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RAMS

Digital Twin-based Prognostics and Health Management for Subsea systems: Concepts, Opportunities and Challenges

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PhD Project Title : *Condition Based Maintenance decisions and Digital Twin for subsea systems.*

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Motivation & Objectives

converge existing perspective for better understanding of DT and its difference to traditional simulation approaches.

Outline opportunities and challenges that DT based PHM brings with an aim of defining future research direction.

Outline

- Part I: DT concepts and difference between DT approach and traditional simulation approach.
- Part II: DT types and classification.
- Part III : Subsea maintenance
- Part IV: DT based PHM : Opportunites and Challenges

Part I: DT concepts and differences between DT approach and traditional simulation approach.

History of DT

- Dates back to 2002 when Grieves introduced a conceptual model in his course for product life cycle management.

- Preliminary model included three parts: physical product, digital replica, and their connections.

- Firstly, named as Mirrored Space Model (MSM) in 2005, Information Mirroring model in 2006 and was later revisited by NASA in 2012 calling it as a Digital Twin

Digital Twin Definitions

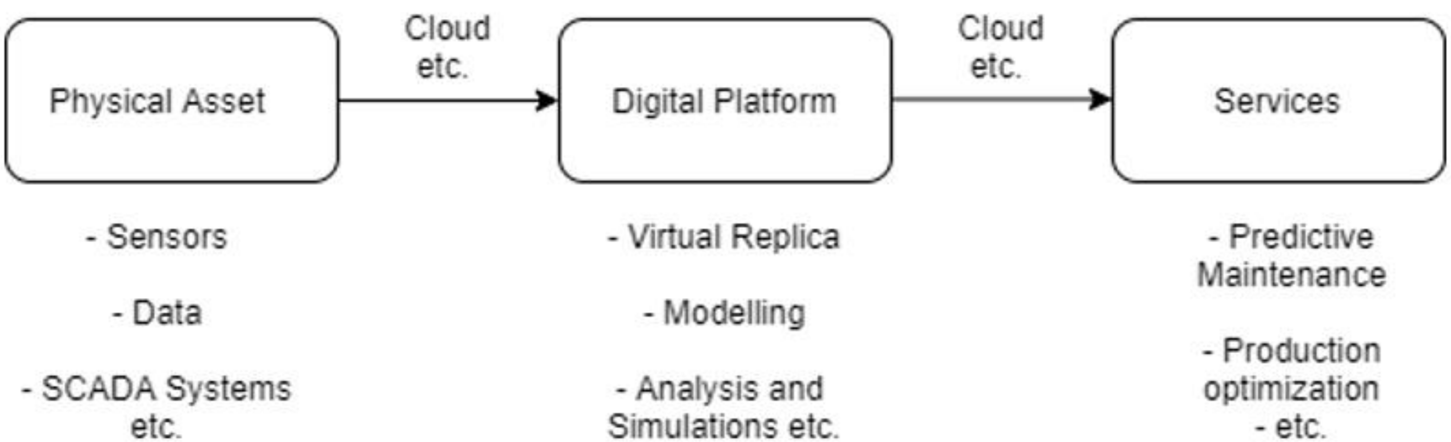
First Definition of Digital Twin by NASA:	
Glaessgen and Stargel [10]	"A Digital Twin is an integrated Multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its corresponding flying twin".
In Production:	
Maurer [17], Tao et al. [12]	"the DT is a real digital mapping depicting the production process and product performance of all components in the product life cycle using physical data, virtual data and interaction data between them".
In Engineering:	
Bajaj et al. [29], Reifsnider & Majumdar [26]	"A unified Ultra-high-fidelity system model that can coordinate architecture, mechanical, electrical, software, verification, and other discipline- specific models across the system lifecycle, federating models in multiple vendor tools and configuration-controlled repositories."
In terms of the purpose of the digital twin:	
Macchi et al. [27], Bolton et al. [13], Gabor et al. [16], Soderbergh et al. [14]	"The DT can be considered as a dynamic virtual entity, relying on the sensed and transmitted data from the existing system, with the purpose to; enable understanding, learning and reasoning, and allow for more accurate simulation in different scales of time and space for optimizations, control and decision-making."
In aviation:	
Tuegel [28]	"Ultra-realistic, cradle-to-grave computer model of an aircraft structure that is used to assess the aircraft's ability to meet mission requirements.
In industry player terms:	
Siemens [36]	"digital copy that is created and developed simultaneously with the real machine"
In Health:	
Ulrik [38]	"transformative platform for patient specific hypertensive intervention"

In General

A DT is a real time :

- virtual replica of a physical entity
- entailing various models
- to control physical counter part, provide services and assist in decision making.

DT Solution Architecture



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Difference Between DT approach and Traditional simulation approach

- **Real Time -** *The DT approach utilizes real-time data to study its physical counterpart behavior, while simulations are mostly based on historical data, assumed, or randomly generated data.*
  - *The time lapse between the synchronization of DT and its physical counterpart may also be utilized as one of the performance measures of DT.*

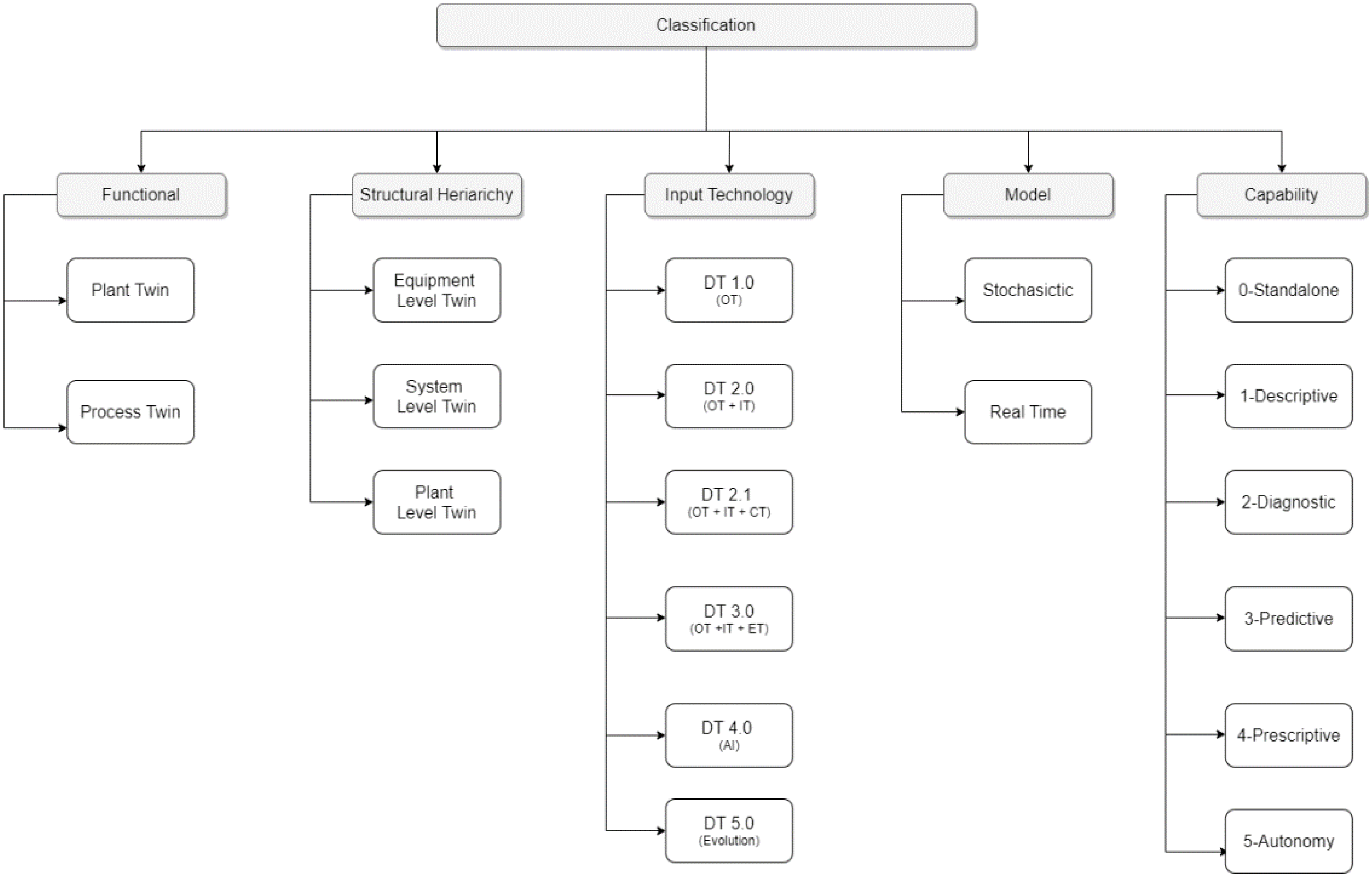
- **Scope -** *DT has broader scope through out lifecycle and process whereas, traditional simulations focuses on use case*.

- **Dynamic-** DT is flexible, incorporate various models and matures with time thorough out the asset's life cycle. On the other hand, simulations are rigid in case of incorporation of other applications and generation of new knowledge once a model is built.

- **Complexity -** Development of DT requires fusion of multidiscipline approaches and multi technologies. Transformation of data various multiple sources and requirement of extensive computational resource make the development of DT complex as compare to conventional simulation.

Part II: DT types and classification.

Digital Twin - Classification



Classification based on functionality

- The plant twin: The plant twin is akin to 3D virtual reality model. This allows for the stakeholders to run a series of what if scenarios to plan the future activities in advance and train personnel beforehand.

- Process twin: is digital replica of on plant processes. This type of twin is used to study current process and operation parameters to optimize process performance.

Classification based on hierarchy

The difference among these groups is reflected in the level of detail and accuracy requirement

- Equipment level: Equipment level twins are the most detailed and accurate as they include detailed engineering drawings, designs and data of the equipment being modelled

- System level: is an integrated version of multiple equipment level twins. The high accuracy requirement is in general at the aggregated level rather than of equipment it is built upon.

- Plant level: The multiple system level twin is further aggregated to create the plant-level twin. The plant-level twin thrives to imitate the overall plant behavior rather than system- or equipment-level behavior.

Classification based on Input Technology

- DT 1.0: incorporates operational technology (OT). Operational data from sensors such as pressure, temperature, etc. are fed into models and algorithms for real-time predictions.
- In DT 2.0: the information from OT is fused together with data from information technology IT (CMMS, ERP etc.). This creates a much richer knowledge base for decision making.
- DT 2.1: fusion of contextual information (geographical area, topography etc.) with IT and OT. Contextual information may provide us answers to question about why the two identical machines behave differently.
- DT 3.0: fuses Engineering Technology (ET) with IT and OT. Data from IT and OT and contextual information is not enough to make reliable decision and predict future. Subject engineering knowledge is needed along with data science.
- DT 4.0: shall incorporate artificial intelligence [AI] to learn from traditional black swan events and able to predict the unseen event of similar scale and magnitude.
- DT 5.0: shall self-evaluate be able to recognize and adjust to the new normal.

Classification based on modelling approaches

- Stochastic models: models the behavior of the entire system / plant in terms of a probability distributions. For example, data of multiple choke valves will be gathered and what if scenarios will be analyzed in term of probability distribution rather than single values

- Real time models: model's behavior and states for each element individually. For example, each valve will have its own DT modelling its behavior instead of getting the results in term of a probability distribution.

Classification based on capability

Classified on a scale from 0-5 in terms of capability level

- 0-standalone: virtual 3D model disconnected from its physical asset
- 1-descriptive: connected to its physical counterpart via information flow through sensors and SCADA systems
- 2-diagnostic: the capability to detect faults and abnormalities within behavior and state of actual asset
- 3-predictive: able to make prediction about future production rate and remaining useful life etc
- 4-prescriptive: prescribe the stakeholders “what to do” and “when”
- 5-autonomy: has the capability to automate tasks paving way for unmanned facilities

Part III : Subsea Maintenance

Subsea Maintenance

- Subsea systems are in general prone to wear and tear due to usage, ageing and exposure to harsh environment.

- The degradation ultimately leads to system failures, which may result in production and economic losses. In case of safety critical equipment, this failure may lead to loss of human life and environment.

- The degradation can be slowed down or reversed by right maintenance activities.

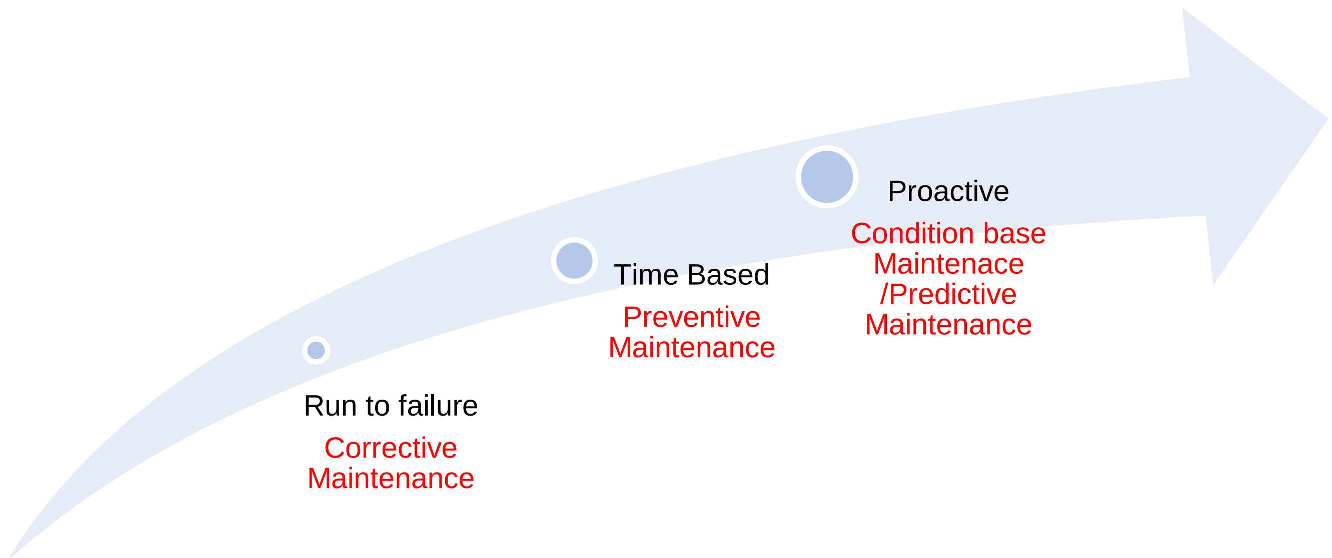
- However, the maintenance of subsea system is challenging. From technical point of view lifting of whole subsea module, sending out unmanned remote vehicles etc. are complex operations.

- Economically the cost of the maintenance interventions could be as high as the cost of production loss due to degradation induced failures

Maintenance Development in Subsea

, find an optimum balance between the risk (production loss) and opportunity (high reliability)

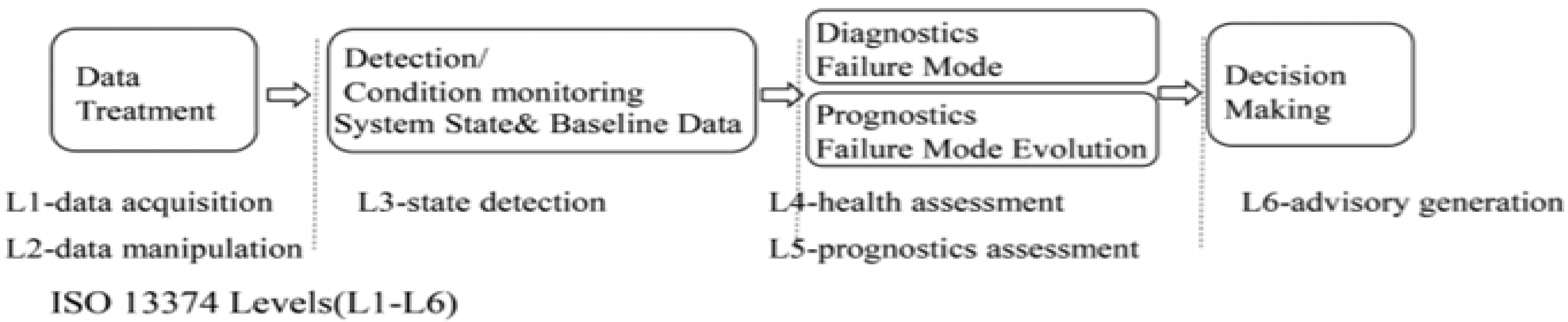
the maintenance interventions need to be well planned in collaboration with operations.

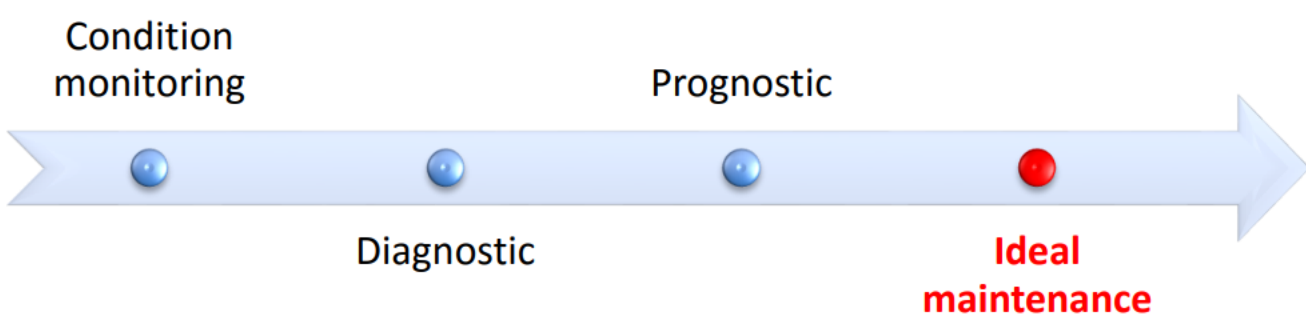


Shift from traditional corrective, calendar - or age-based maintenance polices towards condition-based maintenance.

CBM and PHM

The central idea is that maintenance is only implemented when there is enough evidence of degradation (imminent probability of failure of equipment) derived from observed condition of the system.





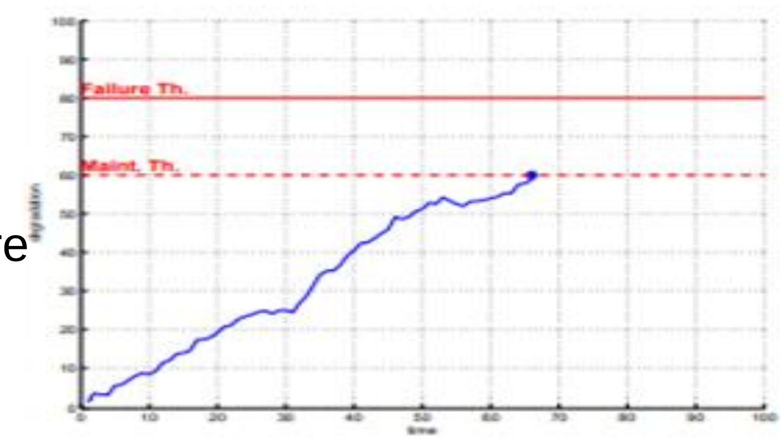
CBM and PHM

Diagnosis : “Where are we at this moment”

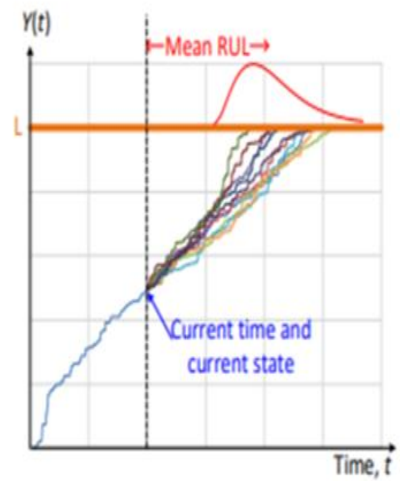
Fault detection: whether a fault is present or not.

Fault isolation: is about identification of the nature of the fault.

Fault estimation: is about estimating the severity of the fault. ¨



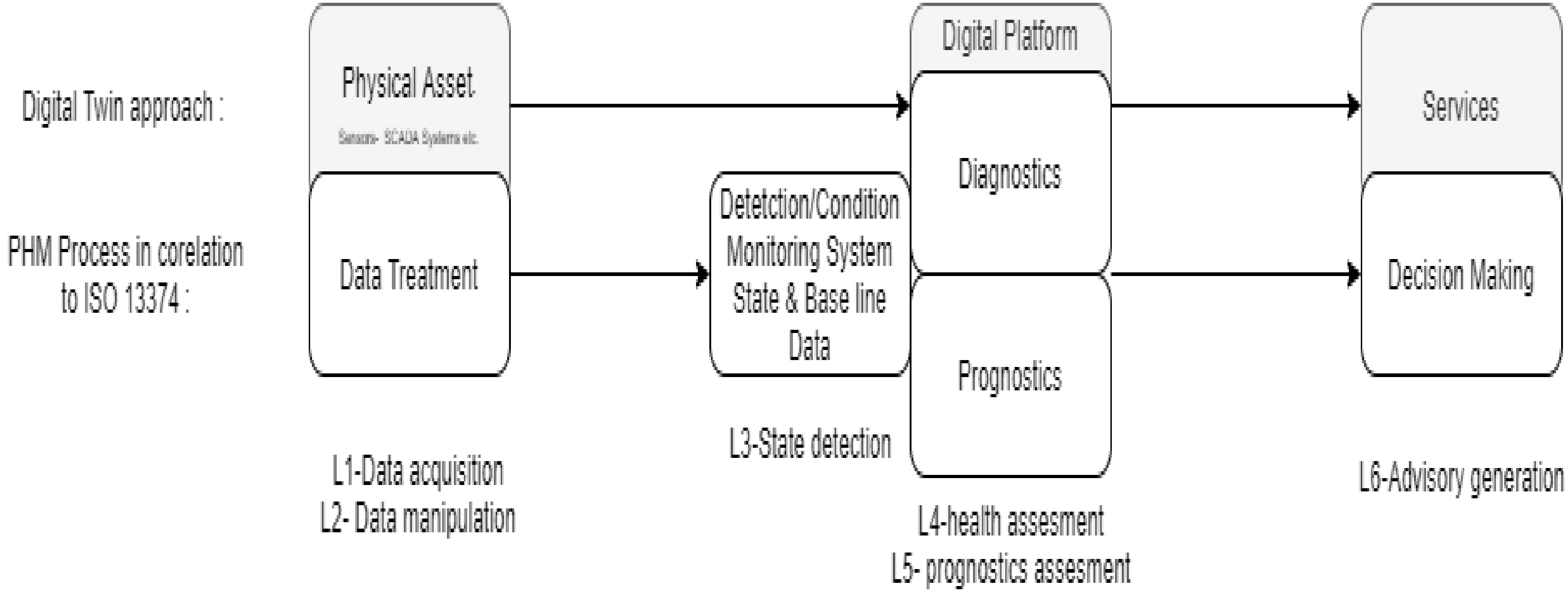
Prognosis : “where we will be in future”
- Degradation Modelling
- Remaining useful life RUL



Degradation Modelling

Prognostics ⟷ Remaining useful Life

PHM Process integration in DT approach



Why Need for DT?

major technological advancement, social and political trends are shifting with focus on green energy, low carbon solutions and digitalization

+

Profit margins are contracting , increase in market competition. Drop-in oil prices

+

the harsh operating environment and the positioning of components on the seabed make the accessibility, maintenance and inspection/monitoring of subsea systems complex, costly and demanding.

↓

This calls for digitalized method, remote operations, online performance and condition monitoring.

Part IV : DT based PHM : Opportunites and Challenges

DT based PHM : Opportunities

Real time Monitoring and Control – DT allows for using real-time sensor data from the subsea components allowing for real-time diagnostics and prognostics resulting in capturing actual degradation for real time control and decision making.

Maintenance Optimization - RUL estimations based on actual operating conditions and parameters will help maintenance staff in formulating more reliable maintenance, repair and replacement plans. Thus, to a large extent eliminating unnecessary interventions and down time.

Synchronization of Operation and Maintenance - maintenance personnel need to align the preventive tasks with the operational personnel considering production plans, operational windows opportunity available for maintenance interventions etc. Digital twin representation enables for such effective synchronization of operation and maintenance

DT based PHM : Opportunities

Remote Operations and Unmanned Facilities – Maintenance personnel will be able to monitor the health of system onshore, dispatching the staff when necessary. Reduction in downtime and losses caused by human errors

Cost reduction and CO_2 Emissions – PHM will realize unmanned facilities and remote operations, this will in turn result in cost reduction in terms of manhours requirements and logistic, which will also result in lower CO_2 emissions and help to achieve the CO_2 emissions targets.

DT based PHM : Challenges

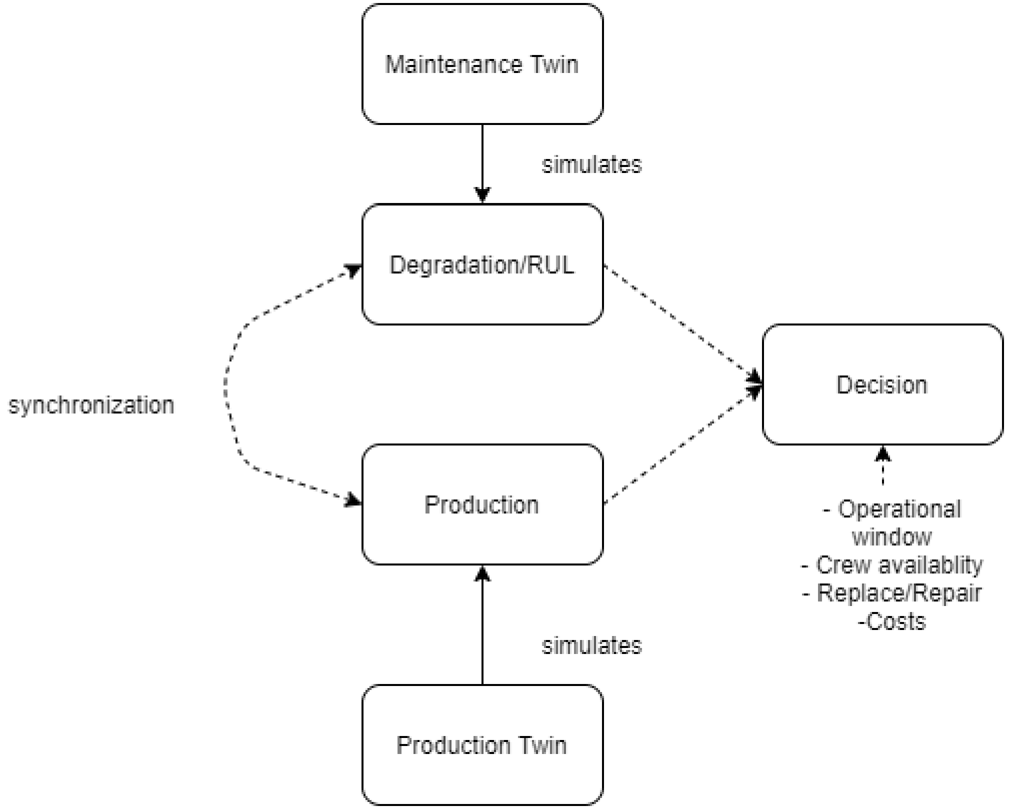
- Models and analytical algorithms capturing uncertainty and impact of maintenance actions

  - Diagnostic and prognostics models at system level
  - Capturing Impact of maintenance action and uncertainty on degradation process w.r.t. to future solicitation, environmental variations ,etc.

- Online algorithms

DT based PHM : Challenges

- Multiple Twins synchronization



DT based PHM : Challenges

- Sensor Drift – Digital twins gather data from various sensor connected to its physical counterpart. The sensors are prone to drift phenomena which affect the accuracy of sensor readings. This challenges the reliability and credibility of the study findings

- Fusion of Multidiscipline – DT based PHM which will require scientist from various sciences especially production, data, risk and reliability to join hands. Fusion of knowledge among these disciplines will require to reach common goal.

- Validation - Models and simulations are to large extent in general are based on assumed or randomly generated data. Validation of the models in real settings is of great importance for large scale implementation of DT based PHM.

Conclusion

- The difference is substantial and explicit in terms of real-time, scope, dynamics and complexity

- The crucial difference being that digital twins have the power to utilize real-time state and process unlike conventional simulation technology.

DT based PHM has its own characteristics which poses new challenges. Some of which to be addressed are:

- Development of probabilistic digital twins that can capture uncertainty in component/system degradation and remaining useful life with respect to future solicitations, environment variations, degradation process and concurrent faults etc.

- Mathematical models and algorithms that can integrate multiple twins (for e.g., “maintenance and production twin”) to optimize maintenance.

- Upgrading of the existing models or develop new algorithms that can be automated to run in real-time.

- Validation of DT models in real settings and data.

- Thank You for Listening!

Questions and Comments?

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