvement	d. Need improvement	c. Average	b. Good	b. Good
2/9/2022 14:21:20	SLNS Dakshina	b. Good	c. Average	c. Average	b. Good	b. Good	b. Good	b. Good	c. Average	c. Average
2/10/2022 4:31:13	KMD Seneviratne	d. Need improvement	c. Average	c. Average	c. Average	c. Average	c. Average	c. Average	c. Average	d. Need improvement
2/16/2022 23:10:07	SLNS RANGALLA	a. Excellent	b. Good	b. Good	a. Excellent	b. Good	b. Good	b. Good	a. Excellent	a. Excellent
2/18/2022 8:30:14	HUNNADENIYAGE CHAN	c. Average	b. Good	c. Average	b. Good	d. Need improvement	c. Average	c. Average	e. Poor	b. Good
2/18/2022 8:56:57	Kad siriwardana	e. Poor	a. Excellent	b. Good	b. Good	d. Need improvement	c. Average	e. Poor	c. Average	c. Average
2/18/2022 13:56:52	Gihan Kavinda	d. Need improvement	c. Average	b. Good	d. Need improvement	d. Need improvement	c. Average	d. Need improvement	c. Average	c. Average
2/18/2022 14:06:17	Naval dockyard trincoma	c. Average	e. Poor	e. Poor	e. Poor	d. Need improvement	d. Need improvement	c. Average	e. Poor	e. Poor
2/18/2022 14:07:00	WGDL Wedikkaragedara	e. Poor	d. Need improvement	e. Poor	d. Need improvement	d. Need improvement	d. Need improvement	d. Need improvement	d. Need improvement	d. Need improvement
2/18/2022 14:08:39	Navdock	c. Average	b. Good	d. Need improvement	d. Need improvement	c. Average	d. Need improvement	d. Need improvement	c. Average	c. Average
2/18/2022 14:09:21	NAVDOCK	c. Average	d. Need improvement	c. Average	b. Good	c. Average	b. Good	b. Good	b. Good	d. Need improvement
2/18/2022 14:09:47	Naval Dockyard, Trincom	e. Poor	d. Need improvement	d. Need improvement	d. Need improvement	d. Need improvement	d. Need improvement	d. Need improvement	d. Need improvement	d. Need improvement
2/18/2022 14:10:07	NAVDOCK	c. Average	b. Good	c. Average	c. Average	c. Average	c. Average	c. Average	d. Need improvement	d. Need improvement
2/18/2022 14:10:50	SLN DOCKYARD	b. Good	c. Average	c. Average	b. Good	c. Average	b. Good	b. Good	b. Good	b. Good
2/18/2022 14:13:27	SLN navdock	b. Good	b. Good	b. Good	b. Good	c. Average	b. Good	b. Good	b. Good	c. Average
2/18/2022 14:21:39	SLN Dockyard	d. Need improvement	d. Need improvement	d. Need improvement	d. Need improvement	d. Need improvement	d. Need improvement	d. Need improvement	d. Need improvement	c. Average

CBM Operators

Sample

25

Timestamp	Email Address	Name	Base	Level of work efficiency ir	Level of ROI of all CBM r	Level of cooperation ren	Level of knowledge trans	Level of credibility on CB	Extent of support
2/2/2022 2:38:39	shirleypriyashantha6@g	TAS Priyashantha	SLNS Thakshila	a. Excellent	a. Excellent	b. Good	a. Excellent	a. Excellent	a. Excellent
2/8/2022 17:32:25	kushanchandimal15@g	K k chandimal	SLNS Thakshila	b. Good	a. Excellent	b. Good	a. Excellent	b. Good	a. Excellent
2/8/2022 17:35:51	samanthakumara56@gr	SDSK Sesath	SLNS Thakshila	b. Good	a. Excellent	a. Excellent	b. Good	b. Good	b. Good
2/8/2022 18:47:22	eanushkadamith@gmai	Edirisinghe	Thakshila	a. Excellent	b. Good	b. Good	a. Excellent	a. Excellent	a. Excellent
2/9/2022 1:08:08	sujithudayanga7@gmail	APS Udayanga	SLNS Thakshila	a. Excellent	b. Good	b. Good	a. Excellent	b. Good	a. Excellent
2/9/2022 15:37:44	ngnp.eng76@gmail.com	NGNP wickramarathna	Slns thakshila	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
2/9/2022 15:40:07	rdeshapriya56@gmail.c	GWR Deshappriya	SLNS Thakshila	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
2/9/2022 15:44:59	kushanchandimal15@g	K k chandimal	Slns thakshila	b. Good	c. Average	a. Excellent	c. Average	a. Excellent	a. Excellent
2/9/2022 15:45:33	prasadwelikala93@gma	wvdpu welikala	SLNS thakshila	b. Good	b. Good	b. Good	b. Good	b. Good	b. Good
2/9/2022 15:49:35	sujithudayanga7@gmail	APS Udayanga	SLNS Thakshila	a. Excellent	b. Good	b. Good	a. Excellent	a. Excellent	a. Excellent
2/9/2022 15:56:46	dineshskdc@gmail.com	Skdc jayarathne	Thakshila	a. Excellent	a. Excellent	b. Good	b. Good	b. Good	b. Good
2/9/2022 16:30:03	sanjayasandaruwan95@	PS Sandaruwan	SLNS Nandimithra	b. Good	b. Good	b. Good	c. Average	a. Excellent	a. Excellent
2/9/2022 17:04:51	wmssweerasinghe@gm	Sampath Weerasinghe	SLN Dockyard	a. Excellent	a. Excellent	b. Good	b. Good	a. Excellent	a. Excellent
2/9/2022 19:56:34	ae107409@gmail.com	DSL weerasinghe	SLNS Thakshila	b. Good	b. Good	d. Need improvement	c. Average	b. Good	d. Need improve
2/10/2022 8:55:49	aththanayaka56717@gn	Ac Aththanayaka	Sln dockyard	a. Excellent	b. Good	b. Good	a. Excellent	a. Excellent	a. Excellent
2/10/2022 9:11:11	harshamadushan27@g	WPHM KARUNARATHN/	Thakshila	b. Good	b. Good	c. Average	b. Good	b. Good	b. Good
2/10/2022 11:25:23	jmrmjayasundara5@gm	JMRM Jayasundara	SLNS Thakshila	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
2/11/2022 16:02:28	Chamindatmk@gmail.cc	Ac Aththanayaka	Sln dockyard	a. Excellent	b. Good	a. Excellent	a. Excellent	a. Excellent	a. Excellent
2/11/2022 16:05:33	rajendranpriyatharan@g	Rajendran Priyatharan	Navdock	b. Good	b. Good	b. Good	b. Good	b. Good	b. Good
2/11/2022 16:09:30	aththanayaka56717@gn	APC Attanayaka	SLN Dockyard	a. Excellent	a. Excellent	b. Good	a. Excellent	b. Good	b. Good
2/11/2022 16:17:28	sumithchandrarathna@c	PS Chandrarathna	P485	b. Good	b. Good	b. Good	b. Good	b. Good	b. Good
2/11/2022 16:20:11	spnnnayanajith@gmail.c	Spnn nayanajith	Slns thakshila	b. Good	b. Good	b. Good	b. Good	b. Good	b. Good
2/11/2022 16:24:06	randikachami@gmail.co	WARS Weerarathna	SLNS Sindurala	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
2/11/2022 22:05:29	kasunvd@gmail.com	DMK Vimukthi	SLN Dockyard	a. Excellent	a. Excellent	a. Excellent	a. Excellent	b. Good	b. Good
2/17/2022 17:33:48	clementsci38@gmail.co	Chamila Ishan Clement:	Thakshila	a. Excellent	b. Good	b. Good	b. Good	a. Excellent	a. Excellent

#	Name	Level of knowledge pos	Level of knowledge gain	Level of cooperation ren	Level of knowledge tra
1		Level of knowledge pos	Level of knowledge gain	Level of cooperation ren	Level of knowledge tra
2	SLNS Thakshila	a. Excellent	a. Excellent	a. Excellent	a. Excellent
3	Thakshila	a. Excellent	b. Good	a. Excellent	b. Good
4	Parakrama	b. Good	b. Good	b. Good	b. Good
5	SLNS Thammanna	c. Average	c. Average	a. Excellent	b. Good
6	SLNS Mahasen	c. Average	c. Average	b. Good	b. Good
7	SLNS PARAKRAMA	c. Average	c. Average	b. Good	b. Good
8	INS Shivaji	c. Average	c. Average	b. Good	c. Average
9	Lt Wijesinghe	b. Good	c. Average	c. Average	c. Average
10	SLNS Parakrama	b. Good	b. Good	b. Good	b. Good
11	SLN Dockyard	a. Excellent	a. Excellent	b. Good	a. Excellent
12	SLN Dockyard	b. Good	b. Good	b. Good	b. Good
13	SLN DOCKYARD	b. Good	a. Excellent	a. Excellent	a. Excellent
14	SLNS Uththara	b. Good	b. Good	a. Excellent	b. Good
15	SLNS Parakrama	c. Average	c. Average	b. Good	a. Excellent
16	SLNS PARAKRAMA	b. Good	b. Good	b. Good	a. Excellent
17	SLNS Thakshila	c. Average	a. Excellent	b. Good	b. Good
18	SLNS Parakrama	c. Average	c. Average	b. Good	c. Average
19	SLNS Thakshila	b. Good	b. Good	b. Good	b. Good
20	INS Shivaji	b. Good	b. Good	b. Good	b. Good
21	SLNS PARAKRAMA	b. Good	c. Average	b. Good	b. Good
22	NMA	a. Excellent	a. Excellent	a. Excellent	d. Need improvement
23	Slns thaksia	b. Good	b. Good	b. Good	a. Excellent
24	Thakshila	b. Good	b. Good	b. Good	b. Good
25	SLNS Parakramabahu	b. Good	b. Good	a. Excellent	b. Good
26	SLNS Parakrama	b. Good	b. Good	b. Good	b. Good
27	SLNS Parakrama	b. Good	b. Good	b. Good	b. Good
28	SLNS Parakrama	c. Average	c. Average	b. Good	b. Good
29	Parakrama	c. Average	c. Average	b. Good	b. Good
30	SLNS Parakrama	b. Good	b. Good	a. Excellent	a. Excellent
31	SLNS Parackrama	c. Average	a. Excellent	b. Good	b. Good
32	Parakrama	a. Excellent	a. Excellent	a. Excellent	a. Excellent
33	SLNS Dakshina	e. Poor	c. Average	e. Poor	c. Average
34	INS Shivaji	d. Need improvement	e. Poor	a. Excellent	a. Excellent
35	SLN Dockyard	b. Good	b. Good	a. Excellent	b. Good
1		Level of knowledge pos	Level of knowledge gain	Level of cooperation ren	Level of knowledge tra
36	SLNS Rangalla	c. Average	c. Average	b. Good	b. Good
37	SLNS RANAGAJA	c. Average	b. Good	b. Good	b. Good
38	SLNS Uththara - L 821	c. Average	c. Average	b. Good	b. Good
39	Dockyard iuc ws	a. Excellent	a. Excellent	a. Excellent	a. Excellent
40	SLN Dockyard	c. Average	b. Good	a. Excellent	a. Excellent
41	Navdock	b. Good	b. Good	b. Good	b. Good
42	SLNS THAKSHILA	b. Good	b. Good	b. Good	b. Good
43	Sayurala	b. Good	b. Good	b. Good	b. Good
44		b. Good	b. Good	b. Good	b. Good
45	Thammanar	b. Good	b. Good	b. Good	b. Good
46	SLN DOCKYARD	b. Good	b. Good	b. Good	b. Good
47	SLNS RANAWICKRAMA	b. Good	b. Good	b. Good	b. Good
48	Navdock	c. Average	c. Average	c. Average	c. Average
49	Wicrama ii	a. Excellent	a. Excellent	a. Excellent	b. Good
50	Slns Sindurala	b. Good	b. Good	b. Good	b. Good
51	Slns thaksia	b. Good	a. Excellent	b. Good	b. Good

#	Name	Level of knowledge pos	Level of knowledge gain	Level of cooperation ren	Level of knowledge tran	To what level your routin
52	Thakshila	a. Excellent	b. Good	b. Good	b. Good	b. Good
53	SLNS Mahasen	b. Good	b. Good	b. Good	b. Good	a. Excellent
54	SLNS Pandukabaya	c. Average	c. Average	a. Excellent	a. Excellent	a. Excellent
55	NMA	d. Need improvement	c. Average	No experience	c. Average	c. Average
56	Slns thakshila	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
57	Slns thakshila mttu	b. Good	b. Good	b. Good	b. Good	b. Good
58	Thakshila	a. Excellent	b. Good	a. Excellent	a. Excellent	a. Excellent
59	Slns thakshila	b. Good	a. Excellent	c. Average	b. Good	a. Excellent
60	SLNS Thakshila	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
61	SLNS Thakshila	b. Good	b. Good	b. Good	a. Excellent	b. Good
62	SLNS Thakshila	b. Good	b. Good	b. Good	b. Good	b. Good
63	SLNS Mahasen	a. Excellent	a. Excellent	b. Good	a. Excellent	a. Excellent
64	SLNS Thakshila	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
65	SLNS Rangalla	a. Excellent	a. Excellent	a. Excellent	a. Excellent	b. Good
66	SLN Dockyard	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
67	SLNS Gamunu	b. Good	b. Good	a. Excellent	b. Good	b. Good
68	Sayurala					
69	SLNS Rangalla	b. Good	a. Excellent	b. Good	a. Excellent	a. Excellent
1		Level of knowledge pos	Level of knowledge gain	Level of cooperation ren	Level of knowledge tran	To what level your routin
70	SLNS Uththara	b. Good	a. Excellent	a. Excellent	a. Excellent	b. Good
71	SLN Dockyard	b. Good	a. Excellent	a. Excellent	a. Excellent	c. Average
72	SLNS Dakshina	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
73	Gajabahu	a. Excellent	a. Excellent	b. Good	a. Excellent	a. Excellent
74	SLNS Uththara	a. Excellent	b. Good	b. Good	a. Excellent	b. Good
75	SLNS Parakrama	b. Good	a. Excellent	a. Excellent	a. Excellent	a. Excellent
76	Parakramabahu	b. Good	c. Average	b. Good	c. Average	b. Good
77	SLNS Sauyrala	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
78	SLNS Dakshina	b. Good	b. Good	b. Good	b. Good	b. Good
79	SLNS Ranagaja	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
80	Uththara	a. Excellent	b. Good	b. Good	b. Good	b. Good
81	SLNS Gajabahu	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
82	SLNS Sayura	a. Excellent	c. Average	a. Excellent	b. Good	b. Good
83	SLNS kelani	a. Excellent	b. Good	b. Good	b. Good	b. Good
84	SLNS Gajabahu	a. Excellent	a. Excellent	a. Excellent	a. Excellent	b. Good
85	SLNS Parakkramabahu	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
86	Dakshina	b. Good	b. Good	b. Good	b. Good	b. Good
87	SLNS Pandukabaya	b. Good	a. Excellent	b. Good	a. Excellent	c. Average
88	P4446	a. Excellent	b. Good	b. Good	a. Excellent	a. Excellent
89	Parakrama	b. Good	b. Good	b. Good	b. Good	b. Good
90	SLNS Samudura	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
91	SLNS Jayasagara	b. Good	c. Average	a. Excellent	a. Excellent	a. Excellent
92	SLNS ELARA	b. Good	b. Good	b. Good	b. Good	b. Good
93	SLNS Uththara	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
94	P 4444	b. Good	b. Good	a. Excellent	a. Excellent	b. Good
95	Ruhuna	b. Good	a. Excellent	b. Good	b. Good	b. Good
96	SLNS Ruhuna	b. Good	b. Good	b. Good	b. Good	b. Good
97	P 4443	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
98	Slns kashapa	b. Good	a. Excellent	b. Good	b. Good	b. Good
99	SLNS Elara	b. Good	b. Good	b. Good	b. Good	b. Good
100	Kashayapa	b. Good	b. Good	b. Good	b. Good	b. Good
101	SLNS Nandimithra	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent
102	SLNS Prathapa	b. Good	b. Good	b. Good	b. Good	b. Good
103	SLNS Wickrama II	a. Excellent	a. Excellent	a. Excellent	a. Excellent	a. Excellent

End Users

Sample

103

QUESTIONNAIRE EVALUATION - TOP MANAGEMENT

	CBM	PPM	CBM	PPM	CBM	PPM	CBM	PPM	CBM	PPM	CBM	PPM
	Q7											
Suggestions on continual development	30	24									30	24
	Q1		Q2		Q3		Q12		Q15			
Physical effectiveness (Infrastructure)	28	27	34	20	29	24	29	24	31	19	151	119
	Q4		Q13		Q14							
Physical effectiveness (Job satisfaction)	34	21	40	12	39	13					113	46
	Q8		Q9		Q10		Q11					
Physical effectiveness (knowledge transfer)	30	25	30	25	34	21	34	18			128	89
	Q5		Q6									
Physical effectiveness (Fin- individual perception)	26	30	31	23							57	53

	a. Ex	b. Gd	c. Avg	d. NI	e. Pr		
	CBM	CBM	CBM	CBM			
Weightage	4	3	2	1			
			PPM	PPM	PPM		
			1	3	4		

Sample Size : 16	a. Ex	b. Gd	c. Avg	d. NI	e. Pr	CBM	PPM
Q1	1	3	6	3	3	28	27
Q2	1	6	4	4	1	34	20
Q3		4	7	3	2	29	24
Q4	1	7	2	5	1	34	21
Q5		2	6	8		26	30
Q6		5	5	6		31	23
Q7		5	5	5	1	30	24
Q8	1	4	5	4	2	30	25
Q9	1	3	6	5	1	30	25
Q10	1	7	2	5	1	34	21
Q11		6	6	4		34	18
Q12		3	8	4	1	29	24
Q13	1	9	3	3		40	12
Q14	1	8	4	3		39	13
Q15	1	4	6	3	1	31	19

PEA Calculation Top Management

Weighting Top Mgt | Weighting CBM Op | Weighting End User | Charts Top Mgt | Charts CBM op | Charts End User

PHYSICAL EFFECTIVENESS ANALYSIS (PEA)

PEA SUMMARY – TOP MANAGEMENT

Sample
16
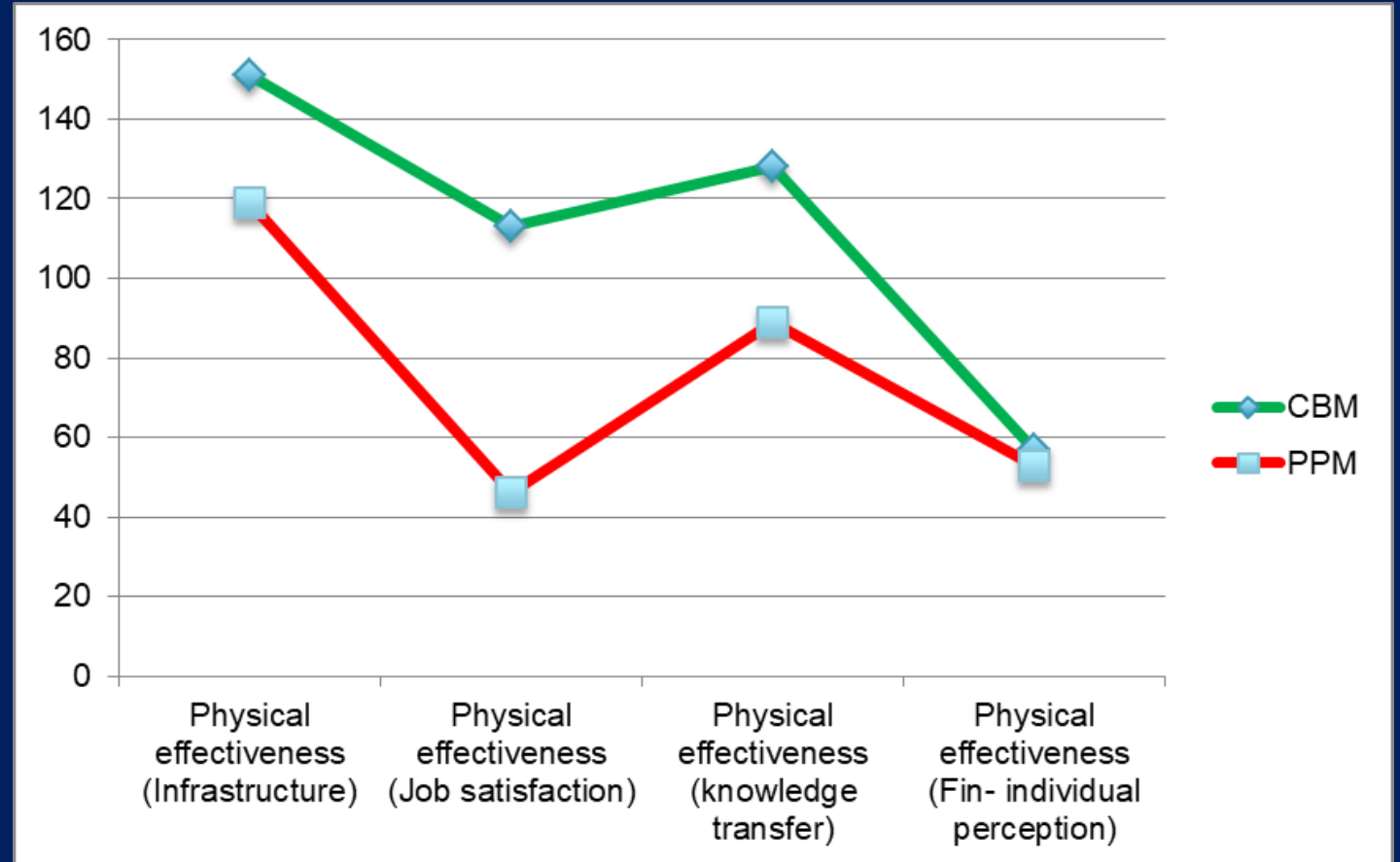
QUESTIONNAIRE EVALUATION - CBM OPERATORS

	CBM	PPM	CBM	PPM	CBM	PPM	CBM	PPM	CBM	PPM
	Q8		Q9		Q12		Q13			
Suggestions on continual development	75	6	79	7	78	8	83	1	315	22
	Q5		Q6		Q11					
Physical effectiveness (Infrastructure)	88	0	89	1	83	0			260	1
	Q1		Q3		Q7		Q10			
Physical effectiveness (Job satisfaction)	89	0	78	4	82	0	82	1	331	5
	Q4		Q14		Q15					
Physical effectiveness (knowledge transfer)	85	3	81	7	82	3			248	13
	Q2									
Physical effectiveness (Fin- individual perception	84	1							84	1

	a. Ex	b. Gd	c. Avg	d. NI	e. Pr
	CBM	CBM	CBM	CBM	
Weightage	4	3	2	1	
			PPM	PPM	PPM
			1	3	4

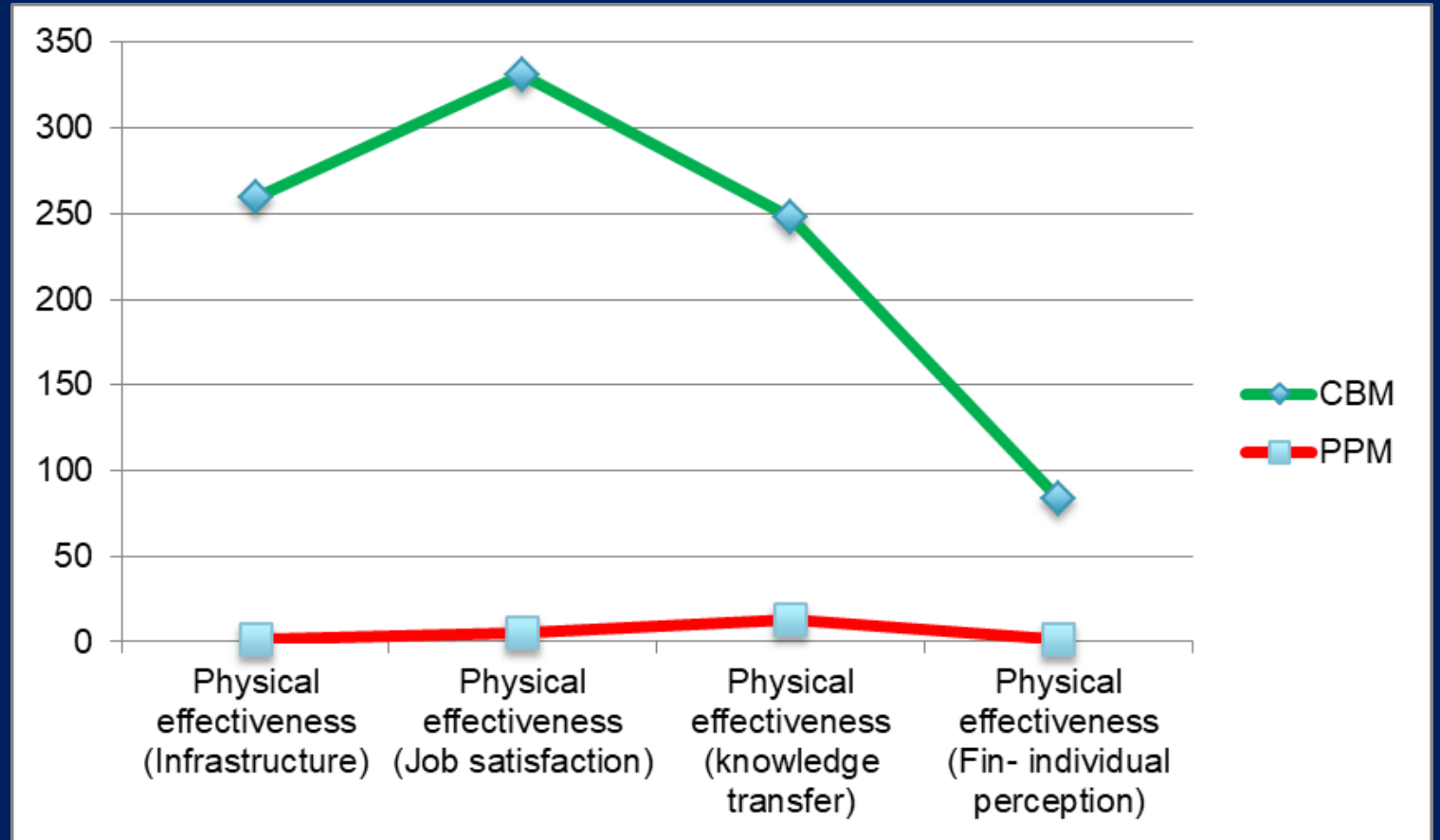| Sample Size : 25						CBM	PPM
Q1	14	11				89	0
Q2	10	14	1			84	1
Q3	6	17	1	1		78	4
Q4	13	9	3			85	3
Q5	13	12				88	0
Q6	16	8	1			89	1
Q7	8	16	1			82	0
Q8	5	16	3	1		75	6
Q9	9	13	1	2		79	7
Q10	8	16	1			82	1
Q11	8	17				83	0
Q12	9	12	2	2		78	8
Q13	9	15	1			83	1
Q14	11	12		1	1	81	7
Q15	9	15		1		82	3

61

PEA Calculation
CBM Operators

PHYSICAL EFFECTIVENESS ANALYSIS (PEA)

PEA SUMMARY – CBM OPERATORS

Sample
25

QUESTIONNAIRE EVALUATION - END USERS

	CBM	PPM	CBM	PPM	CBM	PPM	CBM	PPM	CBM	PPM
	Q12		Q13		Q14					
Suggestions on continual development	310	37	317	25	310	23			937	85
	Q6		Q7		Q8		Q11			
Physical effectiveness (Infrastructure)	314	25	285	68	308	43	297	50	1204	186
	Q3		Q5							
Physical effectiveness (Job satisfaction)	336	6	324	22					660	28
	Q1		Q2		Q4		Q9			
Physical effectiveness (knowledge transfer)	319	26	322	23	328	21	323	19	1292	89
	Q10		Q15							
Physical effectiveness (Fin- individual perception)	319	17	319	24					638	41

	a. Ex	b. Gd	c. Avg	d. NI	e. Pr
	CBM	CBM	CBM	CBM	
Weightage	4	3	2	1	
			PPM	PPM	PPM
			1	3	4

Sample Size : 103	a. Ex	b. Gd	c. Avg	d. NI	e. Pr	CBM	PPM
Q1	33	51	16	2	1	319	26
Q2	35	48	19		1	322	23
Q3	35	64	2		1	336	6
Q4	36	56	7	2	2	328	21
Q5	34	55	11	1	2	324	22
Q6	27	58	15	2	1	314	25
Q7	25	51	8	16	3	285	68
Q8	31	52	9	10	1	308	43
Q9	31	59	11		2	323	19
Q10	34	60	6	1	2	319	17
Q11	25	55	10	12	1	297	50
Q12	30	55	10	5	3	310	37
Q13	29	60	10	1	3	317	25
Q14	28	60	7	4	4	310	23
Q15	30	59	10	2	2	319	24

PEA Calculation End Users

Weighting Top Mgt | Weighting CBM Op | Weighting End User | Charts Top Mgt | Charts CBM op | Charts End User
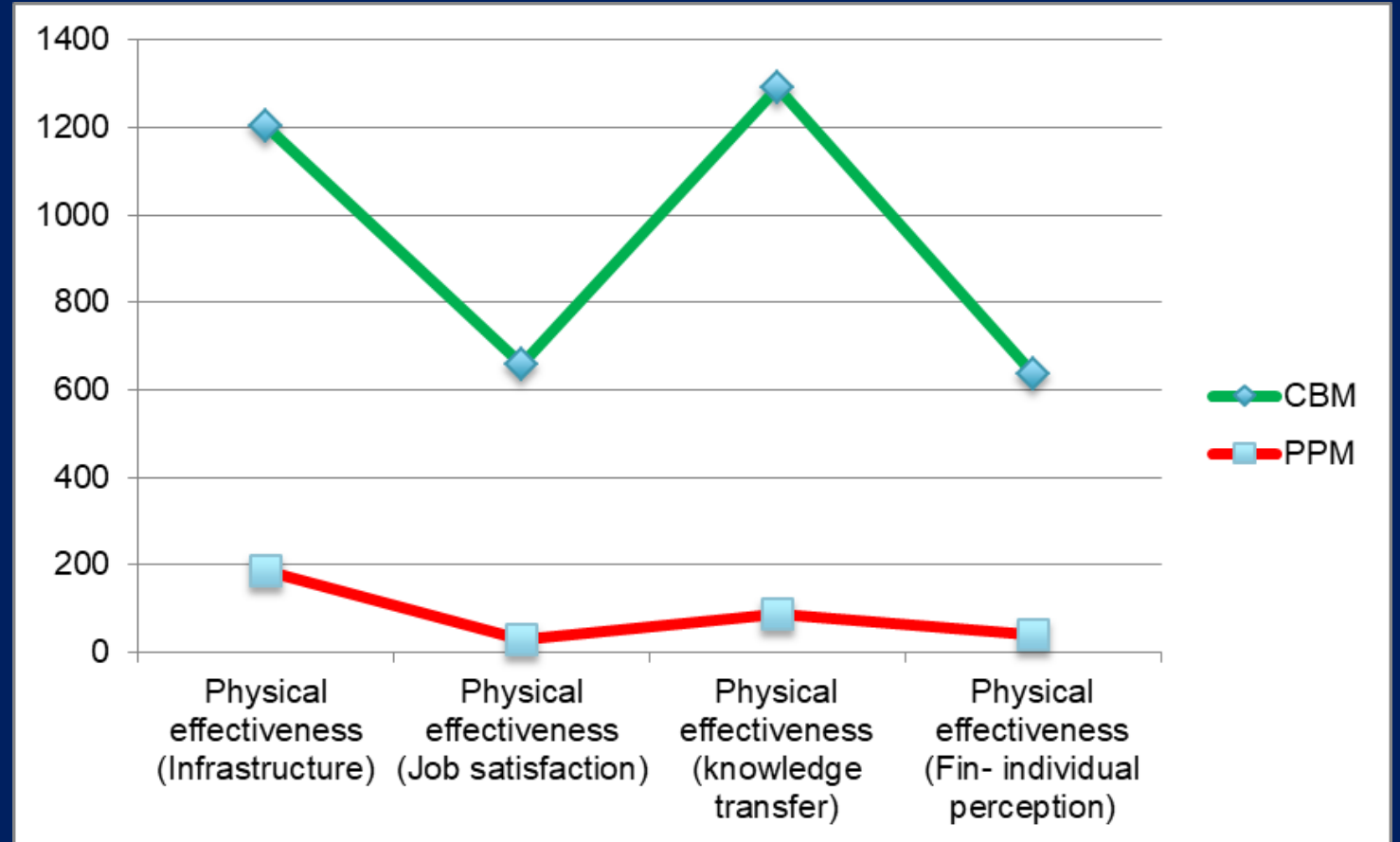
PHYSICAL EFFECTIVENESS ANALYSIS (PEA)

PEA SUMMARY – END USERS

Sample
103

PHYSICAL EFFECTIVENESS ANALYSIS (PEA)

PEA SUMMARY – OVERALL

Target group	Sample
Top Management	16
CBM operators	25
End users	103
Total	**144**
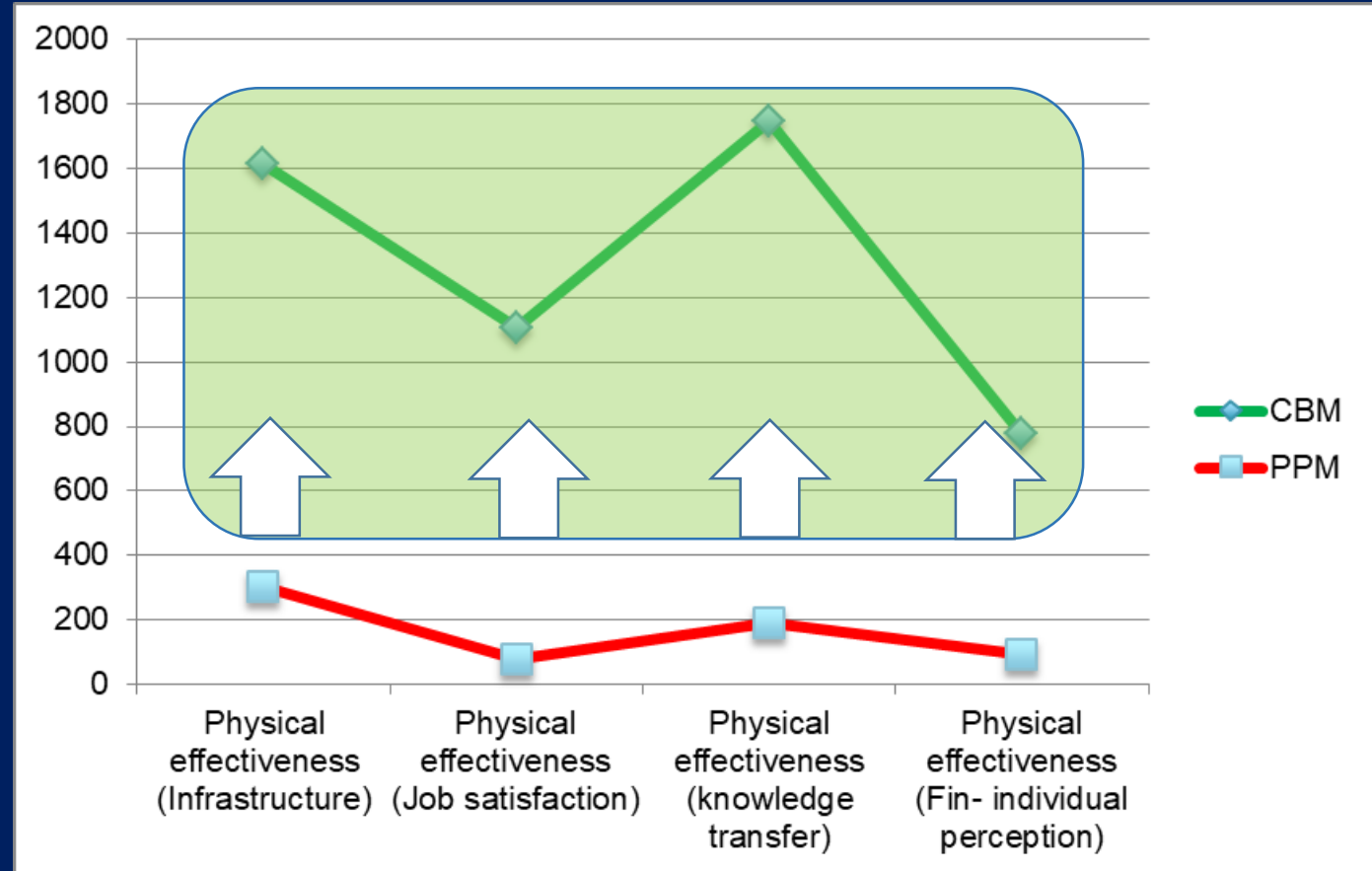
CONCLUSION

CONCLUSION

- Effectiveness in paradigm transition from PPM to CBM

- Hybrid application

- Phases of CBM implementation

- Conceptual in-house evaluation mechanism

- Continual development and upkeep records

- Organisational support at all tiers is important

BIBLIOGRAPHY

1. Steven, William. *Assessment of Condition Based Maintenance in the Department of Defense*. Washington DC: US Department of Defense Publication. 2000.

2. Wright, Jeremy. *Making the Transition to Proactive Maintenance*. Noria Publication. 2016.

3. Blokdyk, Gerardus. *Condition-based Maintenance: Standard Requirements.* California: Create Space Independent Publishing Platform. 2018.

4. Mathew, Joseph. *Engineering Asset Management and Infrastructure Sustainability*. London: Springer. 2011.

5. Barron, Ron ed. *Engineering Condition Monitoring: Practice, Methods & Applications*. Essex: Longman. 1996.

6. Book of Reference No. 1 - Maritime Doctrine of Sri Lanka. 2020

7. Mobley, Keith. *An Introduction to Predictive Maintenance*. Wuburn: Butterworth Heineman, 2002.

8. Plenert Gerhard. *Reinventing Lean, Introducing Lean Management into the Supply Chain*. Oxford: Elsevier. 2007.

9. Ali, Ahad & Abdelhadi, Abdelhakim. "Condition-Based Monitoring & Maintenance: State of the Art Review". *Appl. Sci.*. 12 (2022): 688. https://doi.org/10.3390/app12020688.

10. Mobley, R. Keith. *An Introduction to Predictive Maintenance*. Woburn: Elsevier Science. 2002.

11. US Department of Defense (DoD) policy in DoD Instruction (DoDI) 4151.22. 2021.

12. Christiansen, Bryan. "Complete list of CM techniques." Last modified July 2, 2019. https://www.mromagazine.com/features/complete-list-of-condition-monitoring-techniques/.

13. Reliabilityweb. "Why people do not understand PF curve". Accessed January 2,2022.https://reliabilityweb.com/articles/entry/why_people_do_not_understand_the_p-f_curve.

BIBLIOGRAPHY

14.	Wienker, Mike. Henderson, Keith. Volkerts, Jonathan. "The Computerized Maintenance Management System an Essential Tool for World Class Maintenance". *Procedia Engineering*. no.45 (2016): 216.

15.	Wigren, Anna. "A Study on Condition-Based Maintenance with Applications to Industrial Vehicles". *Teknisk- naturvetenskaplig fakultet UTH-enheten. Uppsala University* (2017): 2.

16.	Broadman, Antony & Greenberg, David. *Cost Benefit Analysis- Concepts & Practice*. Delhi: Pearson Education. 2006.

17.	Weimer, David & Vining, Aidan. *Policy Analysis: Concepts & Practice*. New York: Routledge. 2017.

18.	Salish, Mirjam. "Pareto Efficiency". Last modified March 9, 2020, https://inomics.com/terms/pareto-efficiency-1441708.

19.	Hanley, Spash. *Cost-Benefit Analysis*. Aldershot: Edward Elgar Publishers. 1993.

20.	*Williams,* John. *Davie,* Alan *& Drake,* Paul. *Condition-based Maintenance & Machine Diagnostics.* London : Chapman & Hal. 1994.

21.	Sri Lanka Navy Orders (SLNO) 03, Engineering Orders No. 23, 2000.

22.	SLN Engineering Database at NHQ

23.	Asset Hierarchy Order - Areva Oneprod Vibration Spectrum Analyser

24.	Book of Reference No. 31 (Guidelines for Engineering Maintenance Transition) of SLN. 2021

25.	Olugu, Zutah Udoncy , Wong, Kuan Yew, & Mammedov, Yslam. "Incorporating Sustainability & Maintenance for Performance Assessment of Offshore Oil & Gas Platforms: A Perspective". *Sustainability*, 14 (2022): 807.https://doi.org/10.3390/su14020807.

DYNAMIC TRANSITION TO CONDITION BASED MAINTENANCE PHILOSOPHY : A PROSPECTIVE ANALYSIS

Organised by:
Marine, Hull, Chemical and Process Engineering,
Material Science and Naval Architecture
Sectional Committee

Q & A Session

COLLEGE OF MILITARY ENGINEERING AND TECHNOLOGY SRI LANKA

DYNAMIC TRANSITION TO CONDITION BASED MAINTENANCE PHILOSOPHY : A PROSPECTIVE ANALYSIS

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Thank You.