D.P.M. ANALYTICS INDIA

TECHNICAL MANUAL

12-JAN-2021

WHY D.P.M. MANUAL?

This Manual is intended as a reference handbook for the Dynamic Prescriptive Maintenance (D.P.M.) philosophy and its underlying methodologies.

The D.P.M. system is a tool for prescribing executable-actions by classifying risk, and optimizing life-cycle-cost; while the objective being Just-in-Time maintenance.

It is based on three underlying frameworks:

- **Asset Integrity, Reliability & Maintainability Management System (AIRMS)**
- **Digitized Input Data & IIoS Platform for applying Machine Learning techniques**
- **Risk & Cost Management integration to derive JIT Prescriptive Maintenance recommendation**

WHENEVER PRESENTING TO CUSTOMER – ENSURE TOR (TERMS OF REFERENCE) IS SENT TO CUTOMER, BEFORE 1-2 DAYS

Terms Of Reference – Technical Presentation to Client

Chairman	Presented by	Date / Time
Client Maintenance Management	Team DPM Analytics	15-Jan-2021: 30 minutes

Attendees

- Maintenance Manager / Team Leader, Maintenance Engineer / Supervisor
- Operations Team Leader, Operations Engineers
- Reliability TA, Process TA, Inspection TA
- HSE Senior Engineer or Engineer
- Specialized invitees - As required

Expectations

- Ensure availability & reliability of the plant asset with safe & stable operations
- Maintenance contributes to business profit
- Minimize risk ALARP at lowest maintenance cost
- Address critical and chronic failures resulting significant financial loss
- Optimize maintenance resource utilization

Agenda

- HSE Moment (2 minutes)
- Impact of High Maintenance Cost on Operating Expenditure
- Challenges to reduce Maintenance Cost, while managing Risk
- Concept Just-in-Time - Dynamic Maintenance
- Industry 4.0 – What is it's significance in future business
- Application of Artificial Intelligence in anomaly detection and prognostics
- Model DPLP2 to combine AI and Maintenance diagnostics – How it works
- DPM software Module live demonstration to predict anomaly map
- Project Implementation, Software & Technical Support, and QA session

Key Inputs

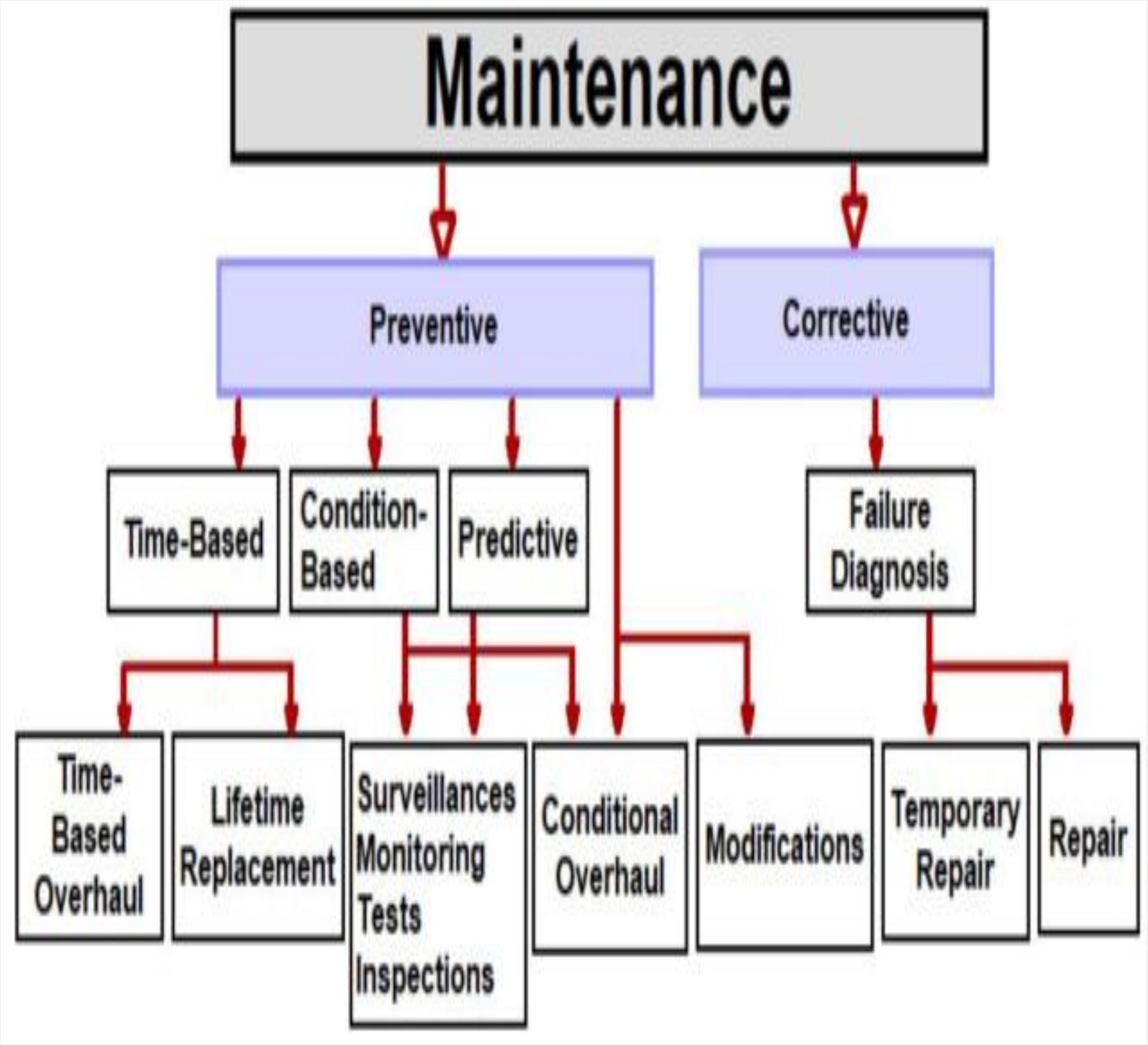
- Failures / History / Process description
- Online sensor / Offline CM record
- Operational / Maintenance reports

Key Outputs

- Maintenance cost reduction by minimum 4%
- Use DPM module as expert system
- Empower maintenance craft to take decisions
- Predict Future Failures & Resource optimization

Meeting Secretary	Team DPM Analytics

Overview – What are Conventional Maintenance Practices



Typical Maintenance Cost in Process Industry

↓

20% of Operating Expenditure

↓

And Failure contributes >50% of the maintenance cost

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Reliability Centered Maintenance – However It Is Static

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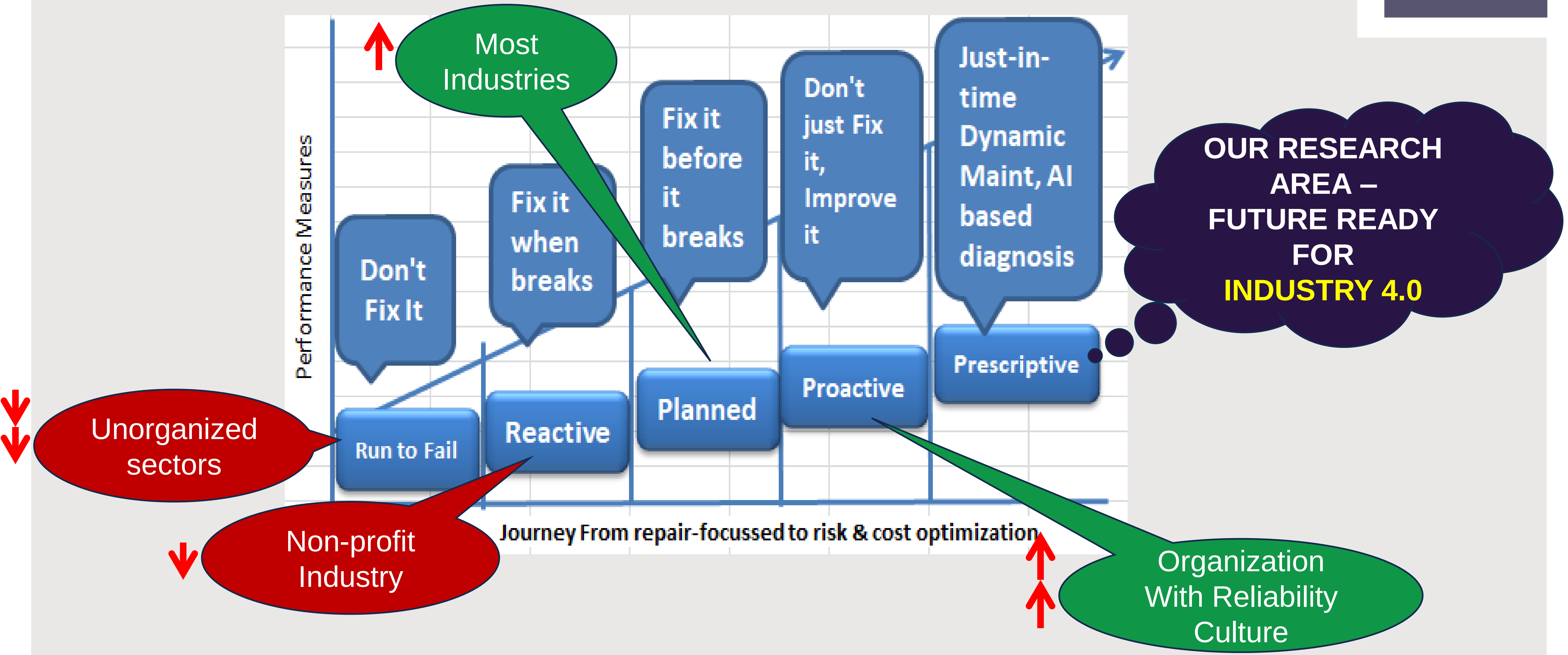
Root Cause Analysis – However it is Reactive

How Maintenance Practices Are Changing?



FROM P.M. TO D.P.M.

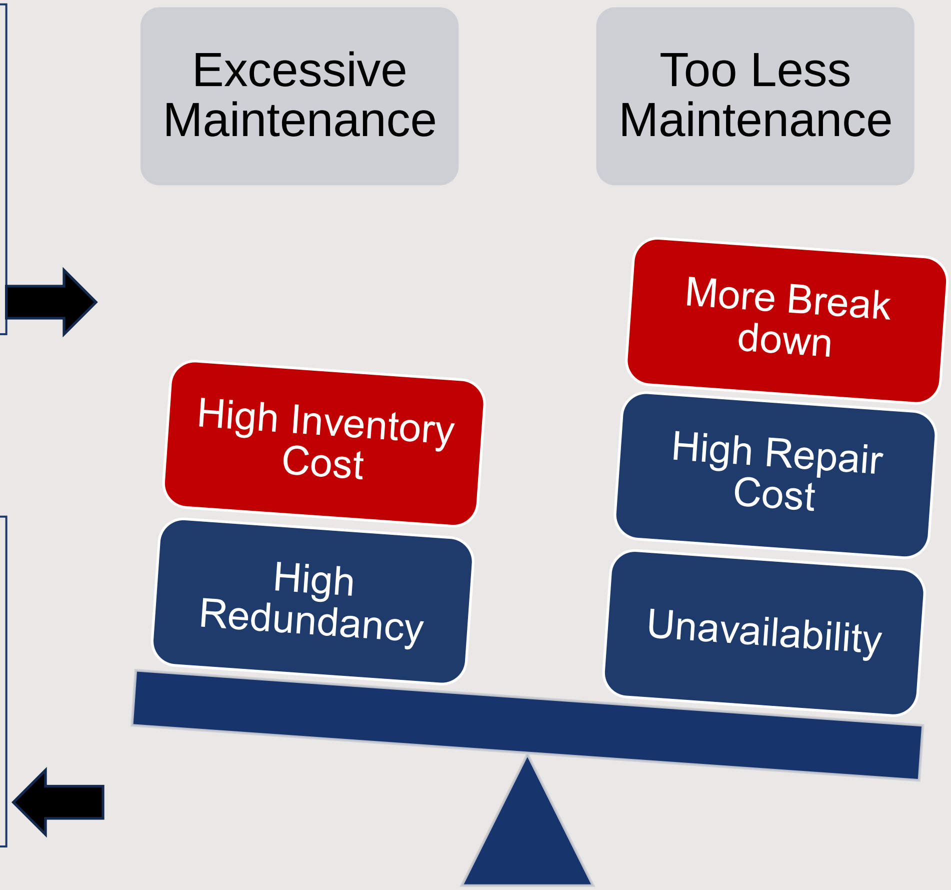
Compare: Conventional vs. Prescriptive Practice

Conventional Maintenance

- **Strategy is Static**
- **Just Right Maintenance Not Possible**

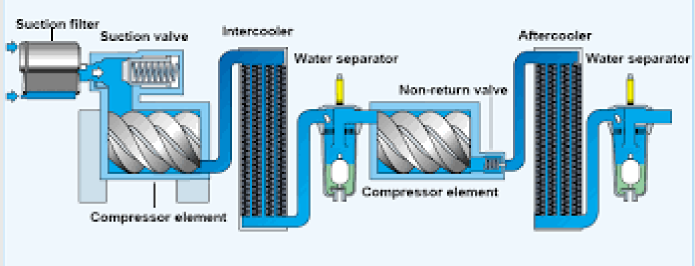
Prescriptive Maintenance

- **Strategy is Dynamic, Near Real-Time**
- **Just-in-Time Maintenance Possible**



LET’S CHALLENGE EXISTING MAINTENANCE PRACTICES

DPM



Oilfree screw compressor.

Actual Case - Typical Oil-free 2-stage Twin Screw Compressor for Instrumented Air Supply

On-line Quality data collected @15 Sec

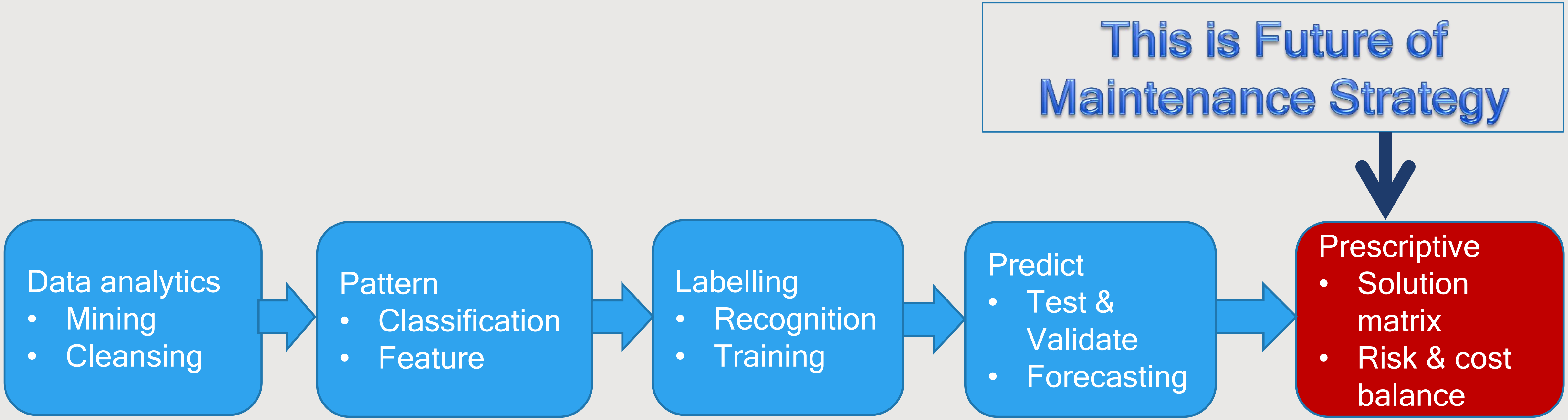
Why database is not analyzed?

Why Compressor behavior cannot be predicted???

Why data is not grouped into few clusters??

MACHINE LEARNING TECHNIQUE CAN BE USED

DPLP² PROCESS UNDERSTANDING



BASICS

D.P.M. FRAMEWORK

The introduction of D.P.M. framework is supported by workshops facilitated by D.P.M. Analytics staff. The benefits of such an approach are:

- it ensures that a framework is applied correctly from the start using proven facilitation techniques, for efficient implantation in organization;
- it provides training of the staff of the Operating Unit;
- current practices are challenged;
- best practices are exchanged
- actual D.P.M. results are delivered for the unit(s) studied in the w/shop
- library is built for continuous enhancement

INTRODUCTION

Maintenance action is essential for every living body; be it human, or any asset in use. Cost is invariably associated. Different methods are applied to sustain utilization & increase longevity at minimum risk & expense. D.P.M. is a methodology for industries of 21st century.

Industrial evolution broadly classified in 4-stages. Pre-1900 is termed as Industry#1.0. It is now Industry#4.0 phase. However majority (almost 90% plus) industries are still operating without taking advantage of digital power. I4.0 implementation potentially reduces operating cost by 3-10%.

D.P.M. is a tool to assist in migration. Implementation of D.P.M. Framework facilitates gradual transformation to IIToS AI backed digital era. D.P.M. Is artificial intelligence based application module. Underlining idea of introducing D.P.M. Is simple. The algorithm asks series of questions.

- Undertake maintenance actions only when needed.
- Minimize life-cycle-cost.
- Risk appetite of deferring repair
- Predict asset operating behavior.
- Prescribe actions based on available logistics.

It enables user to visualize impact on deferment of prescribed actions, to arrive at qualified judgment. As a deliverable, optimized solution is prescribed, considering dynamic field-constraints.

D.P.M. IMPLEMENTATION

The implementation starts with significant PRE-WORK, which is essential for ensuring the quality of development. This pre-work is non-negotiable, and must be accomplished by domain-experts, since it is the back-bone of entire software development.

PREWORK STEPS

Step-1.1: Prioritize categories and asset types, and carry feasibility evaluation

Step-1.2: Identify core focus

Step-1.3: Each Asset/Equipment class has sub-asset types, and has different application.

Step-1.4: Identify credible failure descriptors.

Step-1.5: Identify "maintainable items".

Step-1.6: Identify Failure Modes

Step-1.7: Identify Failure Causes

Step-1.8: Identify Method of Detection

D.P.M. IMPLEMENTATION

Step-1.1: Prioritize categories and asset types, and carry feasibility evaluation based on the following criteria-

Asset current condition	Normal	Incipient	Degraded
Risk ranking	PoF & CoF estimation >> Integrity risk assessment	HSECES identification	Maintenance criticality identification
Asset forecast performance	Remnant Useful Life calculation	Moving average on progression	Shape and scale parameters using median rank regression

D.P.M. IMPLEMENTATION

Step-1.2: Identify core focus

There are 14 categories of assets/equipment types where application of AI can potentially reduce substantial OPEX.

14 CATEGORIES OF ASSETS

D.P.M. STRATEGY
14 CATEGORIES OF ASSETS

LIST OF ASSETS AND SUB-UNITS

1. COMPRESSOR
   1. SCREW COMPRESSOR
   2. CENTRIFUGAL COMPRESSOR
   3. RECIPROCATING COMPRESSOR
2. PUMP
   1. CENTRIFUGAL PUMP
   2. RECIPROCATING PUMP
3. PIPELINE
4. GAS TURBINE
5. ELECTRIC MOTORS
6. ELECTRIC GENERATORS
7. COMBUSTION ENGINES (PISTON)
8. CONTROL LOGIC UNITS
9. FIRE AND GAS DETECTORS
10. HEAT EXCHANGERS
11. PROCESS SENSORS
12. TURBO-EXPANDERS
13. VALVES
14. VESSELS

D.P.M. IMPLEMENTATION

Step-1.3: Each Asset/Equipment class has sub-asset types, and has different application.

The concept development starts from this stage. Example

Equipment class	Type	Application
Description	Description	Description
Compressor	Centrifugal	Gas processing
	Reciprocating	Gas export
	Screw	Gas injection
	Blowers/fans	Lift gas compression
	Axial	Compressed air
		Refrigeration

D.P.M. IMPLEMENTATION

Step-1.4: Identify credible failure descriptors.

Mechanical failure - general		
	Leakage	
	Vibration	
	Clearance/alignment failure	
	Deformation	
	Looseness	
	Sticking	
Material failure - general		
	Cavitation	
	Corrosion	
	Erosion	
	Wear	
	Breakage	
	Fatigue	
	Overheating Burst	
Instrument failure - general		
	Control failure	
	No signal/indication/alarm	
	Faulty signal/indication/alarm	
Out of adjustment **Software failure**		
Common mode failure		
Electrical failure - general		
	Short circuiting	
	Open circuit	
	No power/voltage	
	Faulty power/voltage	
	Earth/isolation fault Etc.	

D.P.M. IMPLEMENTATION

Step-1.5: Identify “maintainable items”.

List is as follows for Equipment Type “Compressor”-

Sub unit		Power transmission		Compressor	Control and monitoring	Lubrication system	Shaft seal system	Misc.

Each sub-unit is split into maintainable items. For “Compressor” it is shown below”-

Casing
Rotor with impellers
Balance piston
Interstage seals
Radial bearing
Thrust bearing
Shaft seals
Internal piping
Valves
Antisurge system including recycle valve and controllers
Piston
Cylinder liner
Packing

D.P.M. IMPLEMENTATION

Step-1.6: Identify Failure Modes

For “Compressor” it is shown below-

Unable to activate compressor
Unable to stop or incorrect shutdown action
Unexpected shutdown of compressor
Serious damage (seizure, breakage, etc.)
Output pressure/flow above specification
Output pressure/flow below specification
Oscillating or unstable pressure/flow
Process medium escape to environment
Lube/seal oil, coolant, etc.
Excessive vibration
Excessive noise
Excessive temperature
Monitored parameter exceeding tolerances
E.g. false alarm, faulty reading
E.g. cracks in support or suspension
Loose items, discoloration, contamination, etc.
None of above apply
Inadequate/missing information

D.P.M. IMPLEMENTATION

Step-1.7: Identify Failure Causes

It is shown below-

		Failure causes	
No.	Notation	Description	
1.0	Design-related causes - general	Failure related to inadequate design for operation and/or maintenance, but no further details known	
1.1	Improper capacity	Inadequate dimension/capacity	
1.2	Improper material	Improper material selection	
1.3	Improper design	Inadequate equipment design or configuration (shape, size, technology, configuration, operability, maintainability, etc.)	

D.P.M. IMPLEMENTATION

Step-1.8: Identify Method of Detection

It is shown below-

		Method of detection
No.	Notation	Description
1	Preventive maintenance	Failure discovered during preventive service, replacement or overhaul of an item when executing the preventive maintenance program
2	Functional testing	Failure discovered by activating an intended function and comparing the response against a predefined standard

No.	Activity	Description	Examples
1	Replace	Replacement of the item by a new, or refurbished, of the same type and make	Replacement of a worn-out bearing
2	Repair	Manual maintenance action performed to restore	Repack, weld, plug, reconnect,
3	Modify	Replace, renew, or change the item, or a part of it, with an item/part of different type, make, material or design	Install a filter with smaller mesh diameter, replace a lubrication oil pump with another type, etc.

D.P.M. IMPLEMENTATION: MAIN DELIVERABLES AND TIMELINE

Step-2.1: Main deliverable:

The main deliverable is “Artificial Intelligence based Software Platform” that enables

- Data analytics & Pattern recognition
- Forecast Failure & Cost, and
- Conduct Maintenance Strategy Review, and
- Recommend “Maintenance Task” only when required
- Decision as above drives “OPEX” optimization.

D.P.M. IMPLEMENTATION: MAIN DELIVERABLES AND TIMELINE

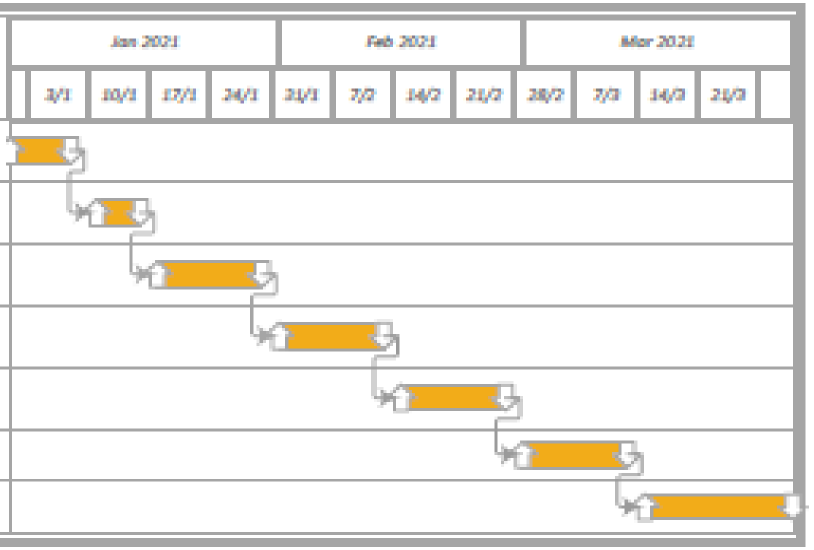
Step-2.2: Time line:

Each case study is expected 3-months period for field implementation.

High level schedule is as follow (typical)-

PRODUCT DEVELOPMENT (HIGH LEVEL SCHEDULE)

ID	Task Name	Start	Finish	Duration
1	Kick Start Sessions	1/1/2021	1/7/2021	1w
2	Developing Train and Test Data	1/11/2021	1/15/2021	1w
3	Software Development – Back end	1/18/2021	1/29/2021	2w
4	Proof of Concept (POC) – Release-0.1	2/1/2021	2/12/2021	2w
5	Software Development – Front end (UI)	2/15/2021	2/26/2021	2w
6	Proof of Concept (POC) – Release-0.2	3/1/2021	3/12/2021	2w
7	Field Trial and Validation and Handover	3/15/2021	3/31/2021	2.6w



D.P.M. IMPLEMENTATION: COST-RISK BENEFIT ANALYSIS

Step-3.1: Cost Benefit Analysis

High level template is as follow (typical)-

COST BENEFIT ANALYSIS TEMPLATE

QUANTITATIVE ANALYSIS	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5	TOTAL
BENEFITS						
COST SAVINGS	$ 650,000.00	$ 650,000.00	$ -	$ -	$ -	$ 1,300,000.00
COST AVOIDANCE	$ -	$ -	$ -	$ -	$ -	$ -
REVENUE	$ -	$ -	$ -	$ -	$ -	$ -
OTHER	$ -	$ -	$ -	$ -	$ -	$ -
TOTAL BENEFITS	**$ 650,000.00**	**$ 650,000.00**	**$ -**	**$ -**	**$ -**	**$ 1,300,000.00**
COSTS						
NON-RECURRING	$ 46,400.00	$ 20,800.00	$ -	$ -	$ -	$ 67,200.00
RECURRING	$ 12,200.00	$ 12,200.00	$ -	$ -	$ -	$ 24,400.00
TOTAL COSTS	**$ 58,600.00**	**$ 33,000.00**	**$ -**	**$ -**	**$ -**	**$ 91,600.00**
NET BENEFIT OR COST	$ 591,400.00	$ 617,000.00	$ -	$ -	$ -	$ 1,208,400.00

D.P.M. IMPLEMENTATION: COST-BENEFIT ANALYSIS

Step-3.2: High Level Risk Analysis (Typical)

Implementation of D.P.M. analytics reduces business risk considerably, as detailed below

Impact HSE –

- None. On the contrary, implementation will reduce Process Safety concerns

Asset Integrity –

- No adverse impact. The asset reliability and integrity shall be improving as a result on AI backed maintenance strategy.

Brand value/ Company image –

- This idea will take Company into Industry#4.0 league of selected industry worldwide

People –

- It will empower Company employees & localization.
- This knowledge will help enhancing Contractor employees as well.

D.P.M. IMPLEMENTATION: COST-BENEFIT ANALYSIS

Step-3.2: Scaling Feasibility within Operating Company (Typical)

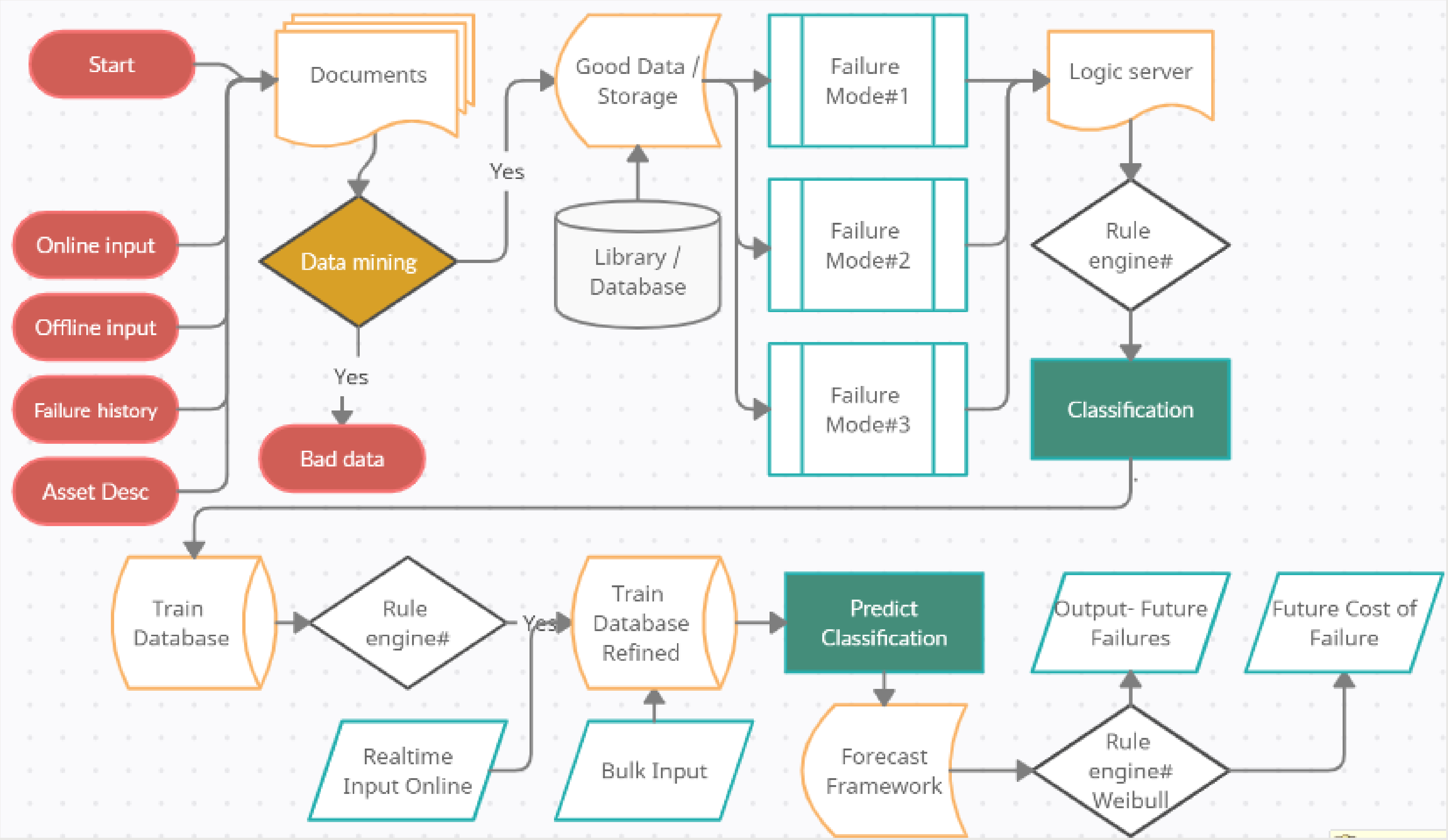
- It is feasible to scale-up. There is existing potential in 14 different Assets.
- Assessment has to be done for other sites / Group companies.
- It is because data management of each companies / site could be different, it needs to be synchronized

ASSET-1: COMPRESSOR

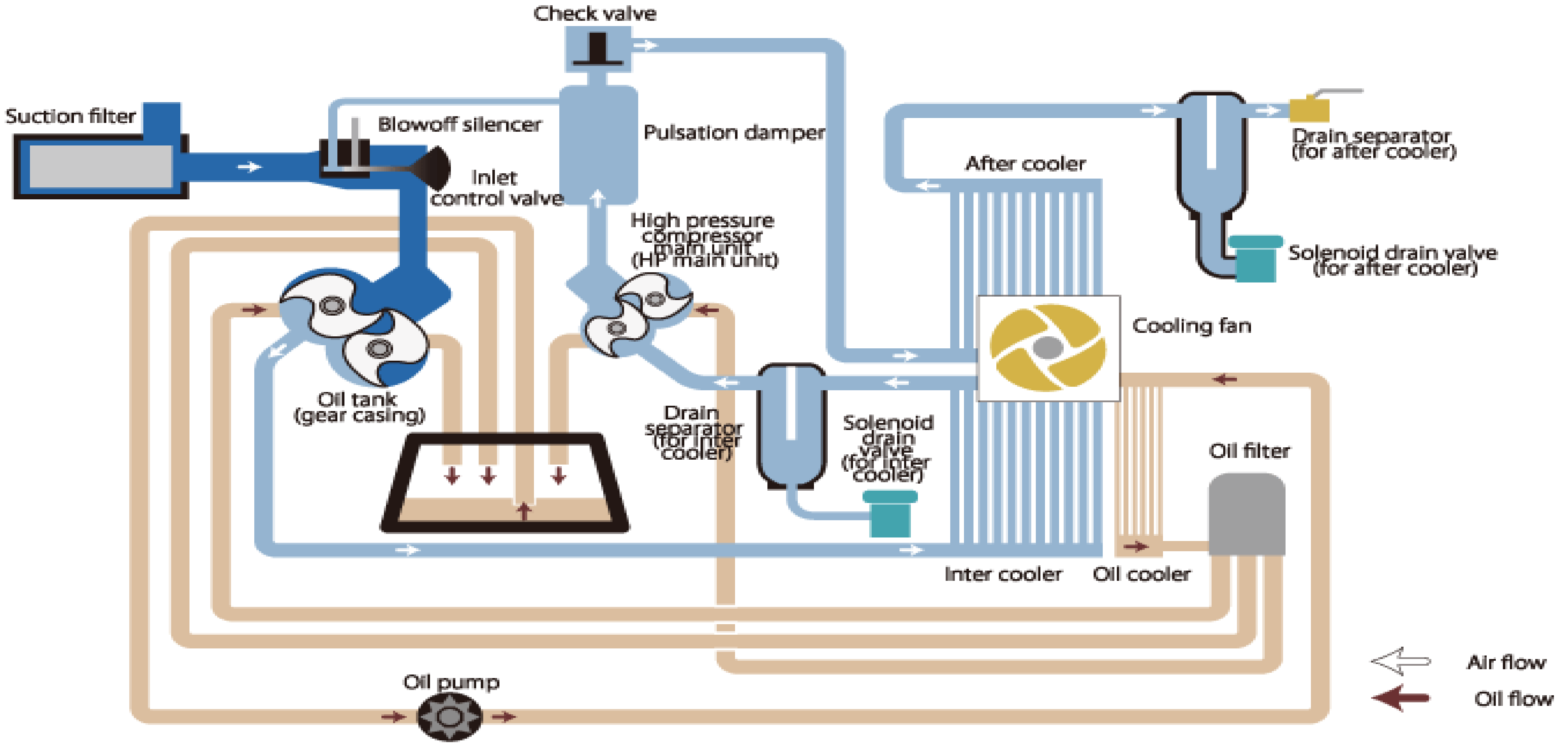
SUB-UNIT 1.1: SCREW COMPRESSOR

SME- DD

FLOW CHART: DATA MINING TO FORECAST



CASE STUDY: COMPRESSOR INSTRUMENT AIR TWIN SCREW OIL FREE



RAW DATA INPUT TEMPLATE: COMPRESSOR

A.2.2 Compressors

Table A.5 — Taxonomy classification — Compressors

Equipment class		Type		Application	
Description	Code	Description	Code	Description	Code
Compressor	CO	Ce Re Sc Bl Ax			

NOTE In Table A.5 the lists in colu
natural gas industries. These lists shou

Table A.6 — Equipment unit subdivision — Compressors

Equipment unit	Compressors					
Subunit	Power transmission	Compressor	Control and monitoring	Lubrication system	Shaft seal system	Miscel-laneous
Maintainable items	Gearbox/variable drive Bearings C di Lu S	Casing Rotor with impellers	Control Actuating device	Oil tank with heating system	Oil tank with heating Reservoir	Base frame Piping, pipe support and

Table A.8 — Failure modes — Compressors

Equipment unit	Code	Definition	Description
	FTS	Fail to start on demand	Unable to activate compressor
	STP	Fail to stop on demand	Unable to stop or incorrect shutdown action
	SPS	Spurious stop	Unexpected shutdown of compressor
	BRD	Breakdown	Serious damage (seizure, breakage, explosion, etc.)
	HIO	High output	Output pressure/flow above specification
	LOO	Low output	Output pressure/flow below specification
	ERO	Erratic output	Oscillating or unstable pressure/flow
	ELP	External leakage process medium	Process medium escape to environment
	ELU	External leakage utility medium	Lube/seal oil, coolant, etc.
	INL	Internal leakage	E.g. process medium in lube oil
	VIB	Vibration	Excessive vibration
	NOI	Noise	Excessive noise
	OHE	Overheating	Excessive temperature
	PDE	Parameter deviation	Monitored parameter exceeding tolerances
	AIR	Abnormal instrument reading	E.g. false alarm, faulty reading
	STD	Structural deficiency	E.g. cracks in support or suspension
	SER	Minor in-service problems	Loose items, discoloration, contamination, etc.
	OTH	Other	None of above apply. Specify in comment field
	UNK	Unknown	Inadequate/missing information

ISO 14224:1999(E) © ISO

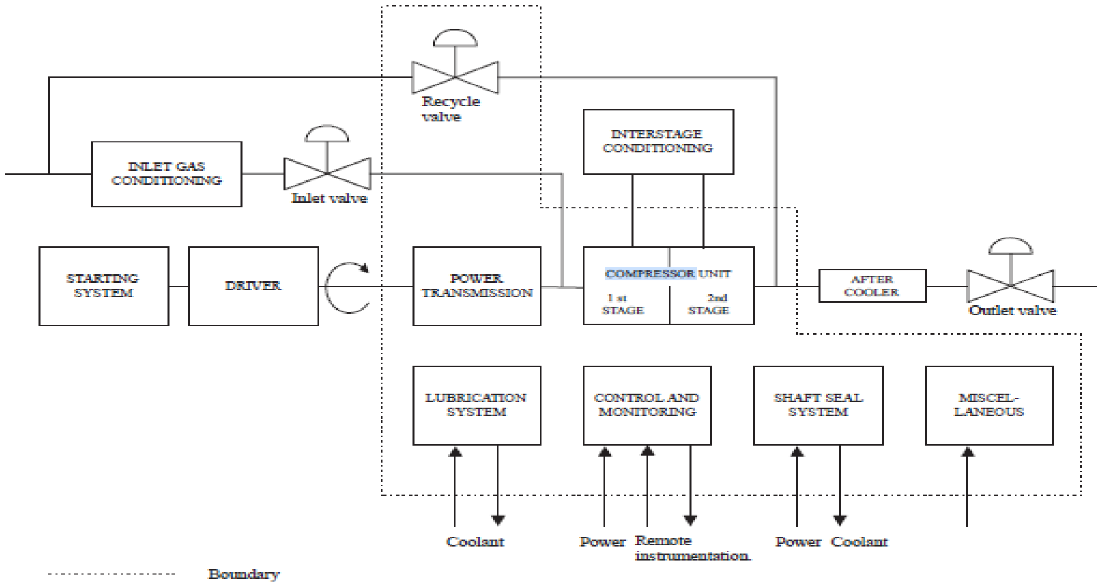
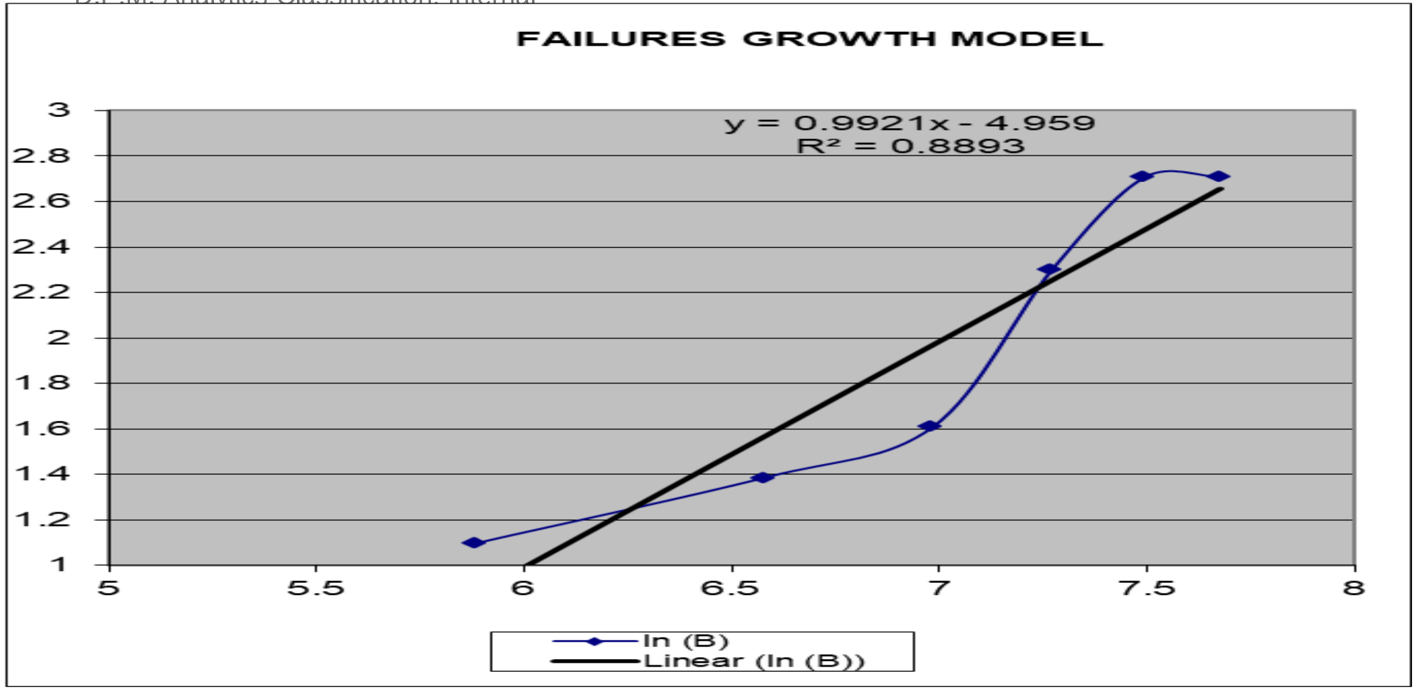


Figure A.2 — Equipment boundary — Compressors



COMPRESSOR: FUTURE FAILURE PREDICTION

DETERMINE BEST MAINTENANCE STRATEGY

ASSET-2: PUMP

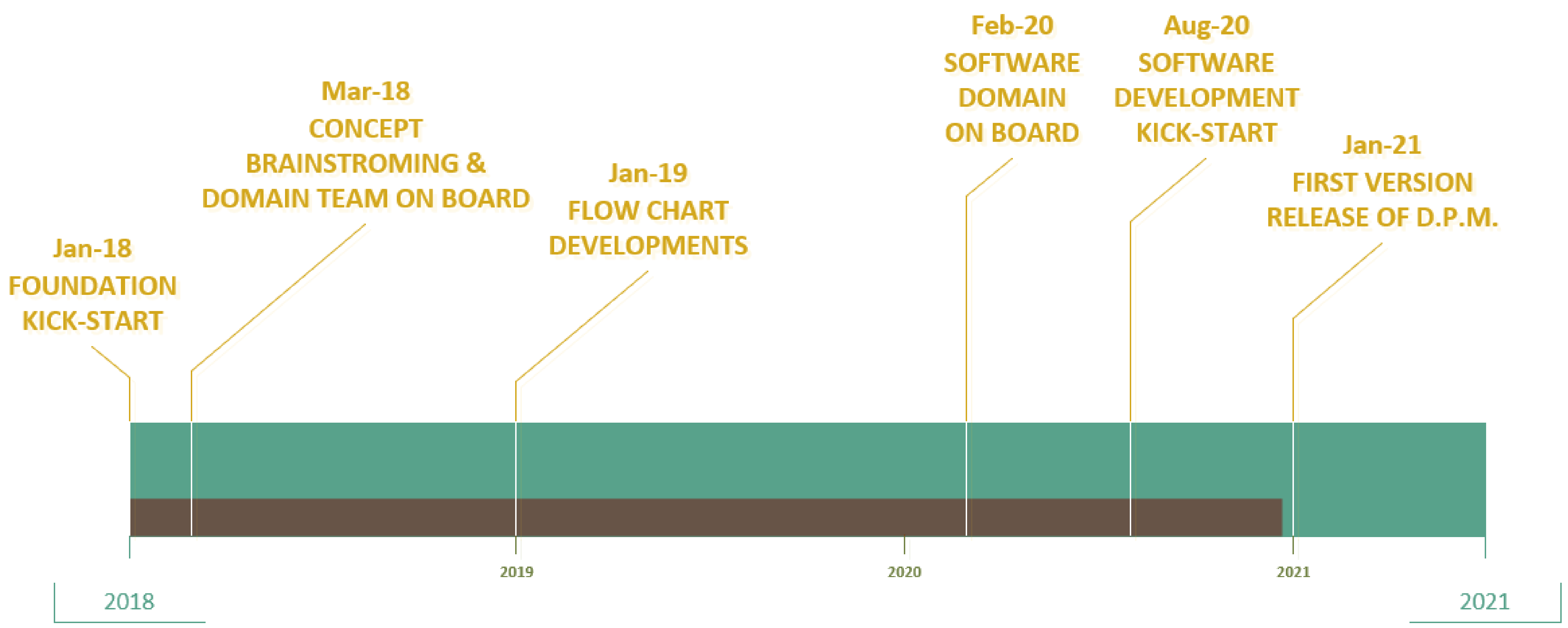
SUB-UNIT 2.1: CENTRIFUGAL PUMP

SME- DIMITRIOS+DD

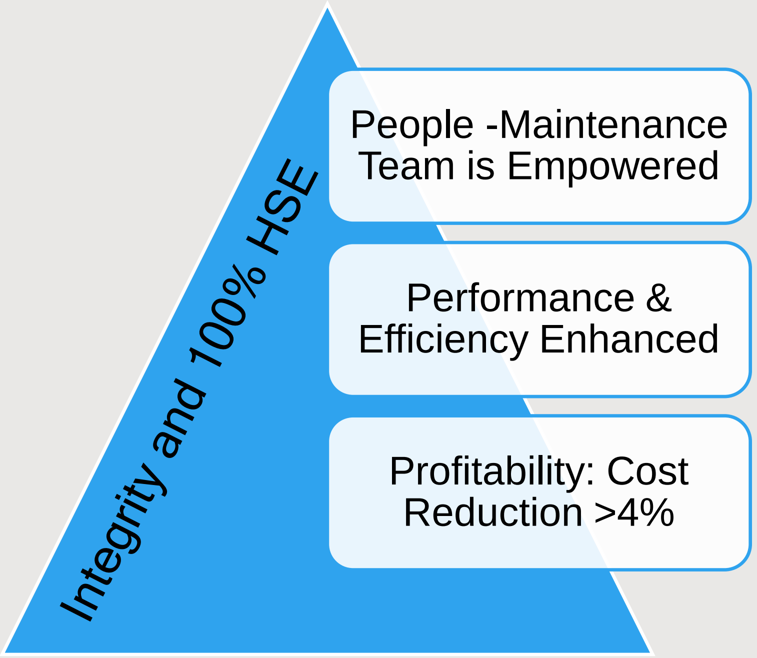
ASSET-3: PIPELINE

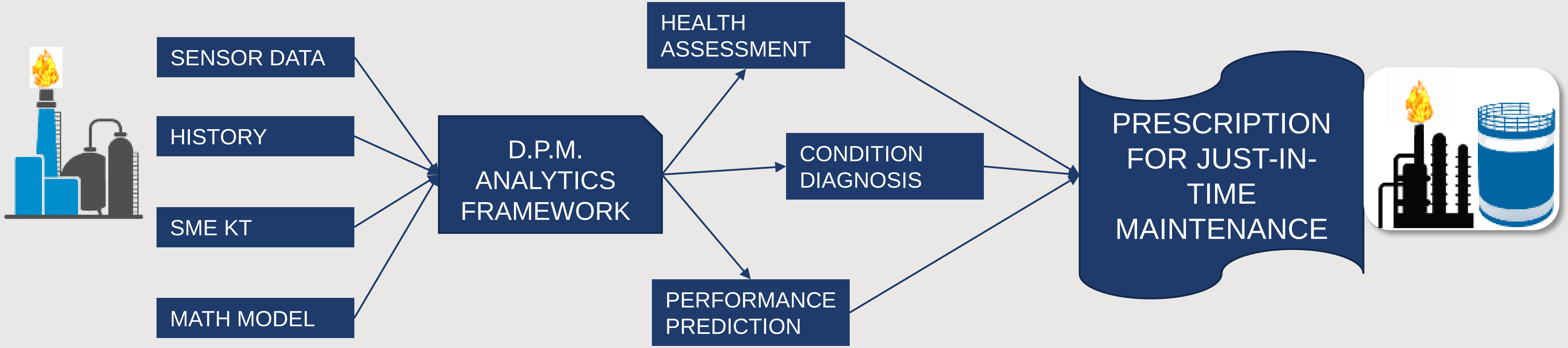
SME- AFTAB+DD

D.P.M. ANALYTICS COMPANY TIMELINE



D.P.M. DELIVERABLES





Can Maintenance Generate Revenue?

How *D.P.M. ANALYTICS* Can Help In Your Mission?

Unique Maintenance Business Model

- Maintenance Contributes 10-30% of Operating Cost. Save Minimum 4-5%
- Move over from PM to DPM – Dynamic Prescriptive Maintenance
- No To Routine Maintenance
  Yes to JUST-IN-TIME Maintenance
- Included Integrity Risk Assessment, Criticality Analysis & HSECES Identification
- Software self enhances with time
- Exceeds Targets of Operation Excellence
- Digital data Analytics at Near Real Time
- Empowers Maintenance Crafts to take decisions
- Acts as Expert System

LOOK OUTSIDE THE BOX – MAINTENANCE MEANS BUSINESS - IN DIGITAL ERA

DPM study - 7 Benefits to Customers/ Management

1. DPM analysis is a living program
2. Maintenance strategy continuously evolves, no-longer static
3. At real-time, identifies pattern of data variation
4. Detects minor/subtle changes at the beginning/onset of degradation
5. Forecasts future failure, defect & cost
6. Eliminates the failure mode, or reduce the frequency of occurrence/ the consequence
7. Determines appropriate maintenance task considering resource availability, and risk acceptance criteria.

DPM study - 7 Benefits to Field Maintenance Team

1. Technician / Craftsman can download software on their Mobile
2. At site, field-technician will collect the data & upload on UI
3. At real-time, software will identify pattern of data variation, forecast future defect, future failure, and cost of repair
4. Software will advice what main tasks to be carried out to eliminate / delay the failure.
5. At real-time, Technician can do JSA (Job safety analysis) to ensure 100% HSE compliance
6. After carrying out site maintenance, Field technician checks parameter improvement
7. Engineer can evaluate online and advice better options

DYNAMIC PRESCRIPTIVE MAINTENANCE (D.P.M.) – DEFINITION

D.P.M. is a maintenance-business-process for production-assurance, an application of near-real-time data analytics, to prescribe just-in-time (JIT) maintenance strategy, and achieves operating cost & risk optimization; by identifying failure-pattern, forecasting asset performance and analyzing resource availability, using semi-quantitative methodology.

D.P.M. will eventually replace conventional P.M.

Maintenance ensures that the physical assets continue to fulfill their intended functions (Ref: RCM-II, John Moubray).

DYNAMIC PRESCRIPTIVE MAINTENANCE (DPM) – IN SIMPLE WORDS

M – Maintenance, to sustain business

P – Prescriptive Task

D – Dynamic, near-real-time data analytics

DPM – A just-in-time (JIT) action

- reduces operating cost & optimizes risk
  - by forecasting failure-pattern
  - by analyzing resource availability

LIVE DEMONSTRATION OF SOFTWARE RELEASE V1.0

❑ PRESENTATION

ACKNOWLEDGEMENT

DPM

Mathematical Modeling - Create Rule Engine

Apply Machine Learning Technique

Validation

Applied on Real time-Streaming input

Team of Domain Experts- Technical, Technology, and Project Management

Team of University students, doing research

Proof of Concept @ Major Oil & Gas Industry

References:

1. Presentation at ADIPEC 2020: Paper No. SPE-202869-MS; "Artificial Intelligence Application For Just-in-time Maintenance"
2. Article Petro Oil Magazine Oct-2020: "Artificial Intelligence Application For Just-in-time Maintenance"

BUSINESS CASE FEASIBILITY REPORT FOR ENGAGING D.P.M. ANALYTICS STUDY

Core Competency: Team has special skill, uses technology, innovative process, proven field-implementation, and 24x7 available expertise:

Valuable – a large revenue generator (by reducing maintenance cost, and eliminating failures)
Rare – no such AI based analytic solution available for maintenance businesses
Non-substitutable – it cannot be replaced by any software capabilities available in market.
Costly to imitate – it is a unique combination of hands-on-maintenance skill & AI specialization, not easy to be duplicated

Concept Test: Successfully conducted proof-of-concept, for major machinery, at Oil & Gas industry, and monitored performance over 3-years, with the purpose to ensure the customer's interest, desirability, and purchase intent.

Target market – Major Assets of Process Industry, Turnaround Optimization, Aircraft Maintenance , Industrial Insurance are few areas for immediate implementation, where product/service provides the benefits to customers.

Market and Industry Research:

Estimated volume of Benefits for using DPM product/service – Typically at one mid-size Refinery, the saving potential per year is 10 million US$
Projected maintenance budget saving – 10-30% of OPEX. A 4-5% saving is minimum expectations for the critical assets digitally connected.
Is the current market attractive for your product/service – Yes, especially attractive during the period of global recession
Are there any predictions for future products – Currently only one model launched. There are total 14 models, to be released gradually over next 3 years.

Organizational Feasibility Analysis: Organizational competency, and developer resource availability is critical success factor

Evaluate level of Expertise requirement – Training shall be provided to use the software module to operate independently.
Designate Responsibilities – Initial data quality shall be cleansed by developer. New data quality can be managed by in-house, or remotely.
Evaluate feasibility of quality resource mobilization – Usually not necessary. However available for short-deployment.

Financial Feasibility Analysis: evaluate other capital requirements, your projected rate of return, and the overall attractiveness of the investment.

Estimate Return-on-investment –It is covered by eliminating just one failure
Estimate Costs - Identify both fixed costs and variable costs - O*ne-time Capital cost and operating cost for IT support service.*
Estimate Break-even Point and Profitability – Expected within first 3-months, to maximum 1-year. Profitability 4-5% of Maintenance cost

Strengths, Weaknesses, Opportunities, and **Threats**

Strengths of DPM Analytics solution – Migration to Industry#4.0 era, digitize maintenance, reduce OPEX & business risk, and empower craftsmen.
Weaknesses of DPM Analytics solution – Assets without sensor data can not be analyzed. DPM not necessary for non-critical assets.
Opportunity of DPM Analytics solution – Tie up with portable sensor providers, to collect data on near-real-time, for assets without permanent sensors
Competitive advantage over competitors – Unique integration of field-maintenance expertise across globe, innovative application developed by AI developers, and project management by industry specialists; support by academicians for mathematical models, are backbone of offered product.

Q&A SESSION

- TECHNICAL CLARIFICATION
- VISIT D.P.M. ANALYTICS LINKEDIN SITE, FOR VARIOUS ARTICLES
- PROJECT IMPLEMENTATION
- TECHNICAL & SOFTWARE SUPPORT

CONTACT

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https://www.linkedin.com/in/dynamic-prescriptive-maintenance-08bb101b8/

Specific

Measurable

Attainable

Relevant

Time Based

SOFTWARE TECHNOLOGY