Propulsion Analytics

Performance Management

FOR THE MARITIME INDUSTRY

Digital Twins for Marine Asset Performance Monitoring

Physics-based vs Machine Learning Models for Different Applications

SNAME Greek Section
22.03.2023

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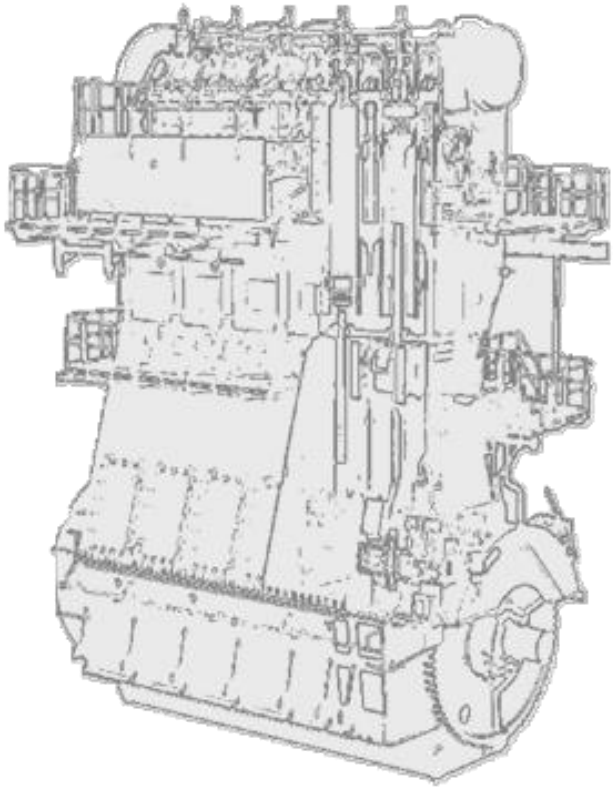
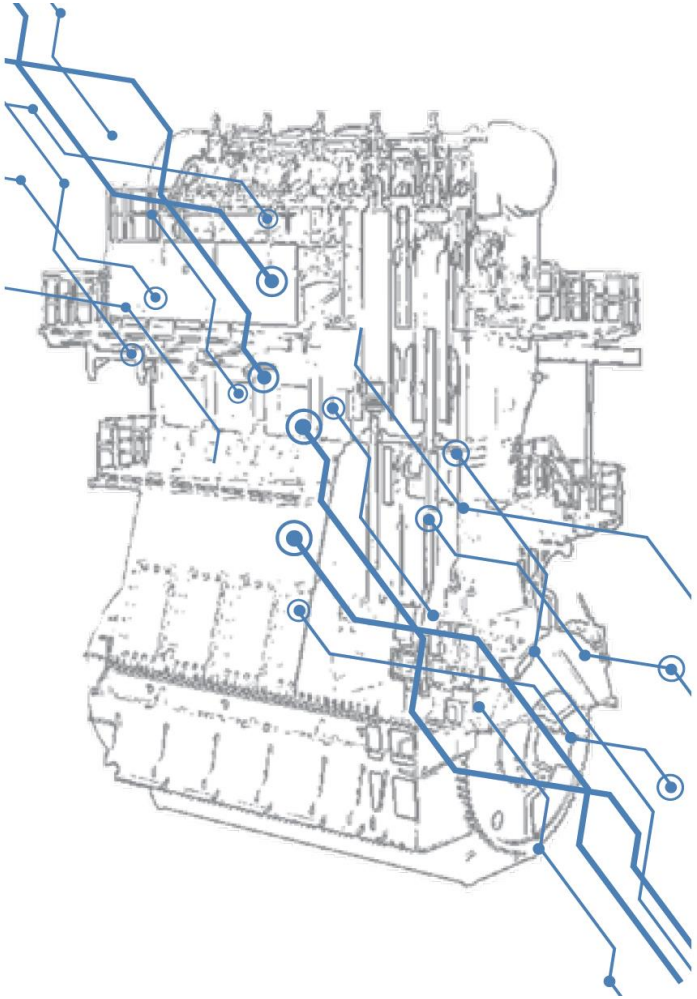
Business Development Manager
Mech. Engineer, PhD, MBA

What is a Digital Twin?

Propulsion Analytics



A **digital twin** is a digital representation of *an intended or actual real-world physical product, system, or process* that serves as the effectively indistinguishable digital counterpart of it for practical purposes



Metrics:

1. Accuracy
2. Speed of execution
3. Ease/cost of construction
4. Ease/cost of maintenance

Where are Digital Twins useful?

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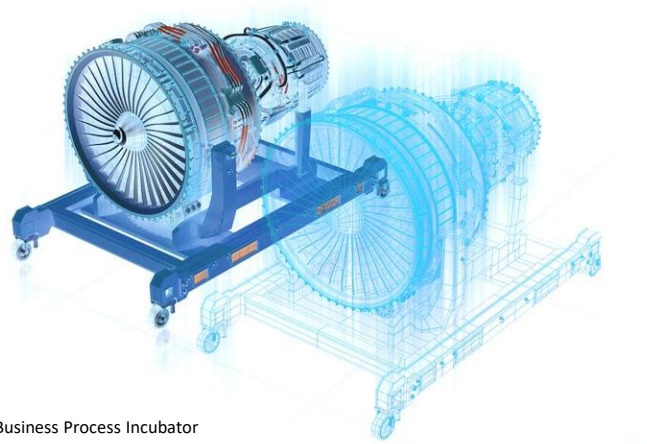
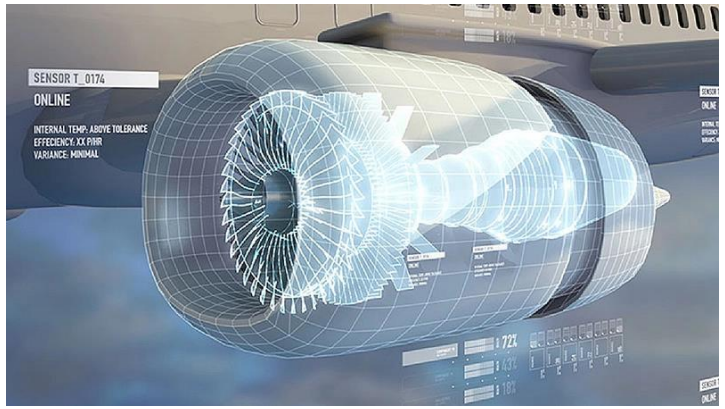
System Brand-New



Credit: Business Process Incubator

Current Condition



Credit: GE

Prognostics

Credit: Aapsky

What has changed?
→ *Diagnostics*

Where are we now?
→ *Current performance*

Where will we be?
→ *Future predictions*

MARINE

Engine Fault diagnostics Vessel hull/propeller fouling	Vessel current performance status FOC/Speed tables	Performance predictions - CII Maintenance decisions

Types of Digital Twins

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“Physics-based”

- Analytical
- Fixed relationships - prescriptive
- Tuning factors - empirical
- Reliable
- Expensive up front – limited need to monitor
- Limited flexibility to changes in system operation

“Physics-Informed” Machine-Learning

- “Grey box”
- Partly fixed relationships
- Useful for many engineering applications

Machine-Learning

- “Black box”
- Can describe very complex relationships
- We don’t always know what happens
- Can require effort to monitor

Why is AI/ML so popular?

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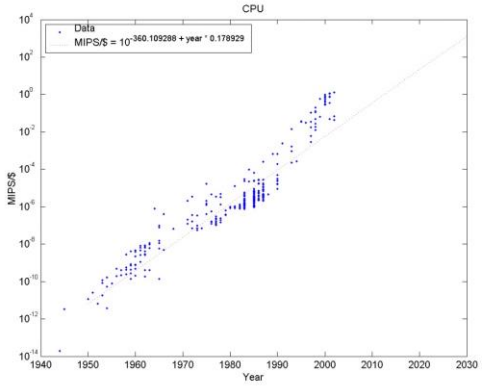
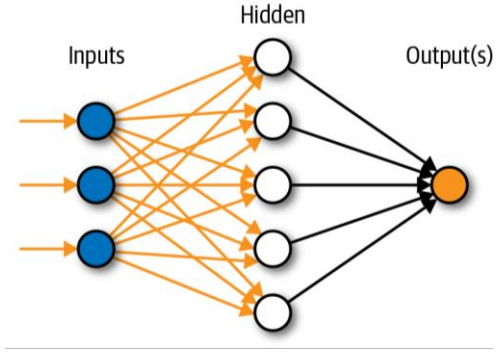
The right place at the right time

Computing Power + Storage

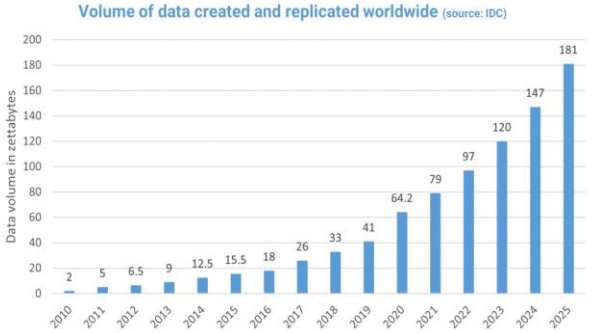


Sandberg and Bostrom (2008)

Advanced Algorithms



Available Data



IDC

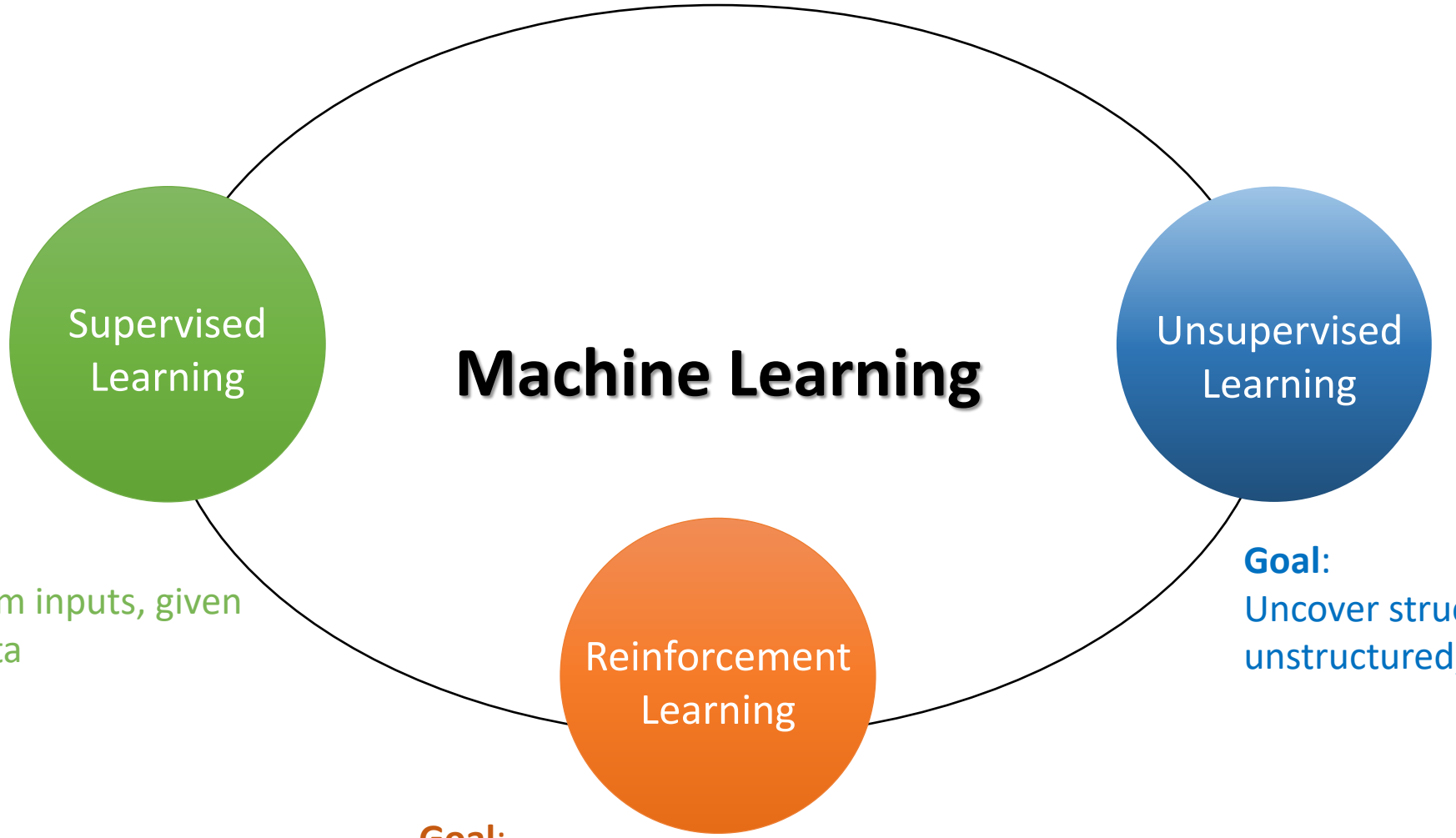
"Success with AI/ML is not about algorithms, but mostly about good data"

Mark DePristo, former Group Head Google Brain

Types of ML Algorithms

Propulsion Analytics

Overview



Goal:
Predict outputs from inputs, given labeled training data

Goal:
Uncover structure within unstructured, unlabeled data

Goal:
Learn actions to maximize outcomes in an environment

ML for Digital Twins

Problem Shape

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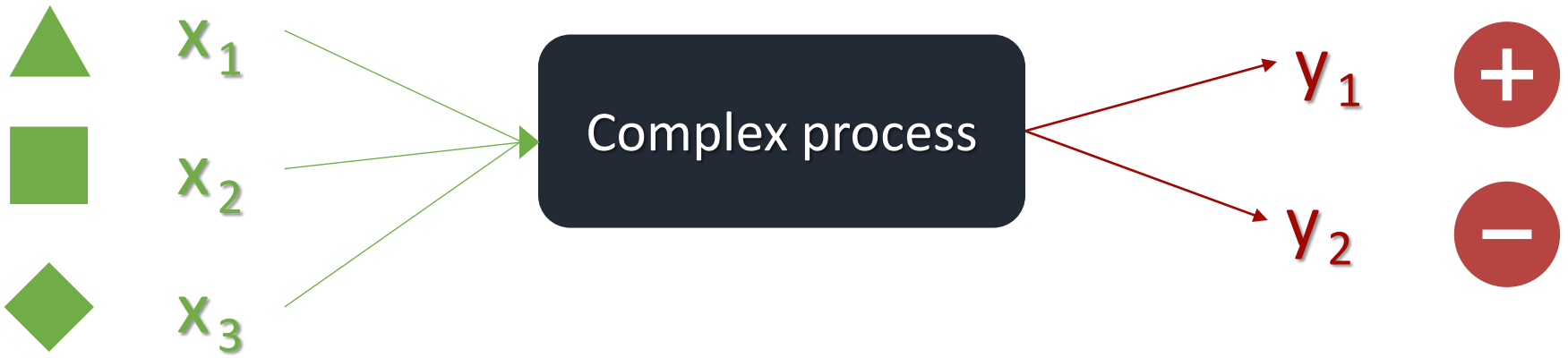
Things you can measure (inputs)

Things too complex to understand/model

Things you can measure (outputs)



$$f(x)=y$$

Digital Twin: Physics-based or ML?

(Not so) simple choice

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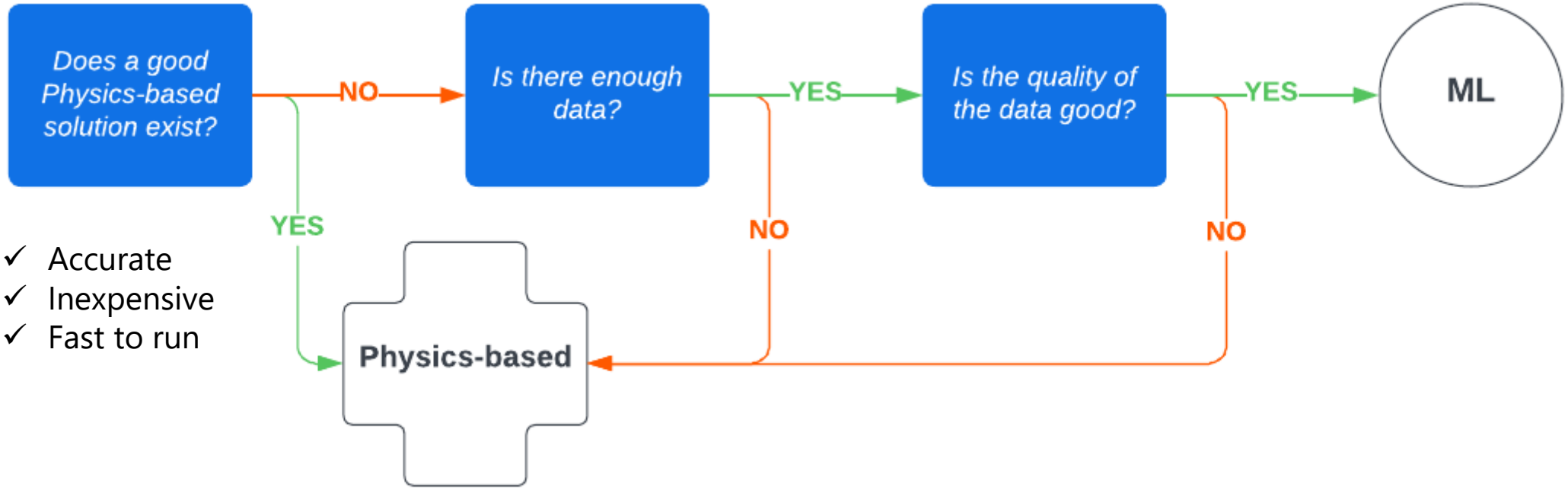
- ✓ Describing the process
- ✓ Covering all likely operating conditions

- ✓ Reliable under all conditions



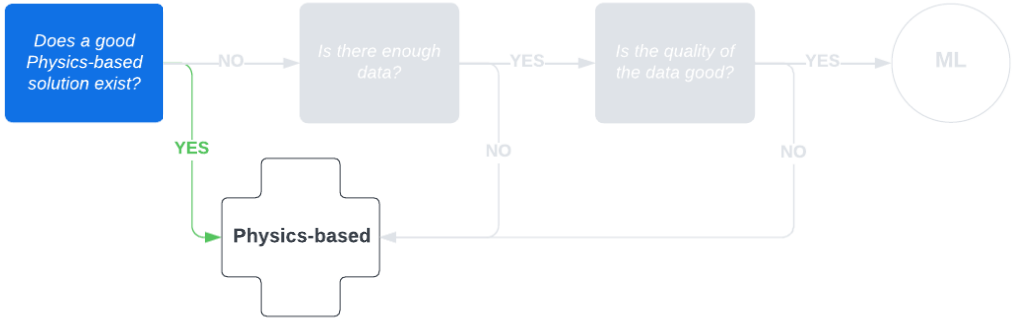
- ✓ Accurate
- ✓ Inexpensive
- ✓ Fast to run

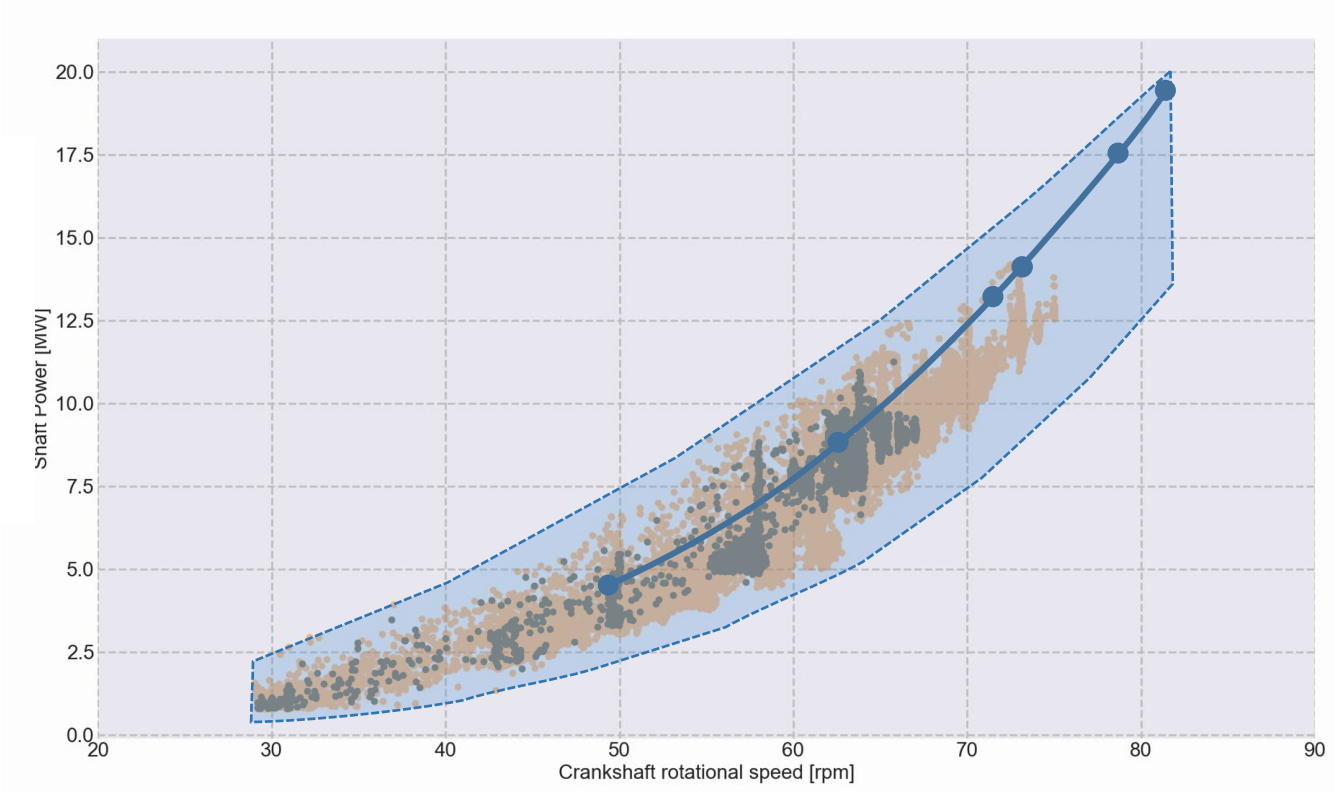
Where does this leave us?

Propulsion Analytics

Marine Applications

Continuous Engine Performance Monitoring





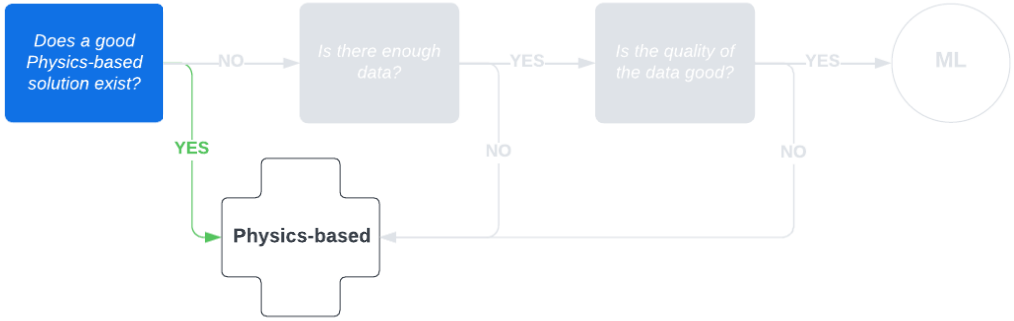
Characteristics:

- Many possible operating conditions
- Increasing number of parameters
- Requirement for accuracy under all operating conditions

Where does this leave us?

Marine Applications

Continuous Engine Performance Monitoring



	Accuracy	Speed	Construction Cost	Maintenance Cost
Machine Learning	Low	High	Low	Med.
Shop Test Reference	Low	High	v. Low	v. Low
Thermodynamic Model	High	High	Med.	v. Low

Characteristics:

- Many possible operating conditions
- Increasing number of parameters
- Requirement for accuracy under all operating conditions

What can be achieved:

- ✓ Early fault diagnostics
- ✓ Differentiation between sensor and actual faults
- ✓ Estimation of efficiency penalty from fault
- ✓ Analysis of trends for prognostics

Where does this leave us?

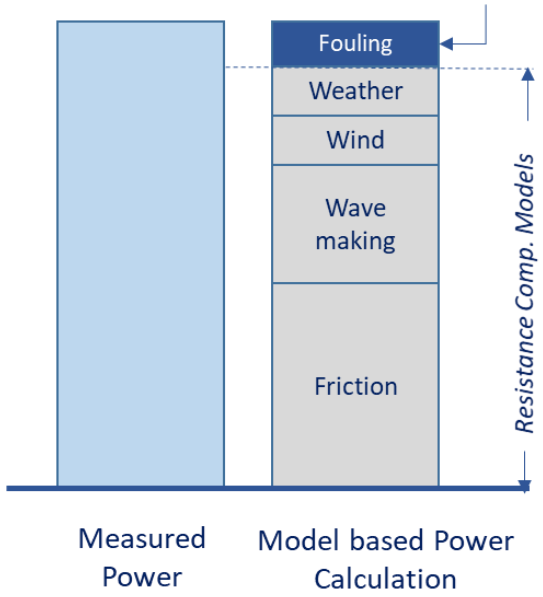
Propulsion Analytics

Marine Applications

Vessel Performance Monitoring

Characteristics:

- Varying operating regimes
- Very complex interaction of parameters – different for each vessel
- High accuracy needed



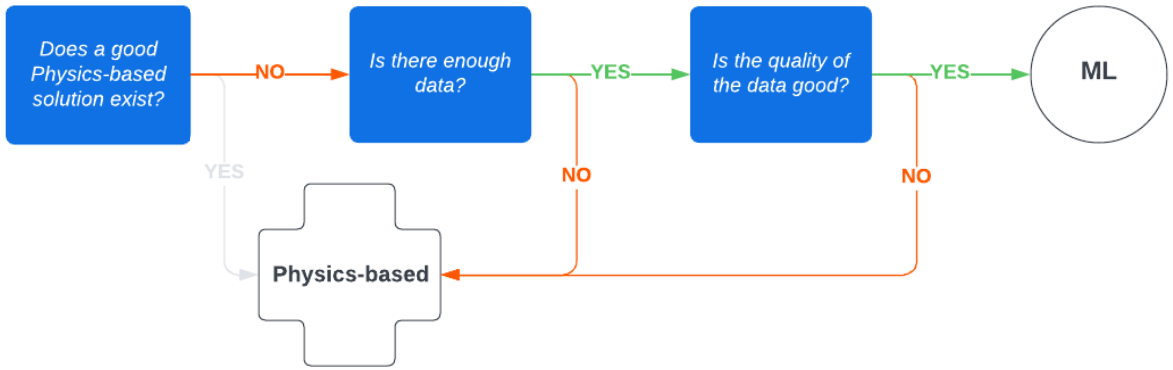
Physics-based models exist

<u>but</u>

Often **cannot capture very complex effects**

Design does not always correspond to reality

Issue of error summation



→ Limited data available – **Physics-based**

Where does this leave us?

Propulsion Analytics

Marine Applications

Vessel Performance Monitoring

Data availability:

- New technology and competition pushing sensor, DAQ and data transmission costs down
- Legislation pushing for increased sensor adoption

When data is available ML models *clearly superior*

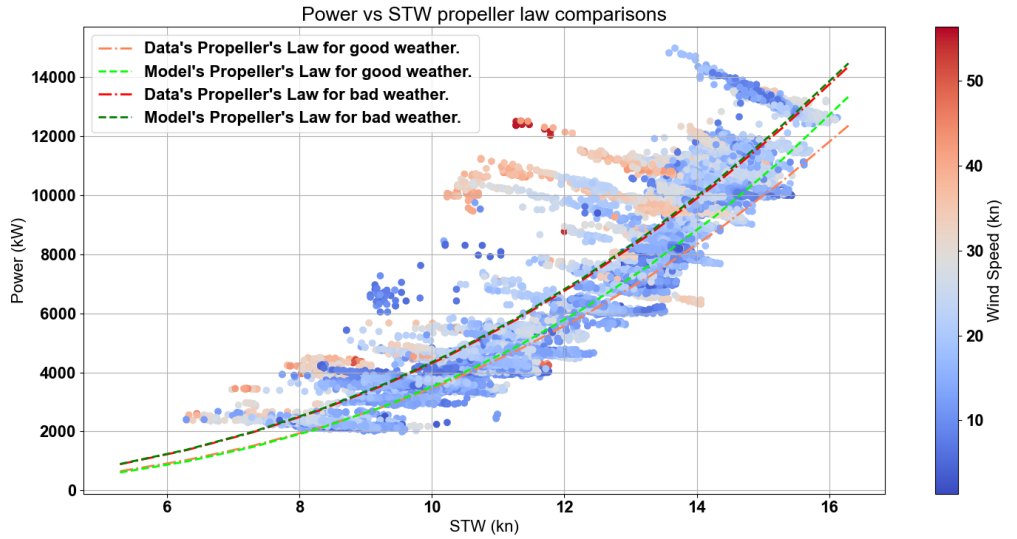
<u>but</u>

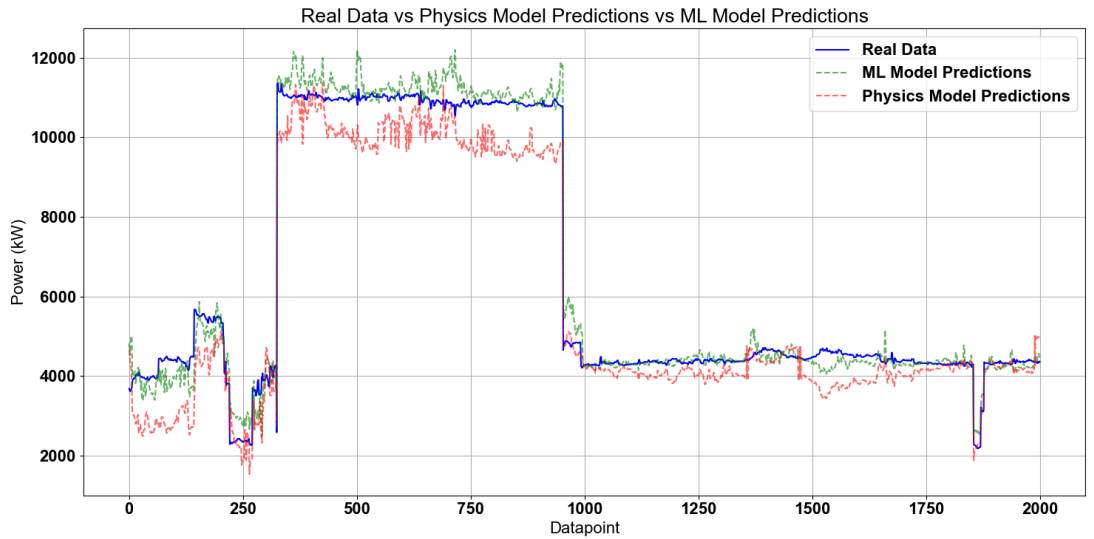
Importance of **data accuracy!**

Power, FOC and STW most important parameters

→ Corroboration of log speed and onboard meteo data with Metocean data

→ Validation for torque and FOC





Who we are

At Propulsion Analytics we specialize in Performance Management Solutions for the maritime industry.

We use **Simulation models**, **Data analytics** & **Machine-learning** to provide:

Engine Hyper Cube® — Engine Performance Assessment & Fault Diagnosis

VesselQUAD® — Vessel & Engine Performance Evaluation & Decision Support

ADQM — Continuous Data Quality Management

2014
Founded
Athens and Piraeus
Greece

2016
Selected by WIN GD
Simply a better different
for the development of their on-board
Engine Diagnostic System EDS

2018
Gold Bite Award with EURONAV
IMPACT bite GOLD Propulsion Analytics & Euronav Maritime Industry solution

2020
Ship CBM with DNV
CM Innovation Norway

2022
Patent EP 3810498B1
Remote assessment of
ship propeller fouling

Engine Hyper Cube®

Engine Performance Evaluation Software

Propulsion Analytics

The *most advanced*

engine performance monitoring solution.

Enables the

continuous monitoring of engine performance

and the

automatic identification of the source of any underperformance

Core technology

Digital Twin – The Reference Model of each engine

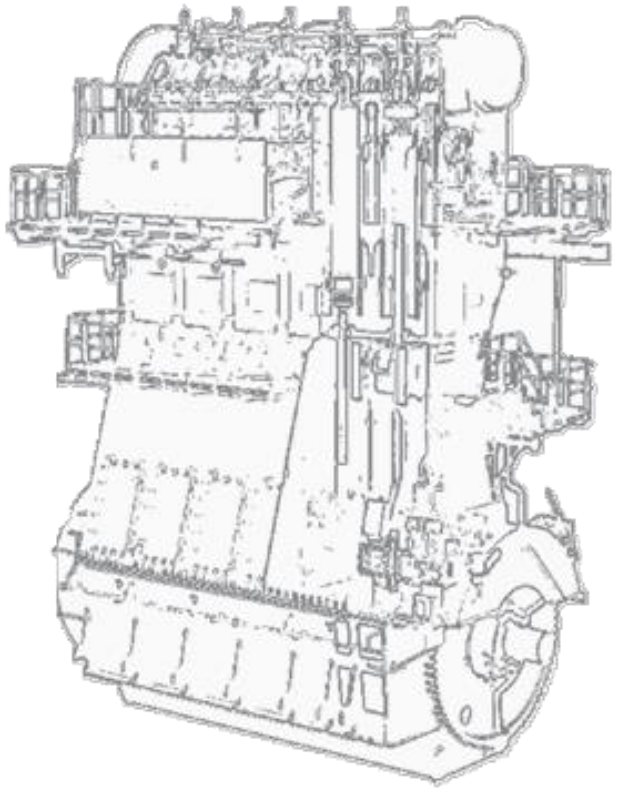
Propulsion Analytics

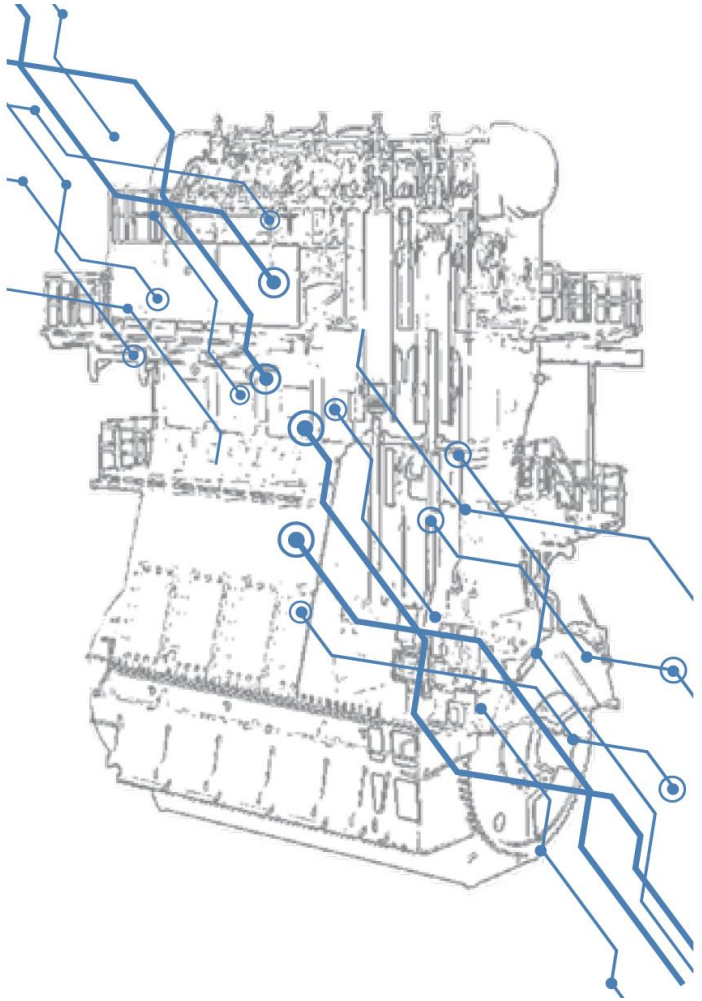
We create the "Digital Twin"

for each specific engine

We *don't just use* the engine shop tests as a reference - we calibrate a full thermodynamic model.

The Thermodynamic Digital Twin provides the "reference" values of *all* performance parameters at *any* operating condition, leading to more advanced and more accurate diagnostics and predictions

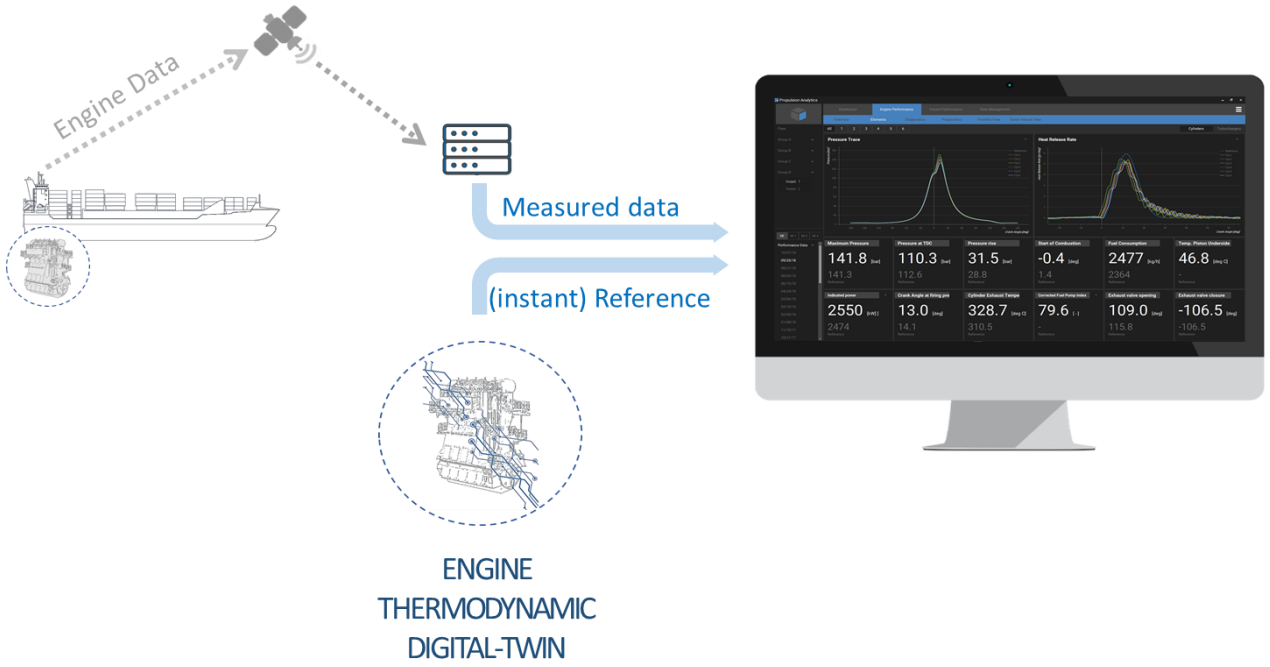




Engine Hyper Cube®

Engine Performance Evaluation Software

Propulsion Analytics



Engine Health Monitoring and Prognostics

- ✓ Automatic **early identification of faults**
- ✓ Identification of **sensor errors**
- ✓ **Quantification** of effect of fault **on FOC**
- ✓ **Fault prognostics**

Engine Performance Optimization

- ✓ Recommendations for engine **performance optimization**

Virtual Sensors

Verified **Torque**
Power
FOC (CO_2)

- ✓ **Validation of key measurements** for vessel performance evaluation

Engine Hyper Cube® can function with either **intermittent (monthly) performance reports** or **continuous data** for immediate identification of engine underperformance

Engine Hyper Cube®

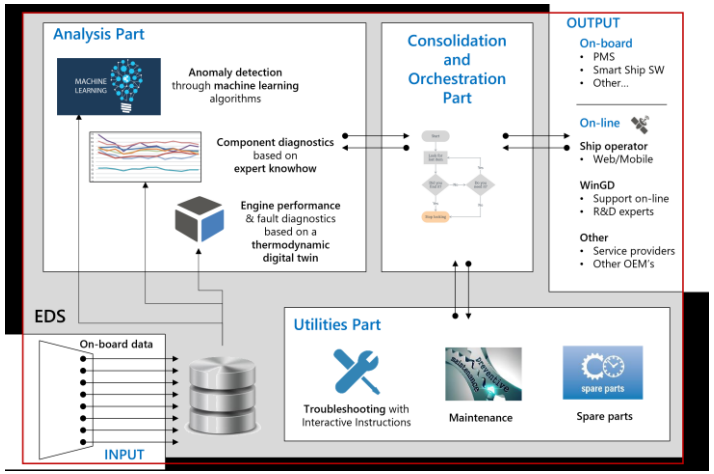
Engine Performance Evaluation Software

Propulsion Analytics

Market Success

Forms the basis of the **Engine Diagnostic System (EDS)** within **WiDE - WinGD Digital Expert**

WIN GD



on-board and on-line system *with* **Engine Hyper Cube®** *inside*

AMPTC · BERGEBULK moving mountains · CMA CGM · COSCO SHIPPING · eaglestar · ENTERPRISES SHIPPING & TRADING S.A. · GASLOG · HLS · FRONTLINE · KYKLADES MARITIME CORPORATION · SCF Sovcomflot · WAN HAI LINES LTD. WE CARRY, WE CARE · KUWAIT OIL TANKER COMPANY · EVERGREEN · GSI 广船国际 · NOVA · LATSCO SHIPPING LIMITED · NEDA MARITIME AGENCY Co Ltd · CHINA NAVIGATION · 宁波海运股份有限公司 NINGBO MARINE COMPANY LIMITED · SEATANKERS · Zodiac Maritime

More than **300 installations** on marine engines to date (>150 WinGD, ~100 MAN 2-stroke, ~50 DGs)

Universally applicable condition monitoring system for **any engine technology**, from **any engine maker.**

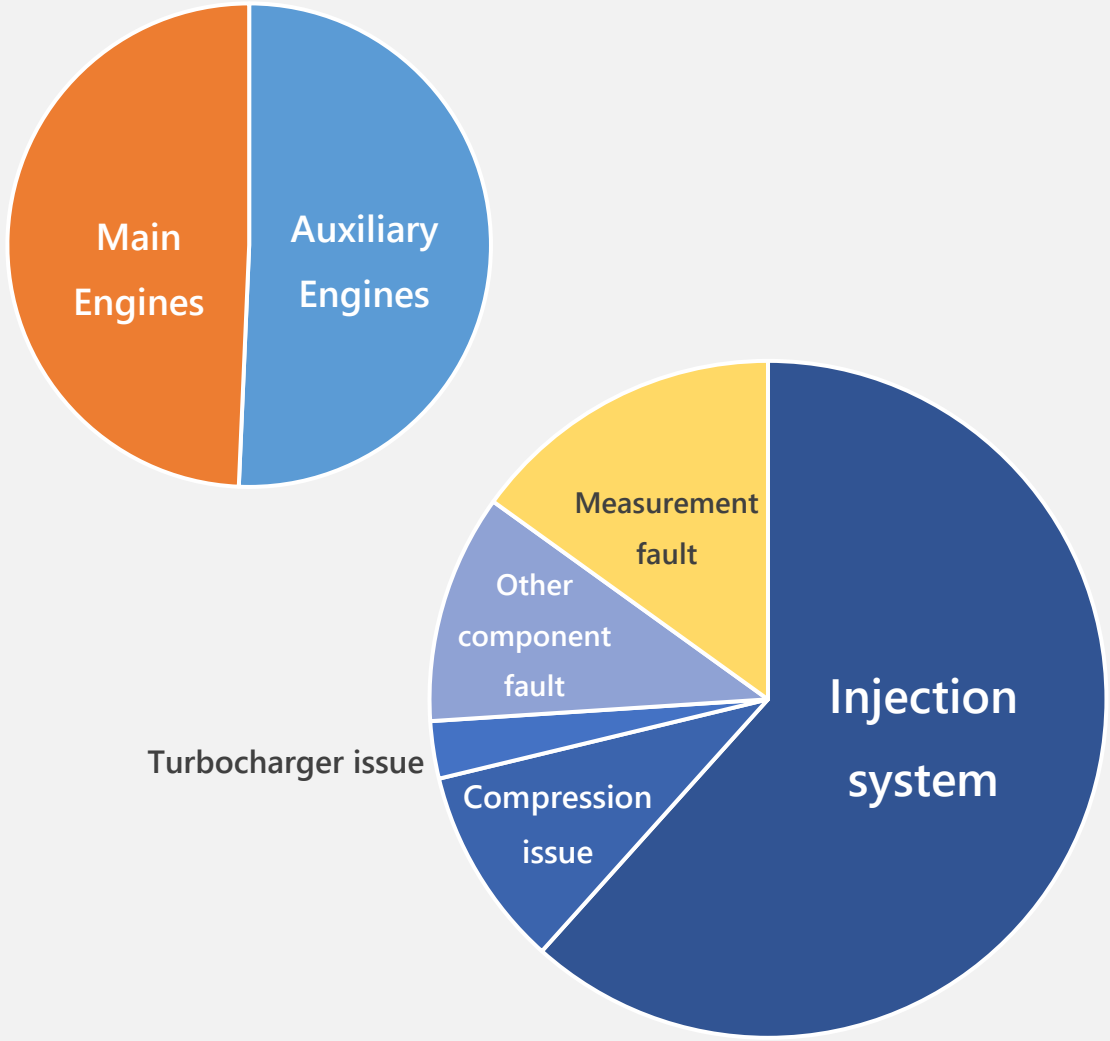
Engine Hyper Cube®

Fault Statistics from Engine Hyper Cube® **Service**

Propulsion Analytics

Fault Statistics for Marine Engines between 2018-2021

- Average 3 faults per vessel per year
- Even split between ME and AE issues
- >50% of faults in the injection system
- Increase in FOC caused by fault:
  - Average: +1.2g/kWh
  - Highest: Compression issue, >+5g/kWh i.e. >1ton/day @10MW
- 12% are measurement faults, from wrong reporting or faulty sensors (often torquemeter out of calibration)



Engine Hyper Cube®

Examples of Faults Detected

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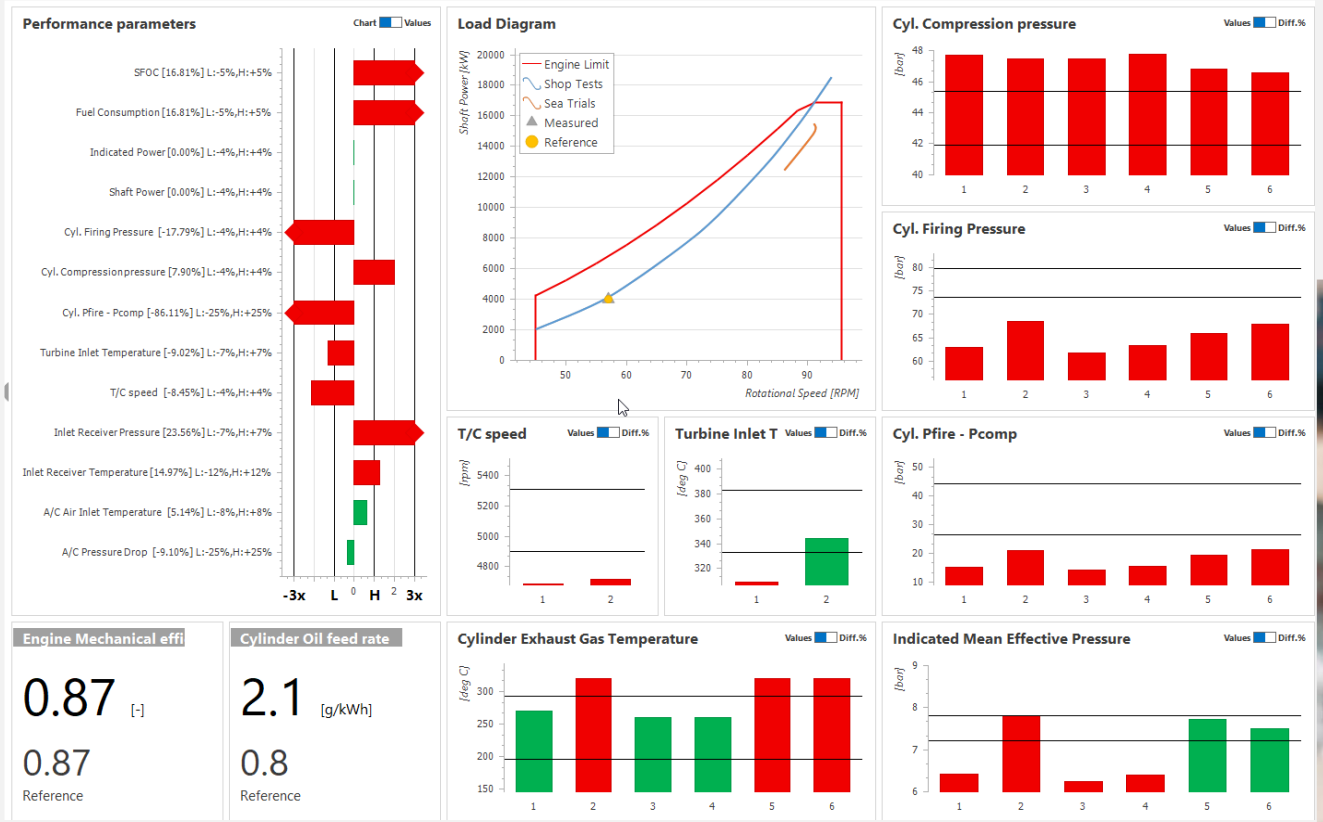
Importance of Digital Twin:

Suezmax ME:

Water contamination of fuel caused damages on all injector plunger barrels and suction valves.

- No temperature deviation between cylinders
- No limits exceeded



→ **Inability to detect fault without digital twin**

Engine Hyper Cube®

Examples of Faults Detected

Propulsion Analytics

Importance of Reference Accuracy:

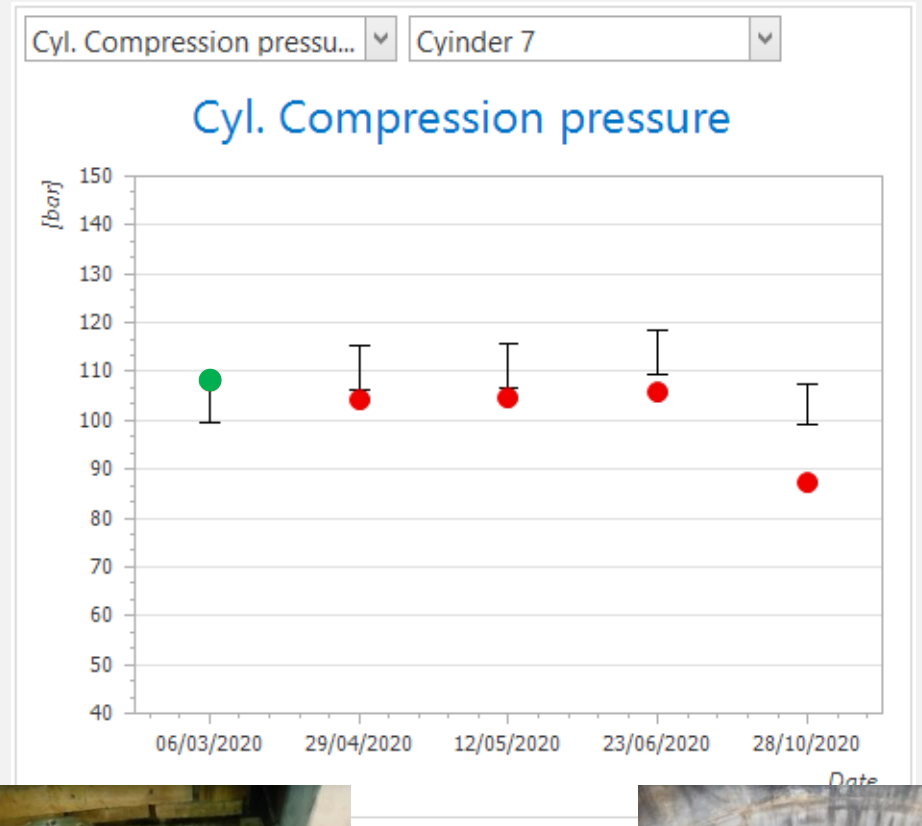
VLCC AE:

May-June 2020:
Detection of slight compression issue on cylinder #7. Instruction to limit use and power of AE.

October 2020:
Test showed severe underperformance of cyl. #7.

November 2020:
Overhauling showed cracked piston bushings and debris causing damage to piston and liner

→ **Early detection allowed unloading of engine, improved planning**

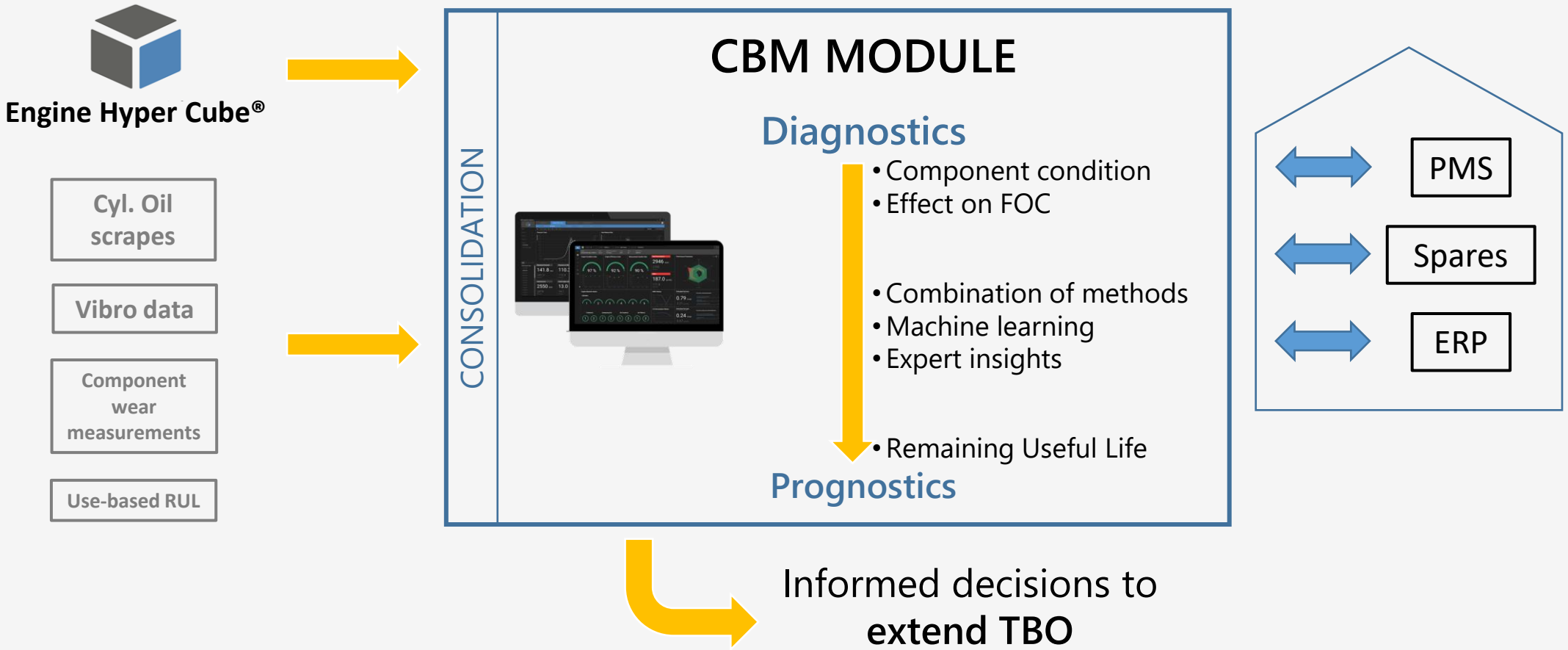


Engine Condition-Based Maintenance

Methodology

Propulsion Analytics

We integrate **5 established CBM methods**:



Engine Condition-Based Maintenance

Propulsion Analytics

Methodology

We integrate 5 established CBM methods:

Engine Hyper Cube®

Cyl. Oil scrapes

Vibro data

Component wear measurements

Use-based RUL

CONSOLIDAT

• Effect on FOC

• Combination of methods
• Machine learning
• Expert insights

• Remainin

Prognostics

Informed
exten

Letter of Professional Opinion from DNV on Engine Hyper Cube® accuracy and use "as an additional tool towards CBM for marine engines."

DNV

Propulsion Analytics IKE
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Greece

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Maritime R&D and Advisory
5 Aitolikou str.
18545 Piraeus, Greece
Phone: +30 210 41 00 200

Date: 2022-04-15 | Our reference: 11320031 | Your reference: PA CBM service assessment

LETTER OF PROFESSIONAL OPINION FOR PROPULSION ANALYTICS CBM SERVICE

DNV Maritime R&D and Advisory (DNV) has participated in a joint project with Propulsion Analytics (PA) under the funding of EEA and Norway Grants.
In the context of this project, DNV has performed an evaluation of PA processes and methods to assess specific elements of standards and recommended practices concerning the verification, validation and accreditation of software or services on condition monitoring (CM) and condition-based maintenance (CBM).

DNV is of the qualified professional opinion that the CBM service of PA meets specific elements of standards as set forth in DNV Class Programme DNV-CP-0484 and US MIL-STD-3022, based on the document review of PA CBM service procedures and methodologies.

This basis of this professional opinion letter is the joint development work in the project between PA and DNV, consisting in a number of workshops, documents review and assessment in accordance with the below documents:
1. DNV Class Programme DNV-CP-0484, Approval of service supplier scheme, Appendix B, Section 5: Service suppliers firms engaged in condition monitoring and condition based maintenance.
2. US Department of Defense Standard Practice, MIL-STD-3022, Documentation of Verification, Validation, and Accreditation (VV&A) for Models and Simulations.
3. Chequemate report "DNV requirements to CBM supplier".

The outcome of the evaluation process can be summarized in the below points:
- The PA Engine Hyper Cube (EHC) methodology uses an engine process simulation model to create a digital twin of any engine in operation.
- The engine simulation model was shown to be accurate over a wide range of engine operation, and thus can be used for engine performance parameter calculation including torque, power production and energy consumption.
- The EHC methodology and application can be used to create reference for engine health and performance evaluation during operation and thus can be used as an additional tool towards CBM for marine engines.

DNV Maritime Advisory acts independently and autonomously from other organisational divisions within DNV. DNV Maritime Advisory is in a different reporting line than DNV Classification / Certification units. If applicable, DNV Classification / Certification will independently verify the given statements and therefore may come to other conclusions than Maritime Advisory. This principle is founded on DNV's management system.

Sincerely, for DNV,

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Successful pilots on **7 vessels (M/E, A/E)**

DNV

Ongoing pilot on **1 vessel**

WINGD LR

Engine Hyper Cube®

Component TBO Extension Examples

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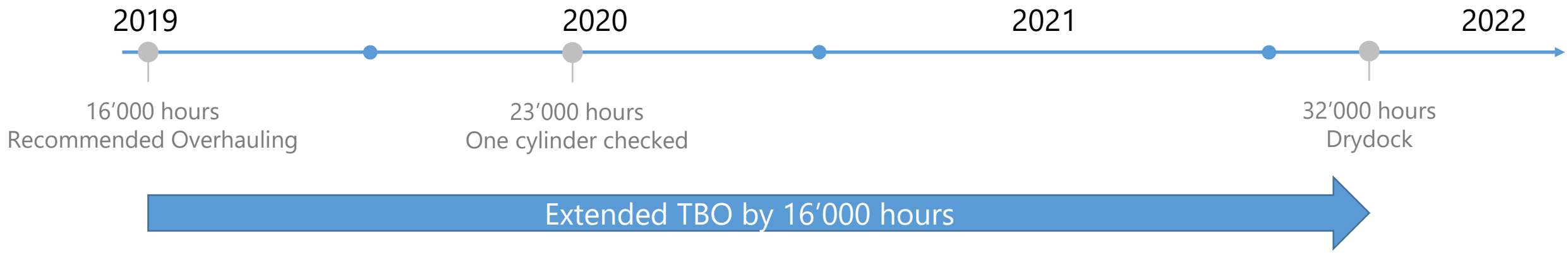
Vessel main engine piston overhauling extended:



At 16’000 hours all pistons overhauling delayed based on good performance reporting from EHC and oil analysis

→ Savings in spares and maintenance costs

At 23’000 hours only one cylinder checked, no issues

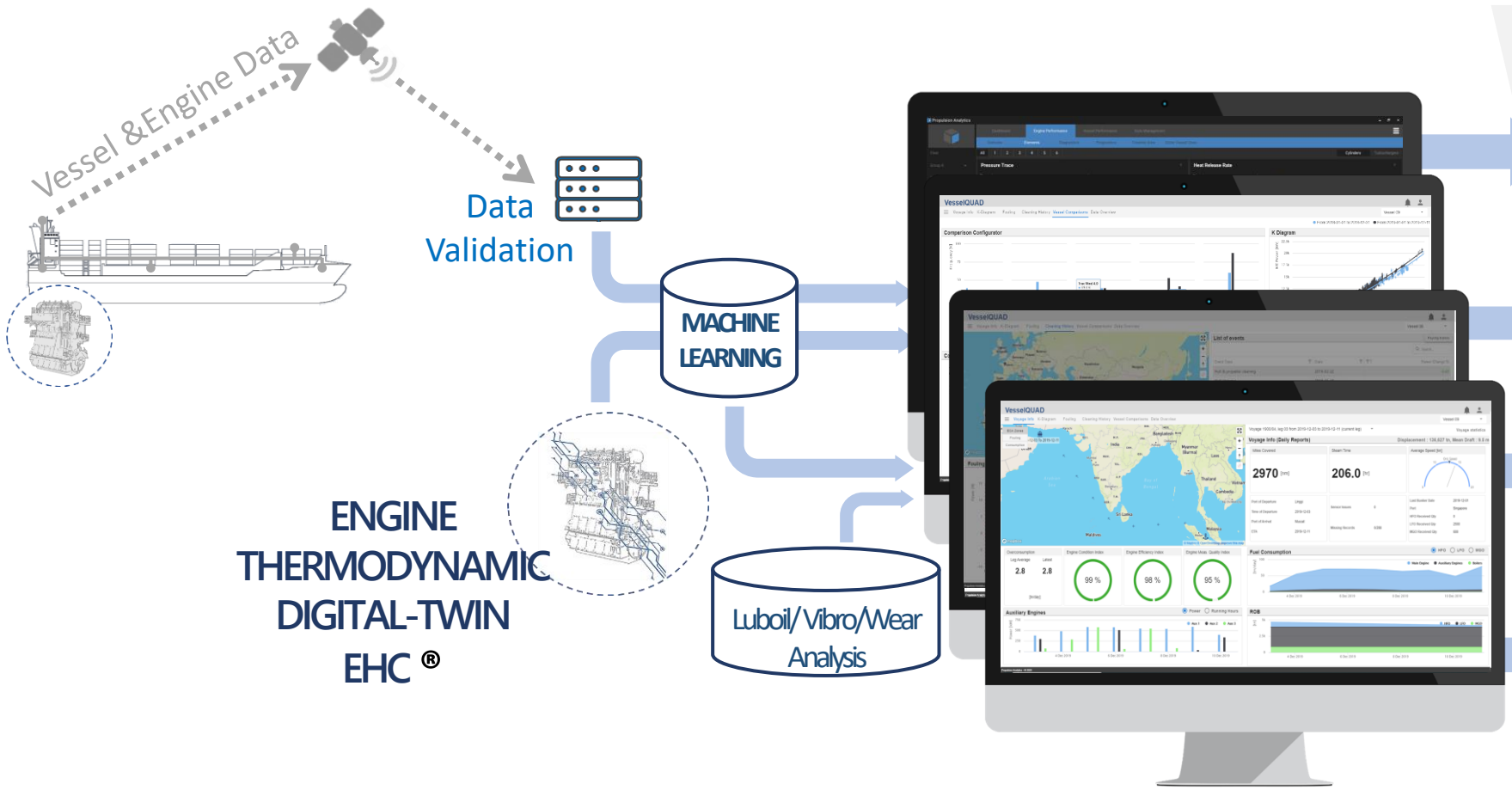
→ Savings in maintenance costs

At 32’000 hours vessel into drydock, no issues with pistons

Engine Hyper Cube®

Propulsion Analytics

Vision



Engine Hyper Cube®

Engine Performance Evaluation Software

Propulsion Analytics

Value for the customer:

- ✓ **Avoid engine underperformance and downtime**
- ✓ **Reduce troubleshooting time**
- ✓ **Optimize engine performance**
- ✓ **Validate key measurements for vessel performance analysis**

Propulsion Analytics

VesselQUAD ®

The most accurate vessel AND engine performance assessment

Combined engine, vessel and fleet performance evaluation

VesselQUAD®

Propulsion Analytics

Telemetry from ships

dB

Raw data

Filters

telenor | maritime

KONGSBERG

EngineHyperCube®

Engine performance & emissions evaluation

Torque, FOC verification

Engine Underperformance?

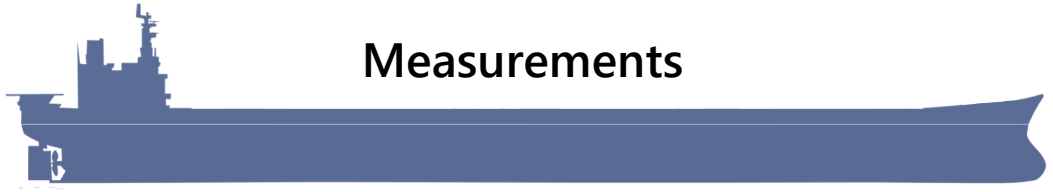
QUAD

Vessel & Fleet performance evaluation

VesselQUAD®

Propulsion Analytics

Combining Engine and Vessel Performance Evaluation



Measurements

Data Analytics/AI

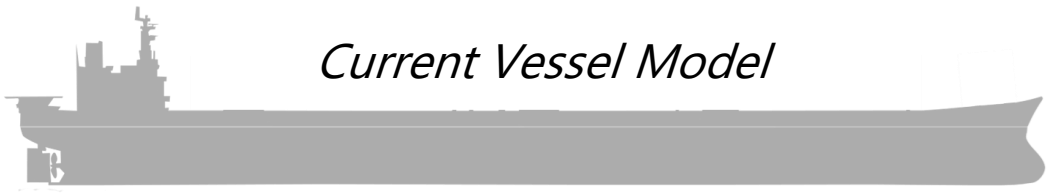
on continuous vessel data

Performance Evaluation

Clean Vessel Model

- ✓ Underperformance evaluation and quantification – fouling/weather/engine
- ✓ Hull/Propeller cleaning suggestions
- ✓ Past cleaning event evaluations
- ✓ Evaluation of vessel adaptations/paints

Performance Prediction



Current Vessel Model

- ✓ Up-to-date speed-FOC tables – input for chartering
- ✓ Input for vessel optimal routing
- ✓ CII projections

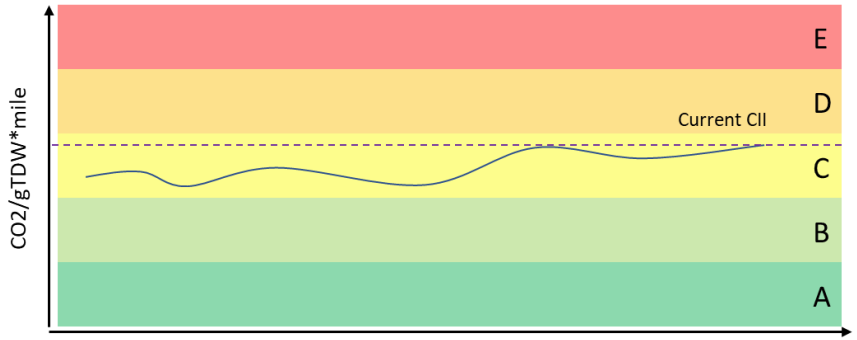
CII Evaluation & Prediction

VesselQUAD®

Propulsion Analytics

Historical CII

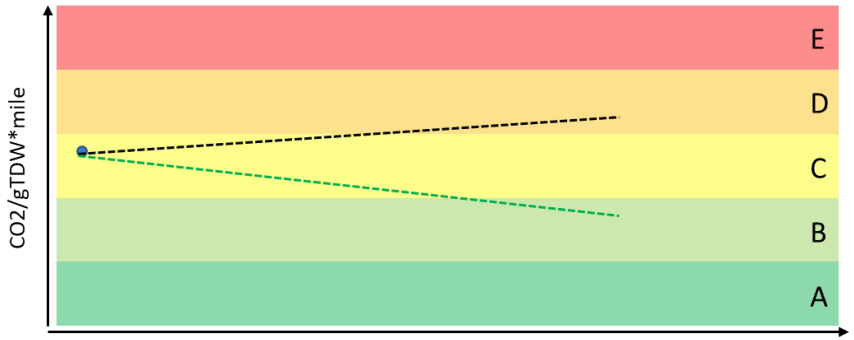
Understand the past



- ✓ *Understanding **of contribution of different trips** (idle, ballast, laden) on CII*
- ✓ *Detailed analysis of **source of underperformance** (weather, fouling, engine)*
- ✓ *Detailed understanding of **effect of adaptations** (performance devices, hull paints etc.) on CII*

Future CII

Predict the future

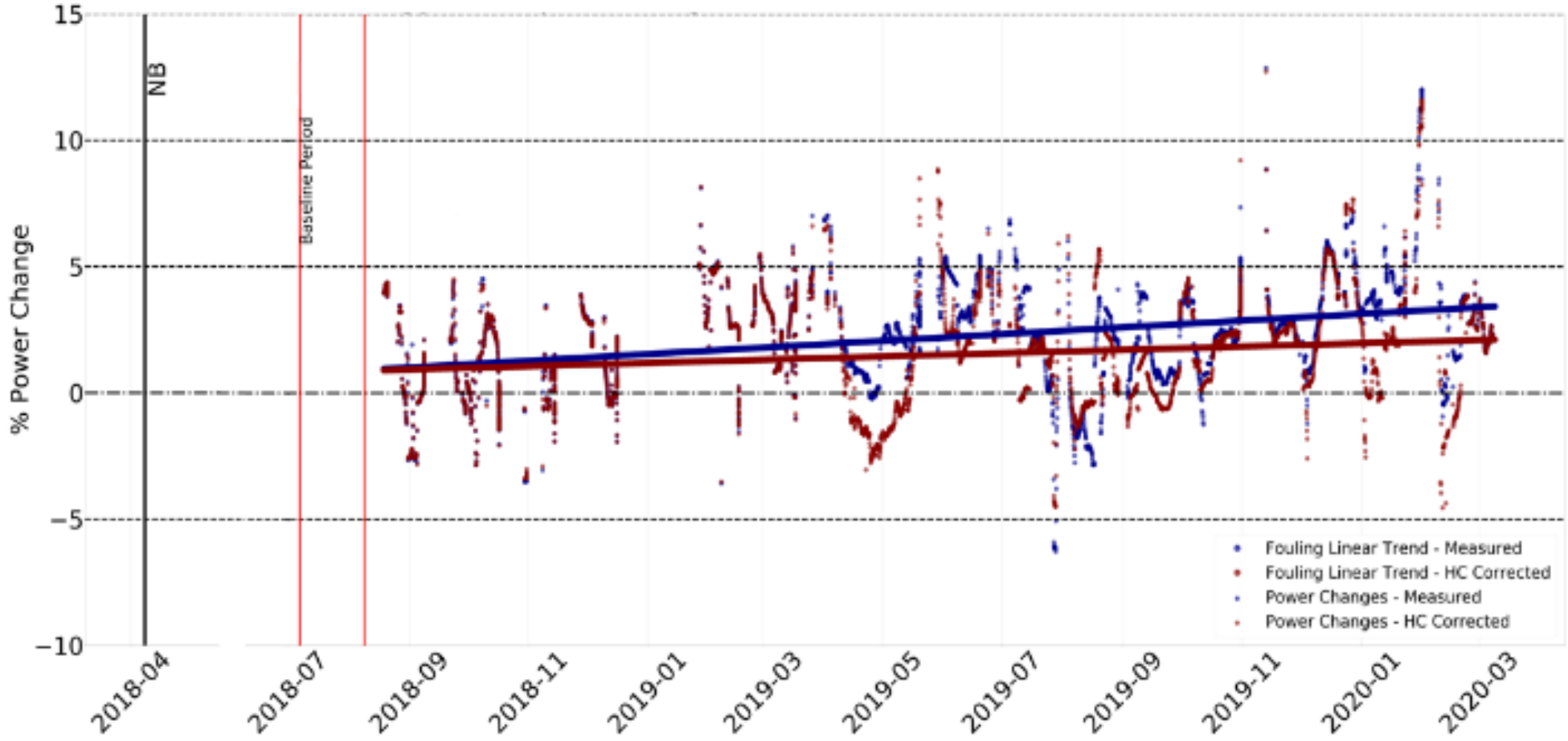


- ✓ *Study of **different scenarios:***
  - *Operating profile*
  - *Speed*
- ✓ *Study of effect of **timing of cleaning events** – help with decision making*
- ✓ *Forward look **on performance in future years***

VesselQUAD®

Propulsion Analytics

Examples from Vessels Monitored



→ **Importance of data quality/validation!**

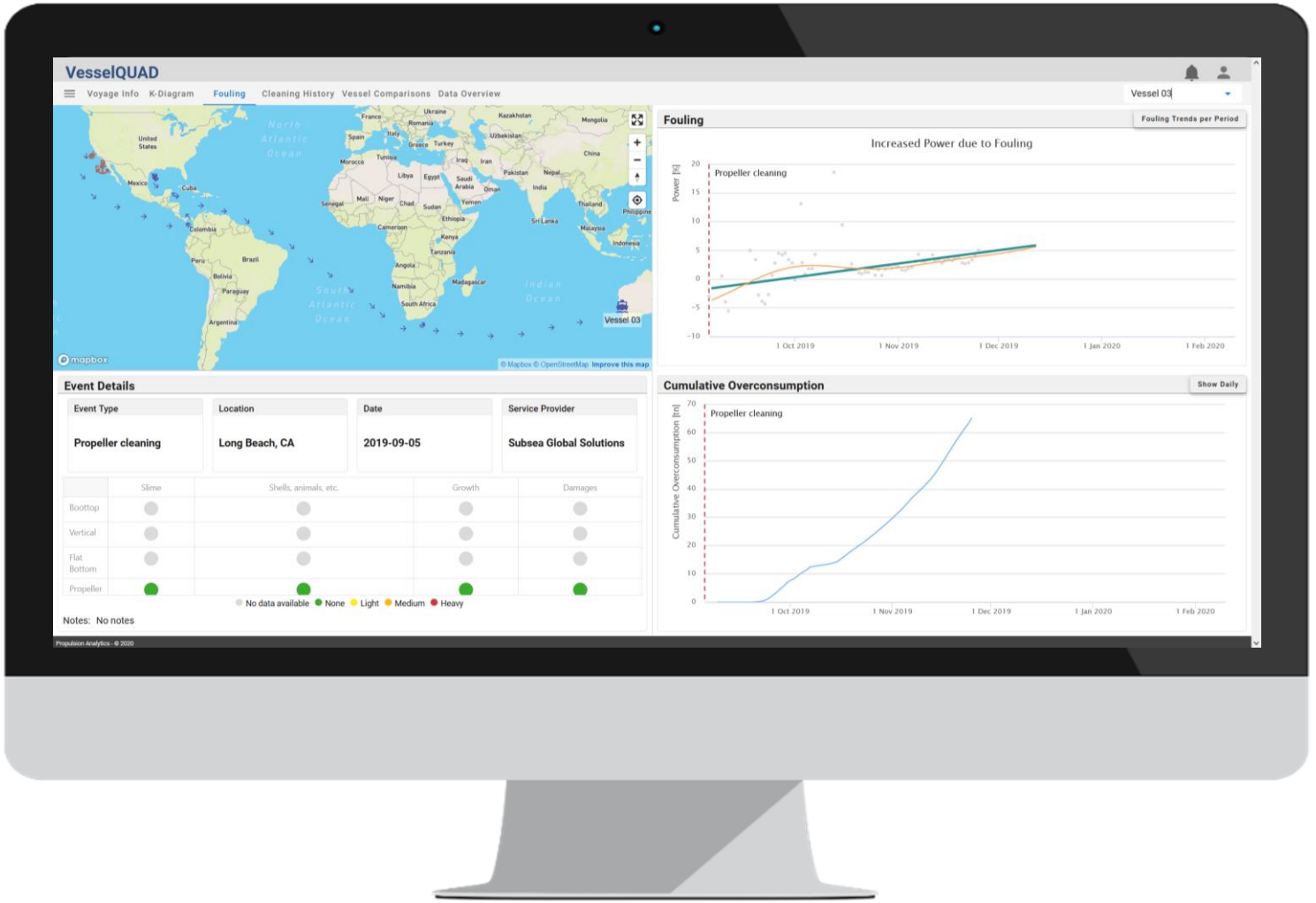
VesselQUAD®

Vessel & Engine Performance Evaluation Software

Propulsion Analytics

Value for the customer:

- ✓ Key **measurement data validation**
- ✓ Real-time identification and analysis of **vessel & engine underperformance**
- ✓ Detailed **engine fault diagnostics**
- ✓ Hull/propeller **fouling analysis** and **cleaning decision support**
- ✓ Accurate **current vessel performance** for chartering and weather routing
- ✓ Detailed **CII analysis and projections**



Digital Twins for Marine Asset Performance Monitoring

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Summary

Digital Twin applications are available today – can help with:

- ✓ **Engine fault diagnostics and optimization** – retain high *availability* and reduction in *troubleshooting time* and *FOC/emissions*
- ✓ **Vessel performance monitoring** – improvement in *performance-related decision making* and *FOC/emissions management*

- ➢ **Physics-based** approaches are established but not always feasible or viable
- ➢ **ML models** are emerging, but not ideal for all applications; they require:
  - Continuous, high quality data – increasingly available, cost-effective
  - Detailed understanding of processes involved

→ *Different solutions are appropriate for each application*

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Thank you!

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