Norwegian University of Science and Technology

SUBPRO

SUBSEA PRODUCTION AND PROCESSING

The qualification of a digital twin for maintenance models

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Agenda

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- Motivations
- Classification of digital twins
- Proposed framework
  - Fidelity
  - Smartness
  - Real-time
  - Interactions
  - Standards
- Case studies
- Conclusions

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Motivation

- Digital twins
  - Useful for maintenance
  - Varies classification
  - Few researches for qualification

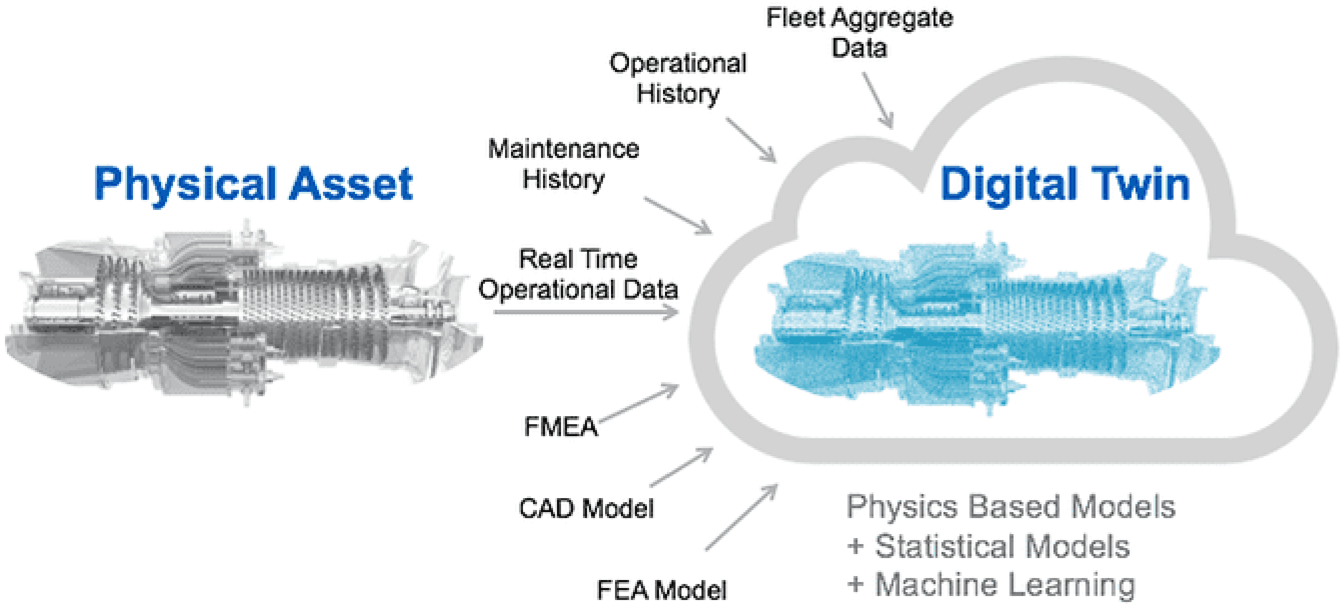

Fig 1: A digital twin is an exact, virtual representation of a physical product or process that exactly replicates the real-world system and its behavior.
Image credit: Entso-E

Definition for digital twins

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ISO 23704-2022 General requirements for cyber-physically controlled smart machine tool systems (CPSMT) — Part 1: Overview and fundamental principles

Digital replica of physical assets (physical twin), processes and systems that can be used for various purposes or a fit-for-purpose digital representation of something outside its own context with data connections that enable convergence between the physical and virtual states at an appropriate rate of synchronization

ISO 23247-1:2021 Automation systems and integration — Digital twin framework for manufacturing — Part 1: Overview and general principles

<manufacturing> fit for purpose digital representation of an observable manufacturing element with synchronization between the element and its digital representation.

Classification for digital twins

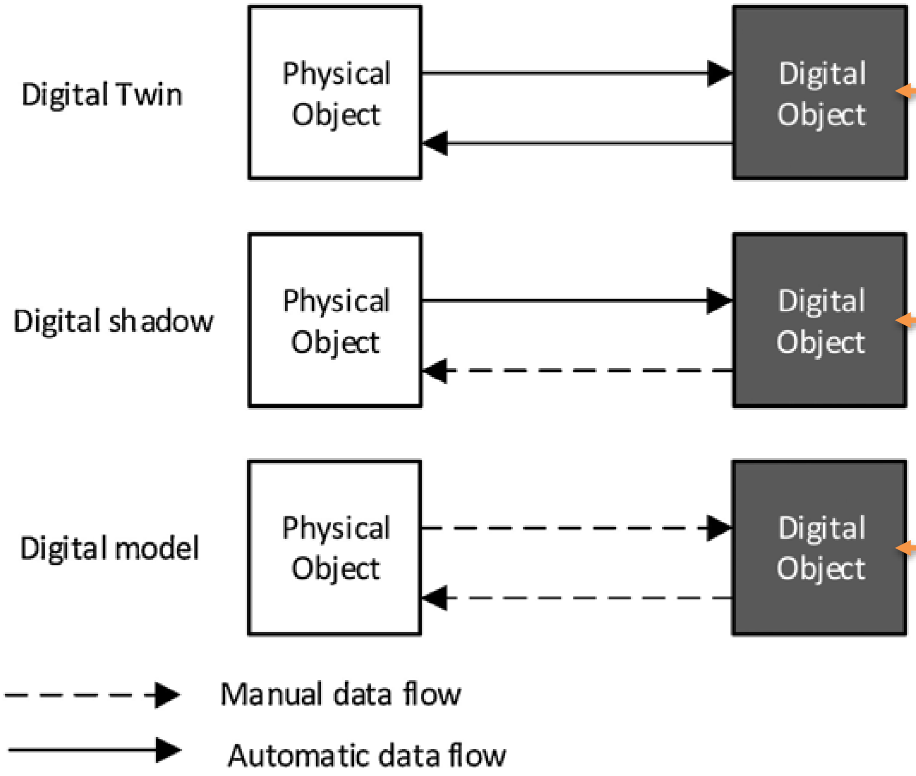


Fig 2: Flow on different integration modes
Kritzinger et al. (2018) (IFAC 2018)

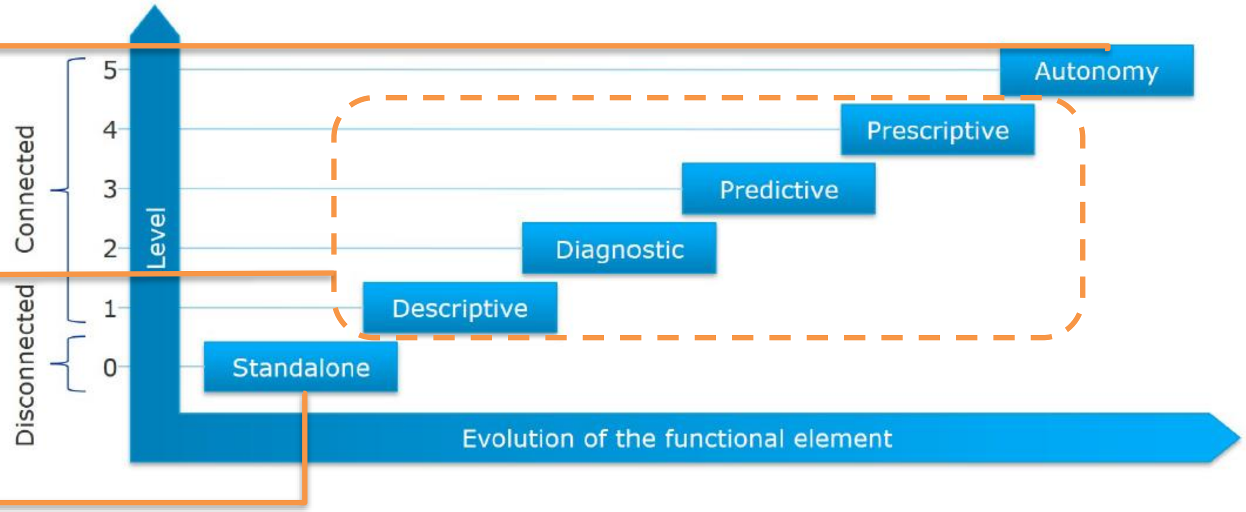
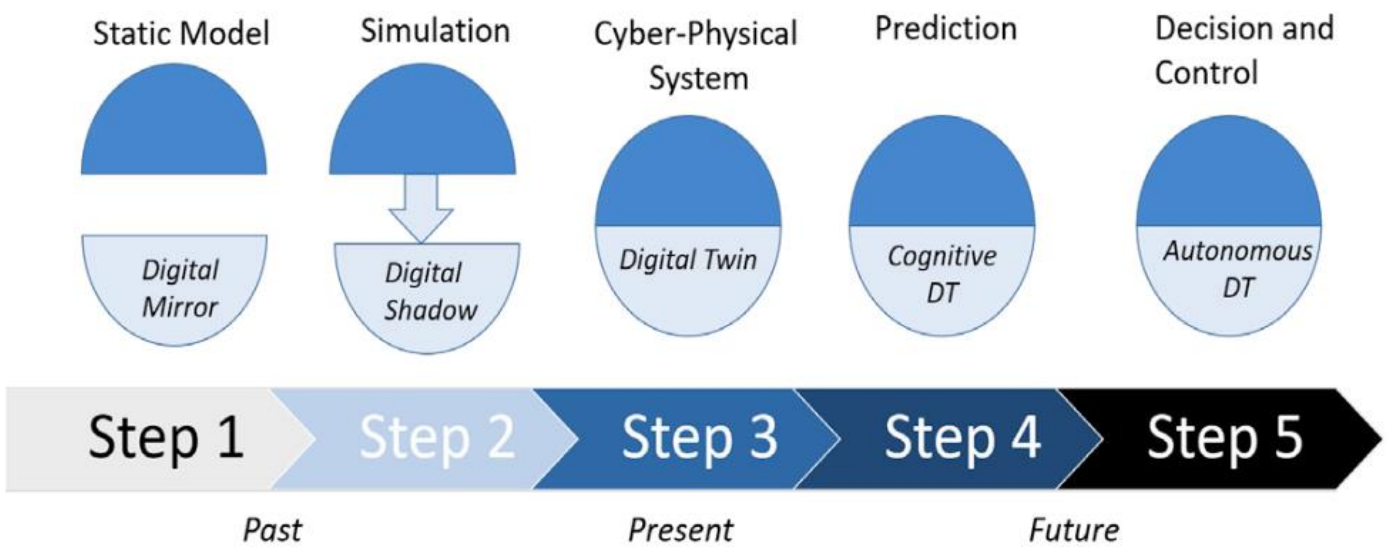


Fig 3: The capability level for digital twins
Altamiranda and Colina (2019) (OCEANS 2019-Marseille)
Cited by DNV in RP-A204 2020.

Classification for digital twins



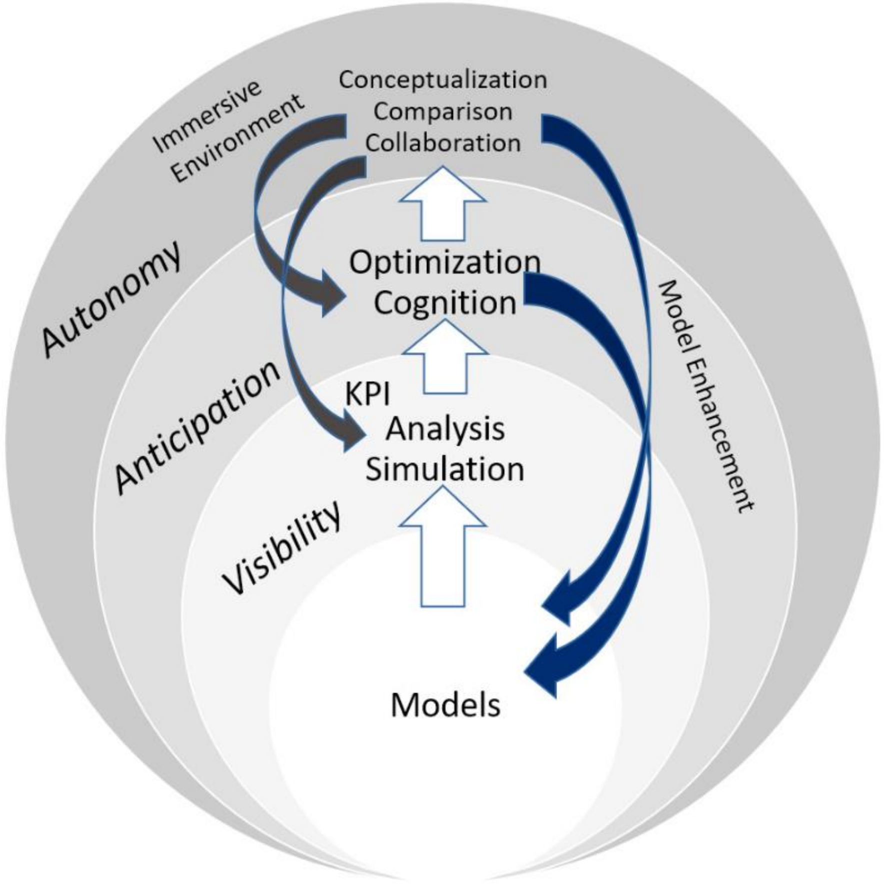


Fig 4.1: numerical representation maturity.

Fig 4.2: Usage hierarchy.

How to characterize a digital twin: a usage-driven classification. Julien and Martin (2021) IFAC 2021

Proposed framework

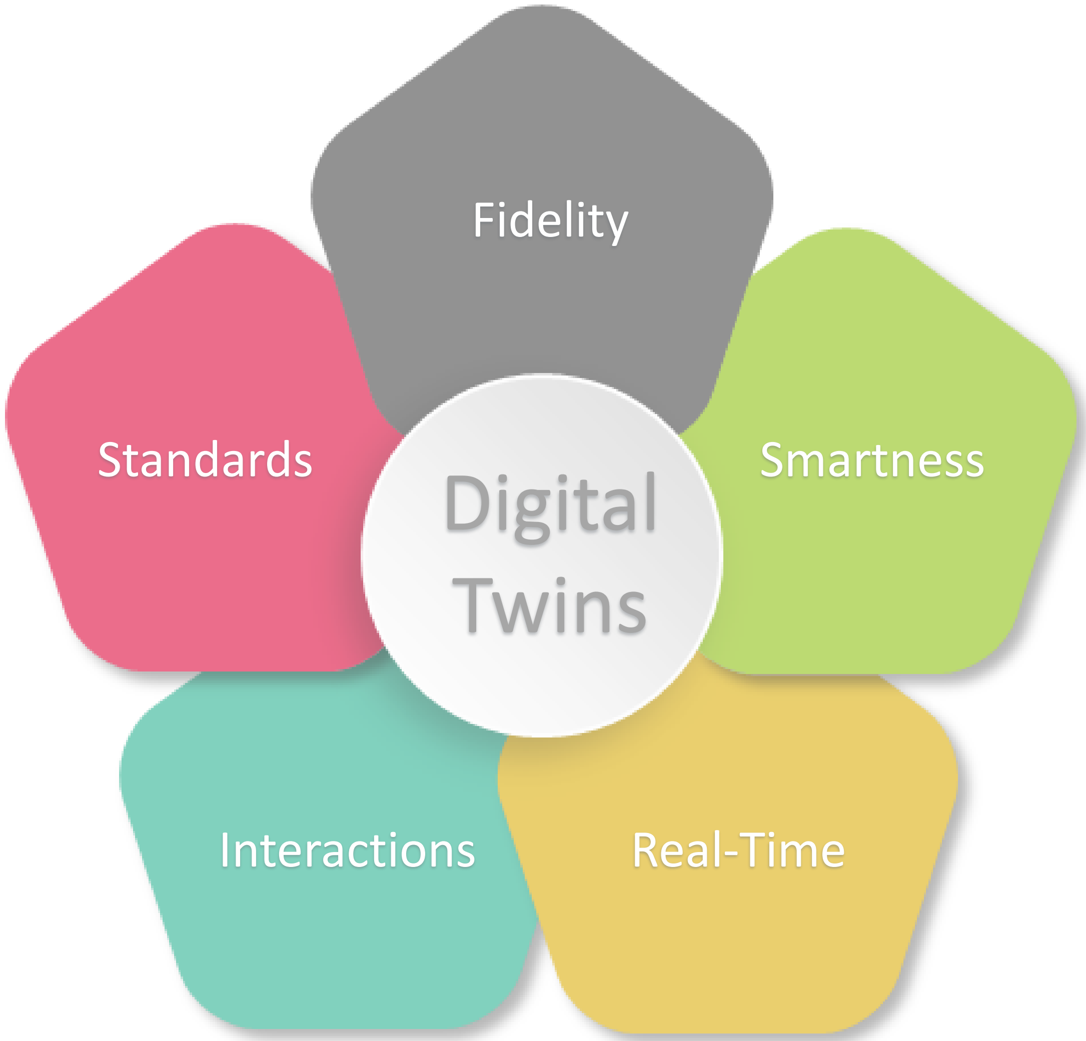


Fig 5: a proposed framework for the qualification of a digital twin for maintenance models.

Fidelity

Fidelity assessment matrix		No. of input parameters		
		Few	Most	All*
Output accuracy	Not precise	Very low	Low	Low
	Precise only for specific working conditions	Low	Low	Moderate
	Precise for normal working conditions	Low	Moderate	Moderate
	Precise for all working conditions	Moderate	Moderate	High

L0: Very low
L1: Low
L2: Moderate
L3: High

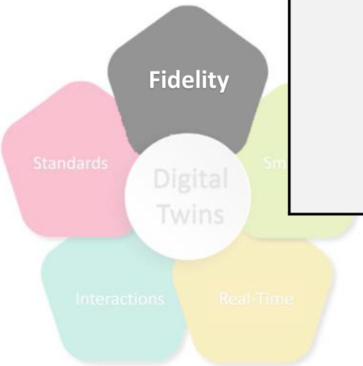


Table 1: fidelity assessment matrix for digital twins
*: all parameters are relevant and can be captured.

Smartness

- L0 – descriptive
- L1 – diagnostic
- L2 – predictive
- L3 – decision-making

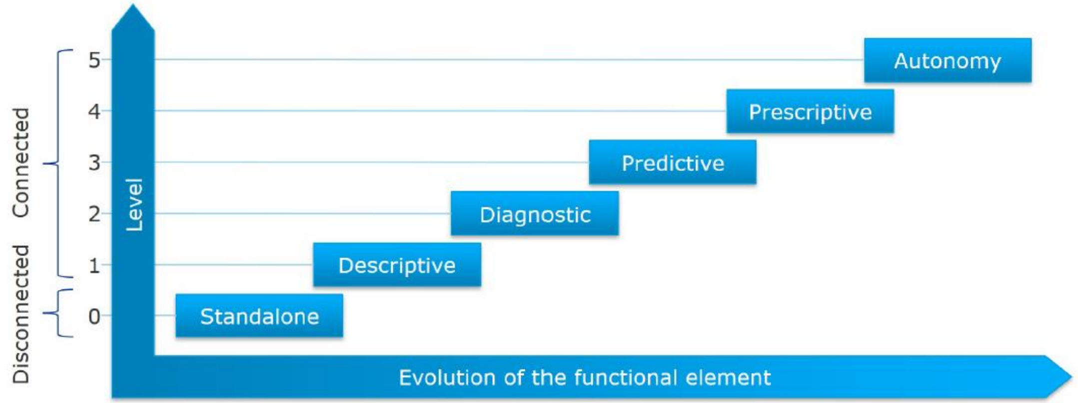
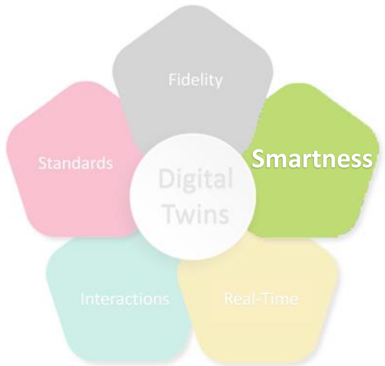


Fig 3: The capability level for digital twins
Altamiranda and Colina (2019) (OCEANS 2019-Marseille*)*
Cited by DNV in RP-A204 2020.



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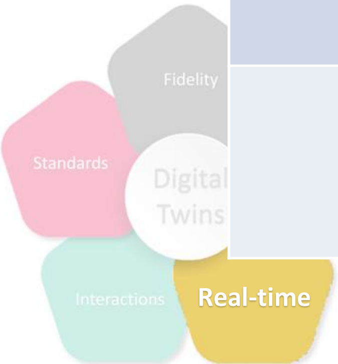
Real-time

Levels	Range	Examples		
		Time unit	**S**	$\ln(t)$
L0	$\ln(t) \geq 15$	Year,	$3.15 * 10^7$,	17.27
L1	$10 \leq \ln(t) < 15$	Month, Week, Day,	$2.59 * 10^6$, $6.05 * 10^5$, $8.64 * 10^4$,	14.77 13.31 11.37
L2	$0 \leq \ln(t) < 10$	Hour, Quarter, Minute, Second,	$3.6 * 10^3$, 900, 60, 1,	8.19 6.80 4.09 0
L3	$\ln(t) < 0$	Millisecond, Microsecond, Nanosecond,	10^{-3}, 10^{-6}, 10^{-9},	-6.91 -13.81 -20.72



Interactions

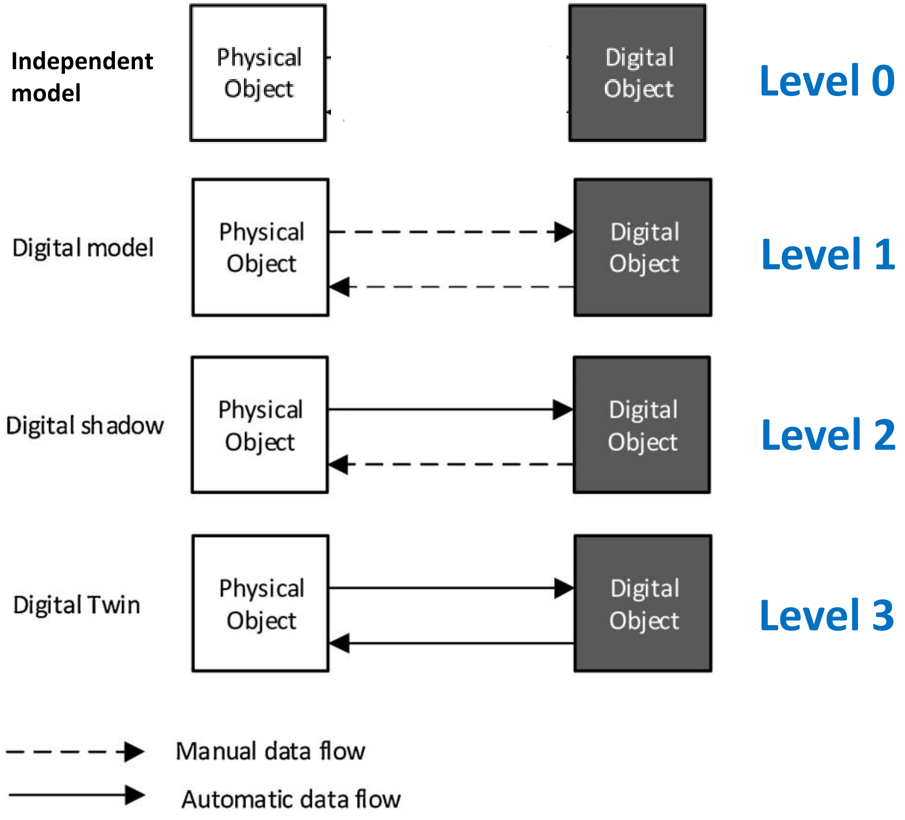
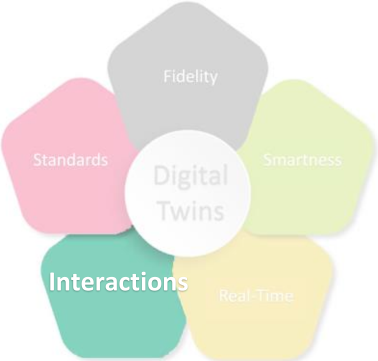


Fig 7.1: interaction level of digital twins



Standard

- Followed standards
- Enabled standards indicator

Table 2-1 DNV documents

Document code	Title
DNV-RP-0317	Assurance of sensor systems for digital twins
DNV-RP-0497	Data quality assessment framework
DNV-RP-0510	Framework for assurance of data-driven algorithms and models
DNV-RP-0513	Assurance of simulation models
DNV-RP-A203	Technology qualification
DNV-RP-G108	Cyber security in the oil and gas industry based on IEC 62443
DNV-RP-O101	Technical documentation for subsea projects
DNV-RU-SHIP Pt.6 Ch.11	Digital features

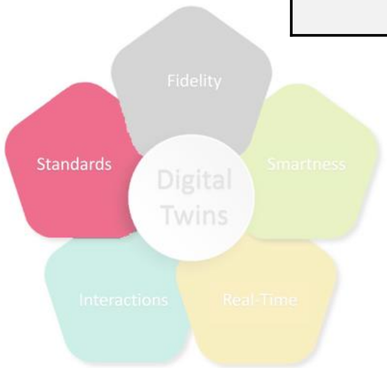
Table 2-2 External standard

Document code	Title
ANSI/ISA 101.01	Human-machine interfaces
API RP 17N	Recommended practice on subsea production system reliability, technical risk, and integrity management
IEC 61508 series	Functional safety of electrical/electronic/programmable electronic safety-related systems
IEC 62443 series	Industrial communication networks - Network and system security
IEC 81346-1	Industrial systems, installations and equipment and industrial products: Structuring principles and reference designation, Part 1: Basic rules
IEC 81346-2	Industrial systems, installations and equipment and industrial products: Structuring principles and reference designation, Part 2: Classification of objects and codes for classes
IEEE 1633	IEEE Recommended Practice on Software Reliability
ISO 14224	Petroleum, petrochemical and natural gas industries - Collection and exchange of reliability and maintenance data for equipment
ISO 15926 series	Industrial automation systems and integration-Integration of life-cycle data for process plants including oil and gas production facilities
ISO 8000	Data quality
ISO 8601	Data elements and interchange formats - Information interchange - Representation of dates and times
ISO/DIS 23247	Automation systems and integration - Digital Twin framework for manufacturing. Part 1 - 4: drafts published 2020
ISO/IEC 27001	Information technology - Security techniques - Information security management systems - Requirements
ISO/IEC/IEEE 12207	Systems and software engineering - Software life cycle processes

Standard

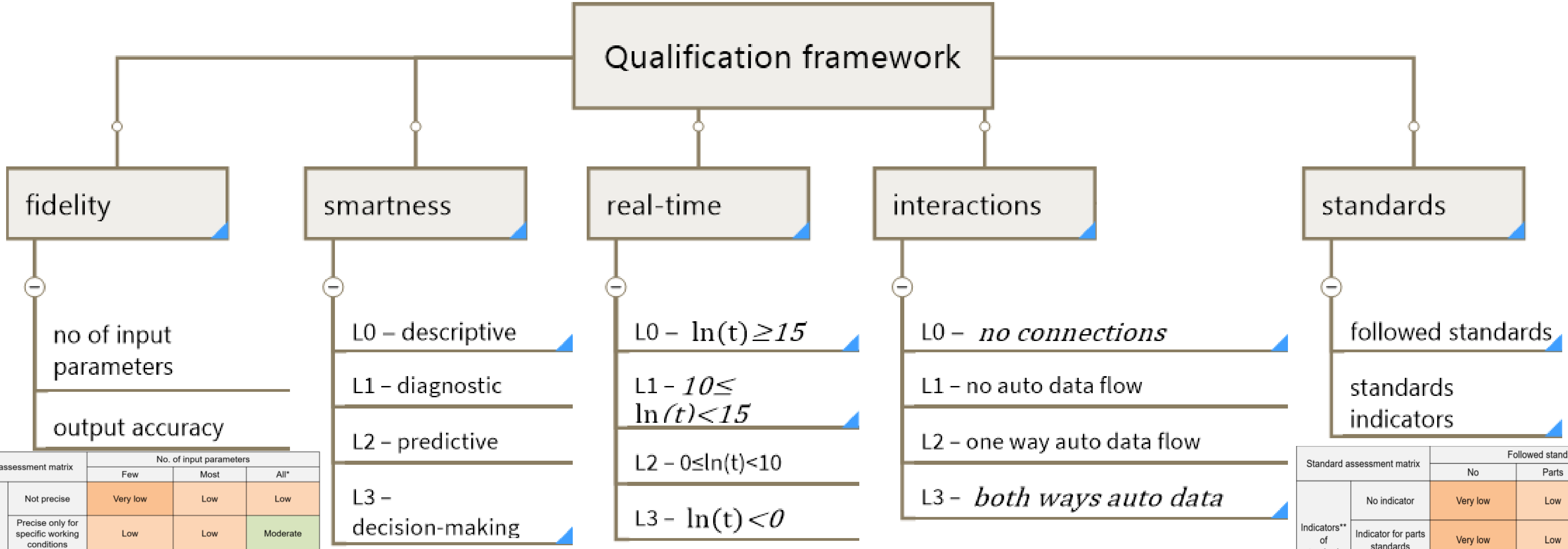
Standard assessment matrix		Followed standards		
		No	Parts	All*
Indicators** of standards	No indicator	Very low	Low	Moderate
	Indicator for parts standards	Very low	Low	Moderate
	Indicator for all standards	Very low	Moderate	High

L0: Very low
L1: Low
L2: Moderate
L3: High



* only relevant standards are considered.
** indicators of followed standards.

Summary of framework



Fidelity assessment matrix		No. of input parameters		
		Few	Most	All*
Output accuracy	Not precise	Very low	Low	Low
	Precise only for specific working conditions	Low	Low	Moderate
	Precise for normal working conditions	Low	Moderate	Moderate
	Precise for all working conditions	Moderate	Moderate	High

Standard assessment matrix		Followed standards		
		No	Parts	All*
Indicators** of standards	No indicator	Very low	Low	Moderate
	Indicator for parts standards	Very low	Low	Moderate
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Case study – digital twin model

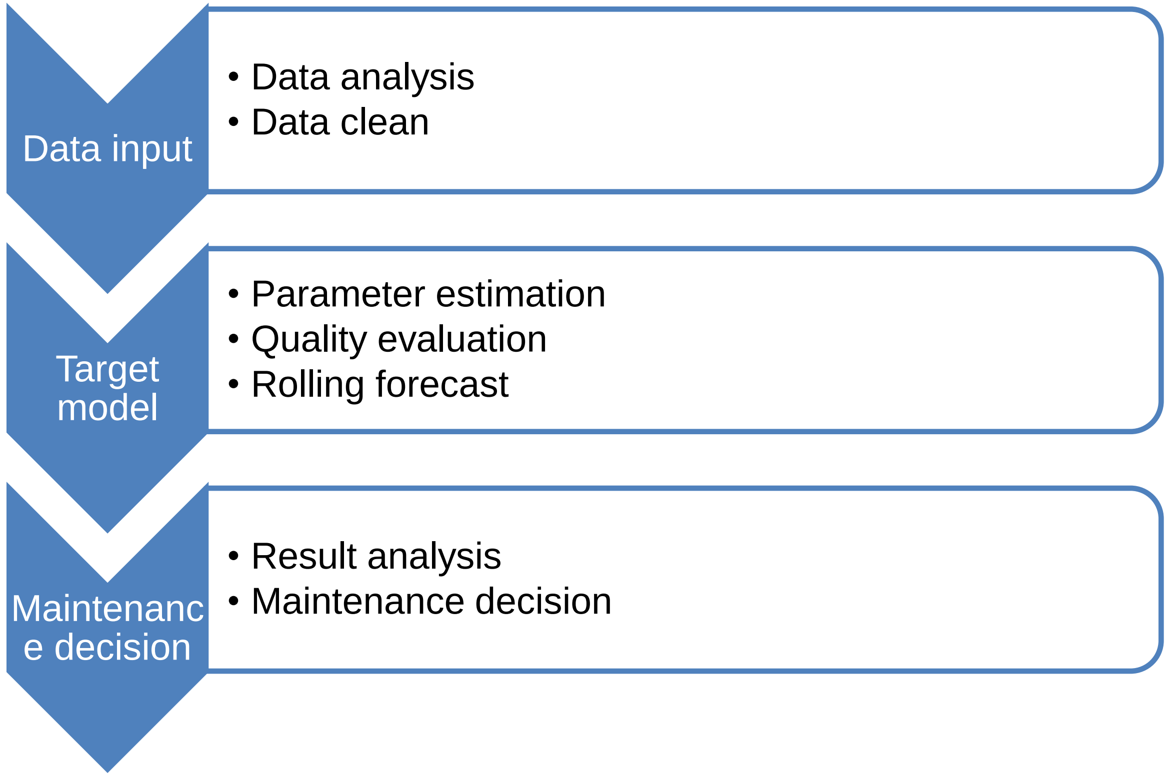


Fig 8: Model structure for Choke valves degradation predictions

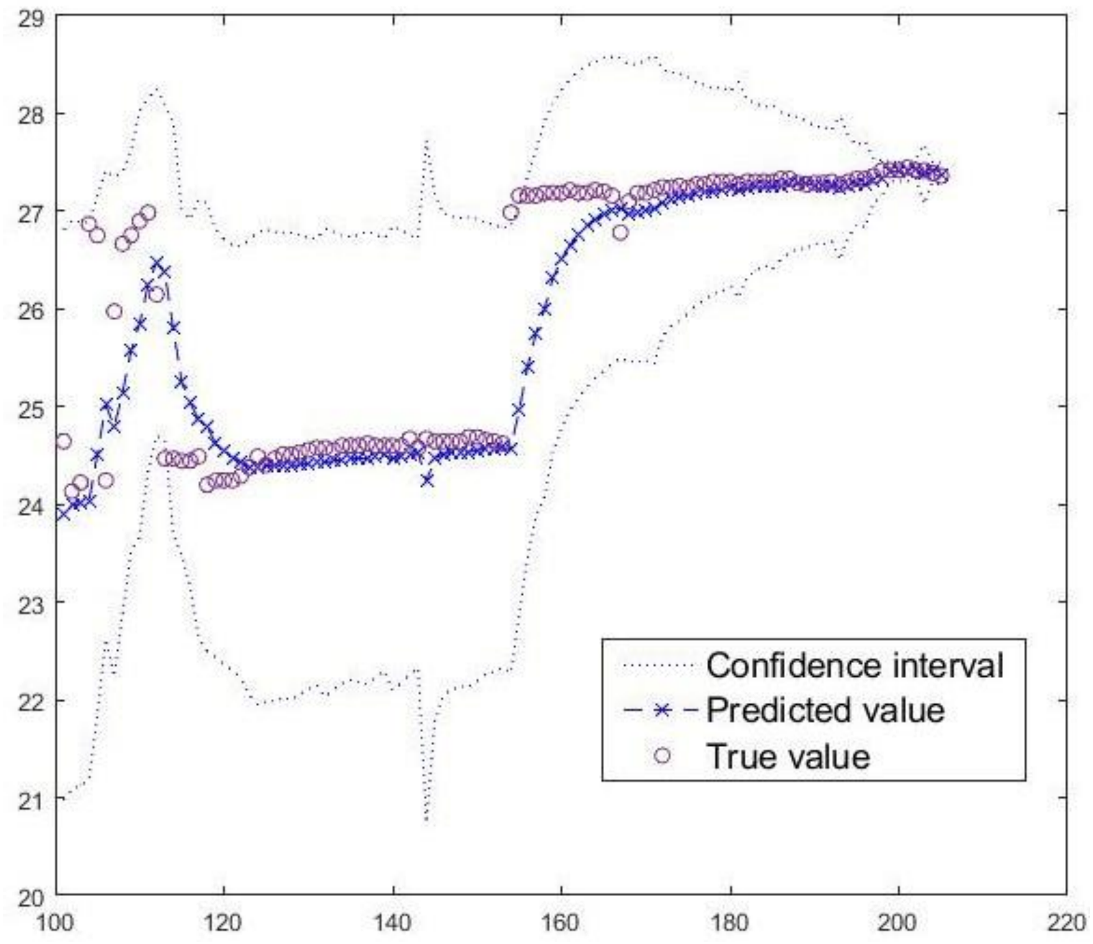


Fig 9: Output of the choke valve degradation predictions model

Case study – evaluation results

Item	Current level	Best practice
Fidelity	L2: moderate (normal working conditions/most parameters)	L3: high (all working conditions/all parameters)
Smartness	L0: descriptive	L2: predictive
Real-time	L1: $10 \leq \ln(t) < 15$ Eg: Day/week/month	L1:$10 \leq \ln(t) < 15$ Eg: Day/week/month
Interaction	L0: no connection	L2: 1 way auto data flow
Standards	L1: Low (parts standards/no indicator) DNV-RP-O501	L2: Moderate (all standards/all indicators) DNV-RP-O501 NORSOK Standards U-001 DNVGL-RP-A204 ISO 23247-1:202

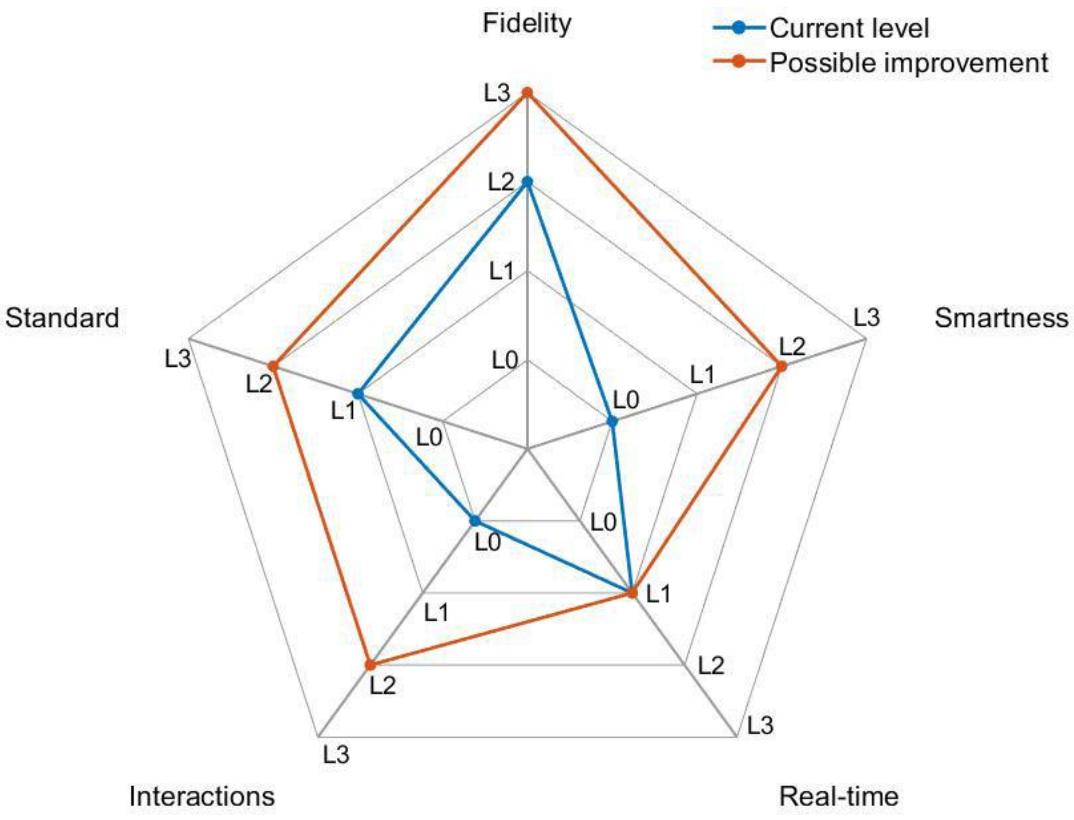


Fig 10: Evaluation results of case study according to proposed criteria

Case study – Corrective maintenance

Item	Minimum	Best practice
Fidelity	L1: moderate (specific working conditions)	L3: high (all working conditions/all parameters)
Smartness	L0: descriptive	L3: predictive
Real-time	L0: $\ln(t) \geq 15$ Eg: year	L2: $0 \leq \ln(t) < 10$ Eg: Hour/ Quarter/Minute / Second
Interaction	L0: no connection	L2: 1 way auto data flow
Standards	L0: Low (don't consider any standard)	L3: High (all standards/all indicators)

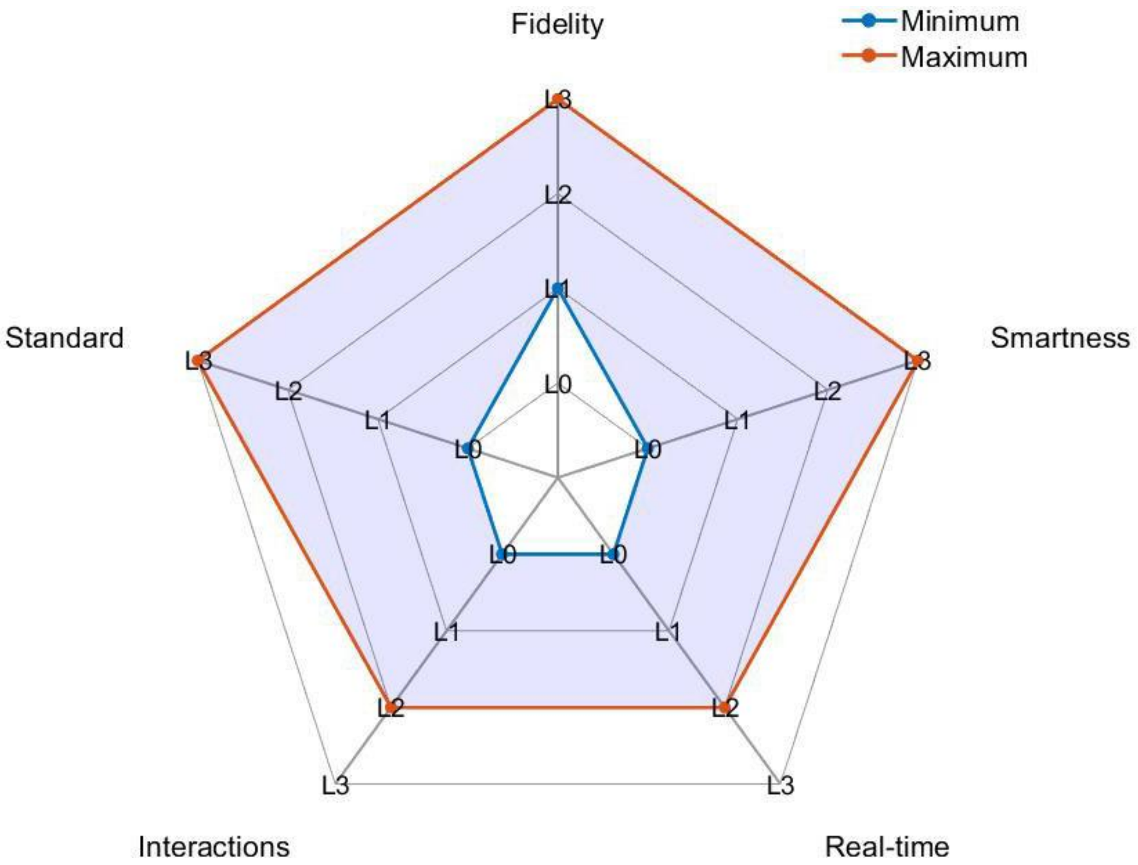


Fig 11: requirements for DTs used for corrective maintenance

Case study – Preventive maintenance

Item	Minimum	Best practice
Fidelity	L1: Moderate (specific working conditions)	L3: High (all working conditions/all parameters)
Smartness	L0: descriptive	L3: predictive
Real-time	L0: $\ln(t) \geq 15$ Eg: year	L1:$10 \leq \ln(t) < 15$ Eg: Day/week/month
Interaction	L0: no connection	L2: 1 way auto data flow
Standards	L0: Low (don't consider any standard)	L3: High (all standards/all indicators)

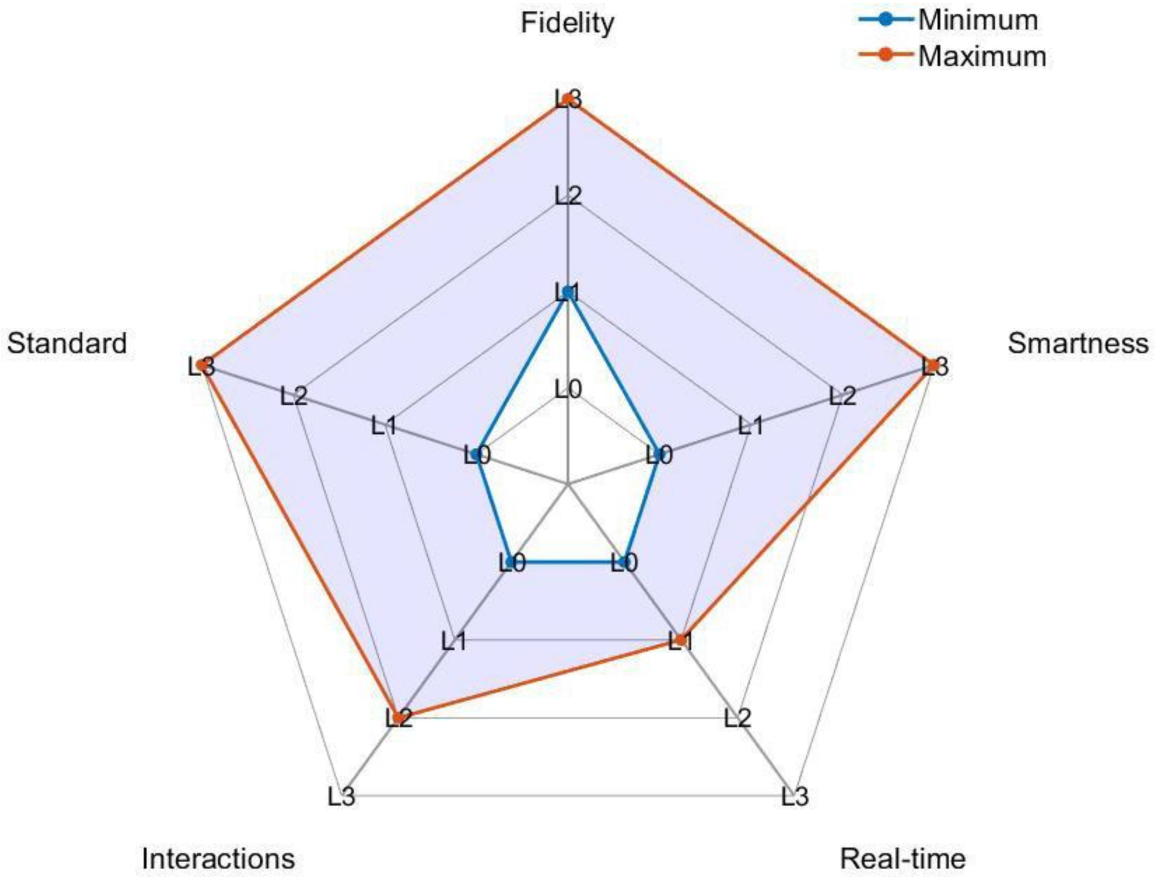


Fig 11: requirements for DTs used for Preventive maintenance

Case study – condition-based maintenance

Item	Minimum	Best practice
Fidelity	L1: Moderate (specific working conditions)	L3: High (all working conditions/all parameters)
Smartness	L1: diagnostic	L3: predictive
Real-time	L0: $\ln(t) \geq 15$ Eg: year	L2: $0 \leq \ln(t) < 10$ Eg: Hour/ Quarter/Minute / Second
Interaction	L1: manual data flow	L2: 1 way auto data flow
Standards	L0: Low (don't consider any standard)	L3: High (all standards/all indicators)

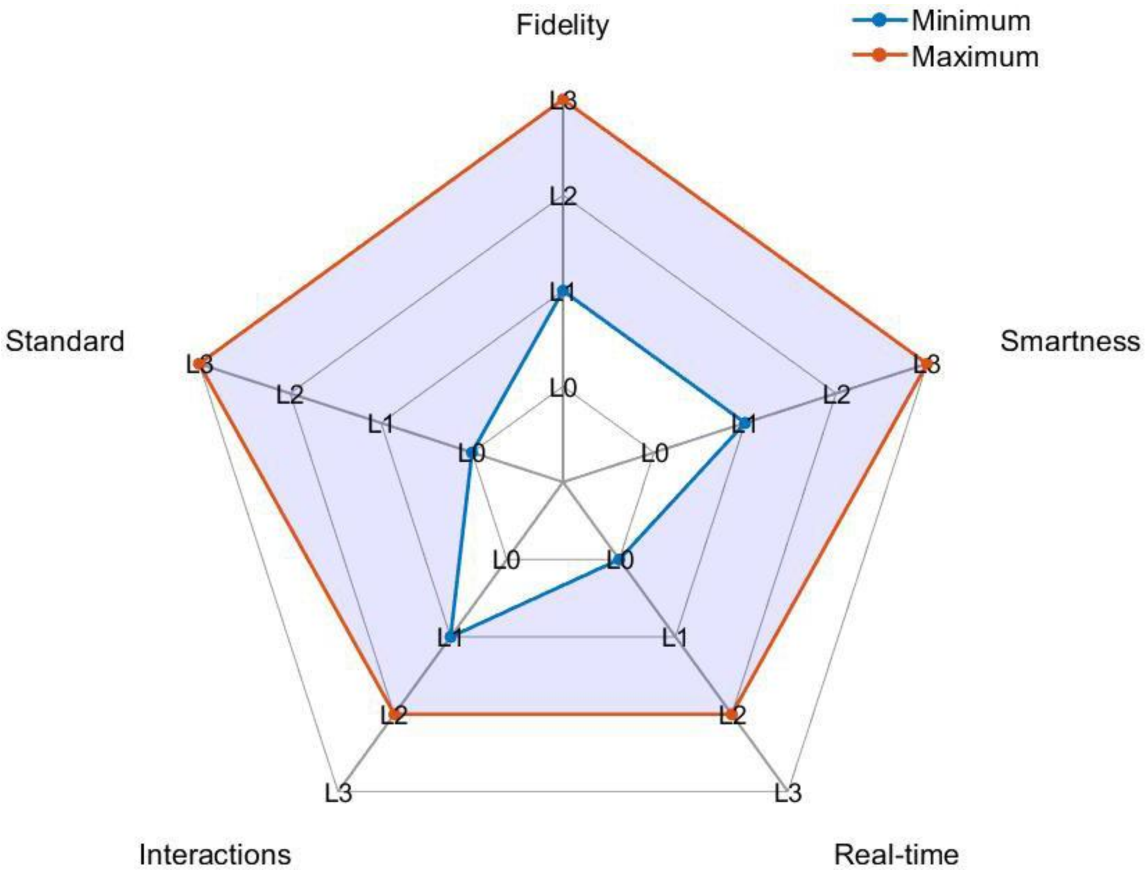


Fig 11: requirements for DTs used for condition-based maintenance

Case study – Predictive maintenance

Item	Minimum	Best practice
Fidelity	L1: Moderate (specific working conditions)	L3: High (all working conditions/all parameters)
Smartness	L2: predictive	L3: predictive
Real-time	L0: $\ln(t) \geq 15$ Eg: year	L2: $0 \leq \ln(t) < 10$ Eg: Hour/ Quarter/Minute / Second
Interaction	L1: manual data flow	L2: 1 way auto data flow
Standards	L0: Low (don't consider any standard)	L3: High (all standards/all indicators)

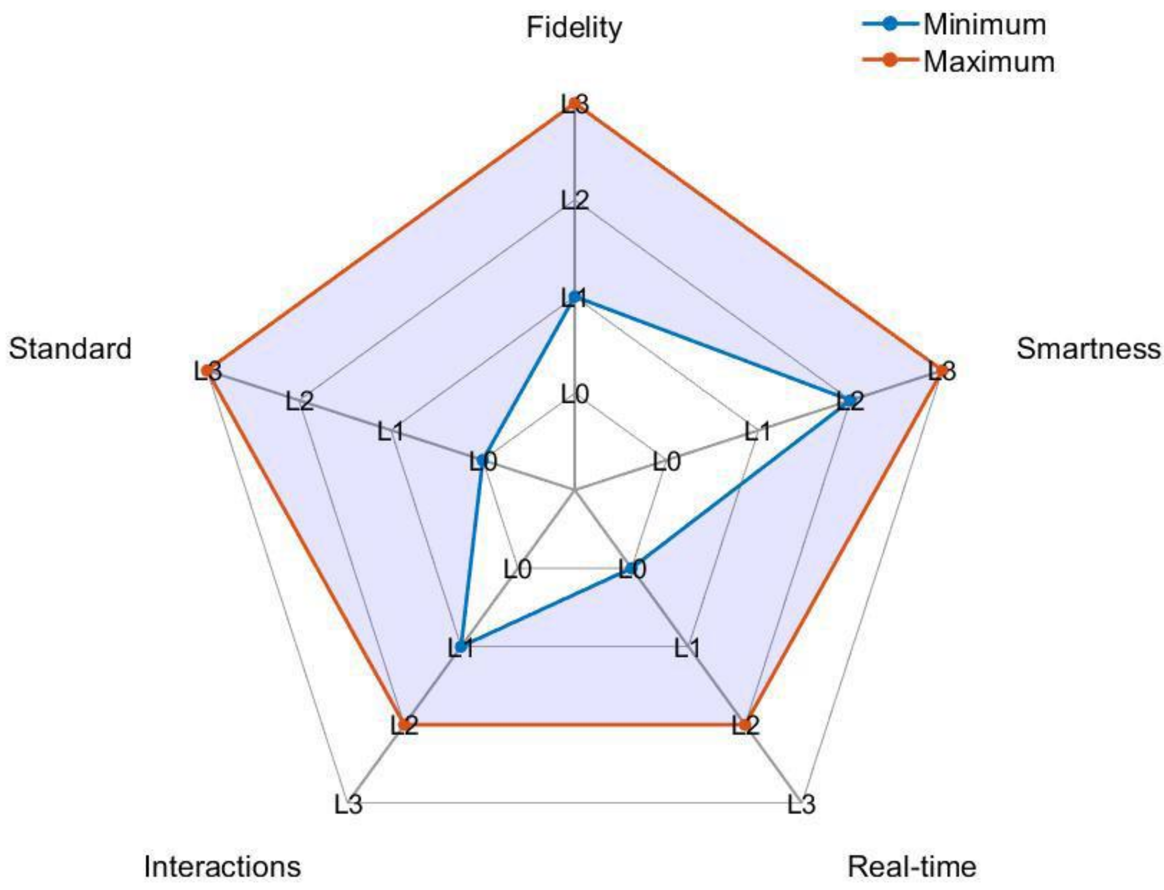
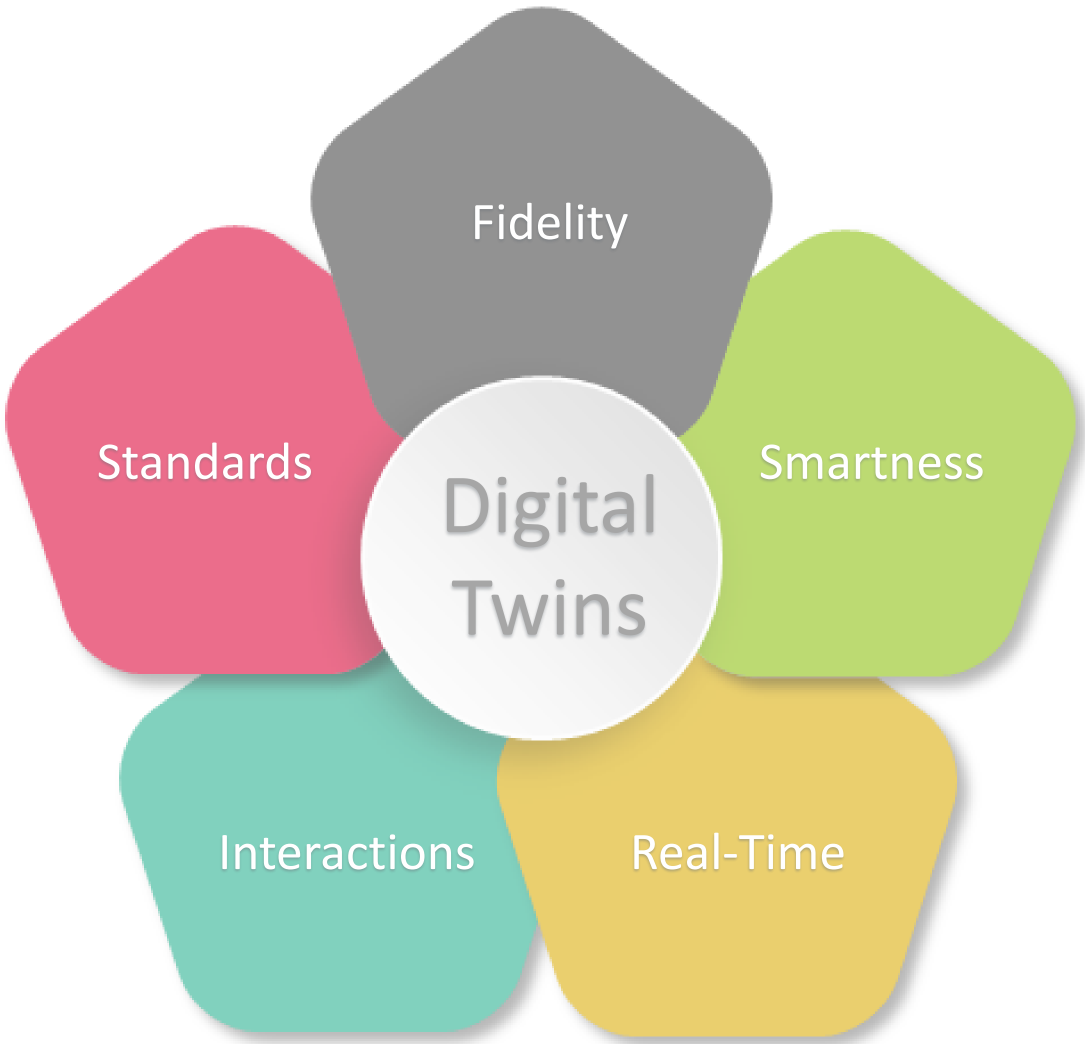


Fig 11: requirements for DTs used for Predictive maintenance

Conclusions

- Evaluation criteria for DTs
  - Fidelity
  - Smartness
  - Real-time
  - Interactions
  - Standards
- Qualification of DTs
- Improvement of DTs



Reference

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