Examining User Requirements for a Digital Twin Capability Supporting Naval Platform Management and Operations

TTCP Digital Twin Community of Interest
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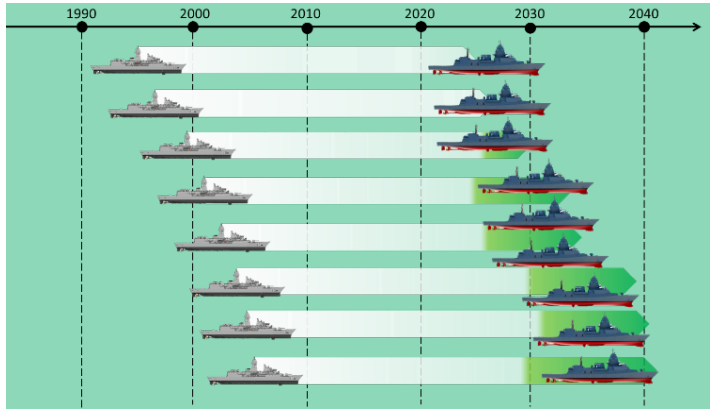
Overview

- Background
- Aim
- Method
- Analysis and results
- Conclusion

Terms ‘platform’ & ‘ship’ used interchangeably



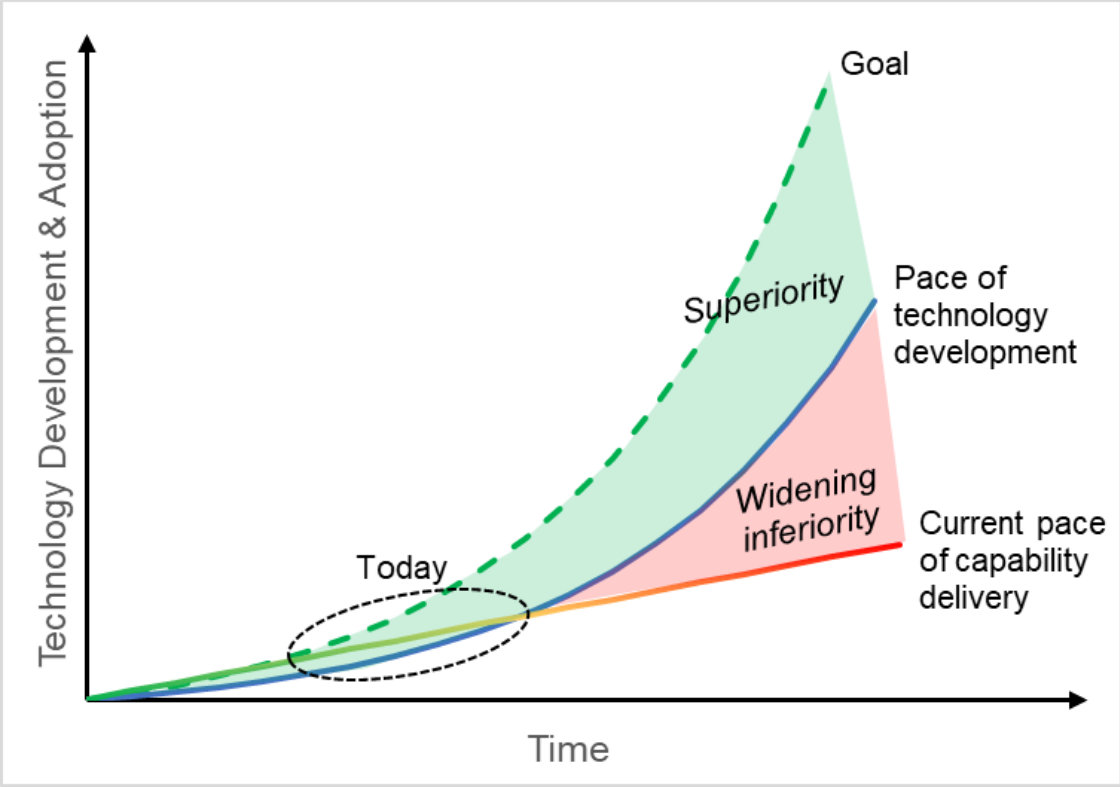
What is TTCP?

- The Technical Cooperation Program (TTCP) is a collaborative five-nation forum between UK, USA, Canada, Australia and New Zealand

- TTCP originated in agreements reached between the President of the United States and the Prime Minister of the United Kingdom in October 1957

- Recently, a Digital Twin Community of Interest was established with participation across the technical divisions

The Need for Digital Engineering Technology



Why

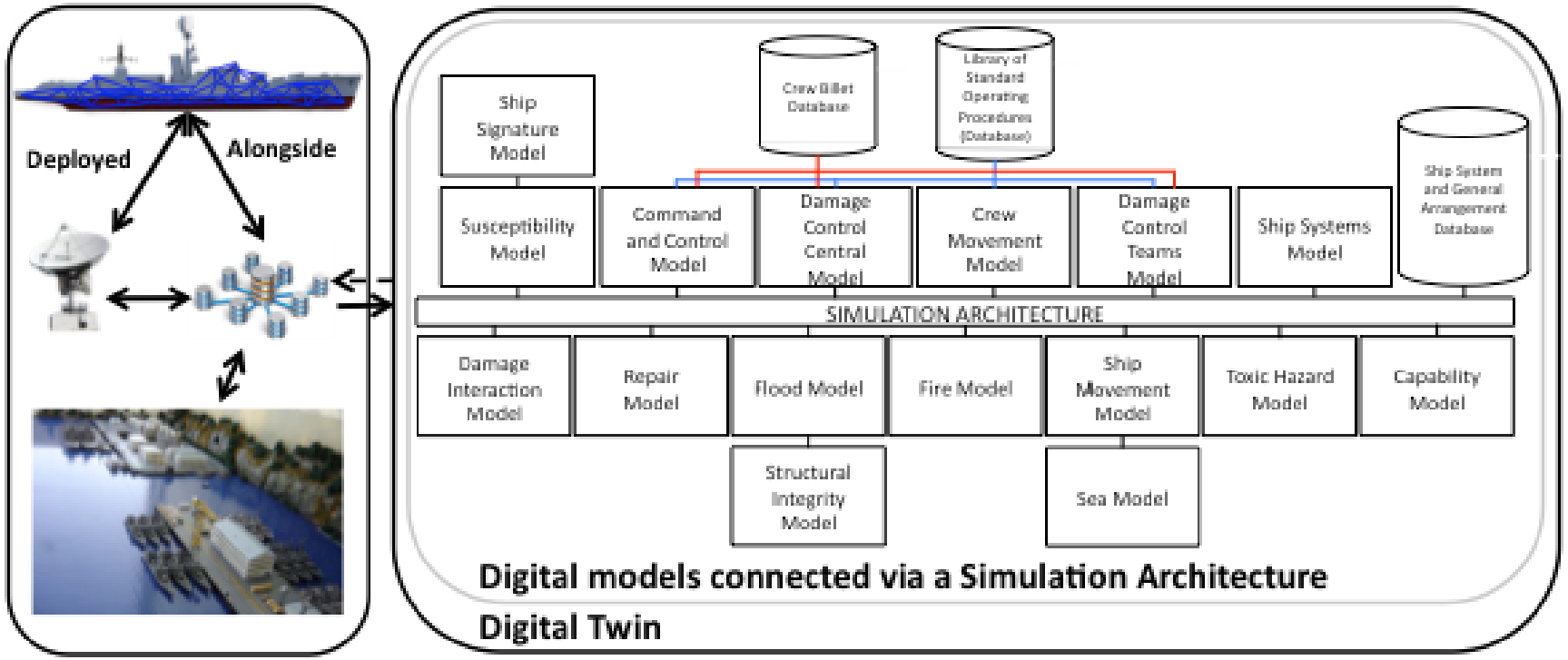
- Ship & fleet preparedness for faster response, longer duration on station and more flexibility in support of operations.
- Highly capable and versatile naval and maritime forces.
- Versatility and flexibility to contribute to a myriad of tasks required across the spectrum of conflict.

How

- Exploit technology advancements in digital engineering e.g. Digital Twin.
- The rapid spread of technology will support and challenge the requirement to maintain a regional capability edge in advanced warfighting and enabling capabilities.

The Digital Twin

A Digital Twin implements a virtual representation of a physical system by way of integrated multi-physics, multi-scale, probabilistic simulation and models of the as-built physical system utilising the best available sensor updates, fleet history, etc., to interact with and mirror the operation of the corresponding physical system.



Digital Twin in the Naval Environment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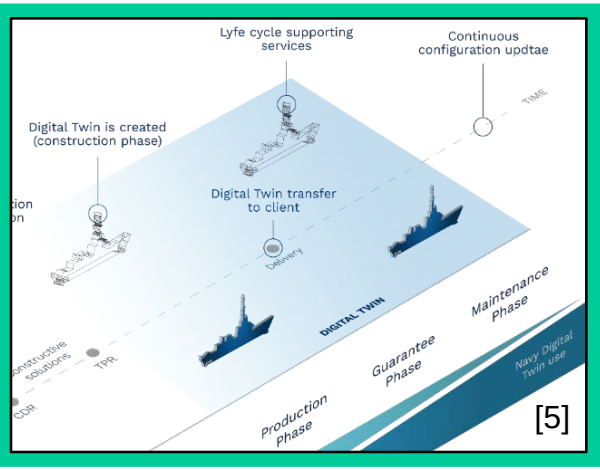

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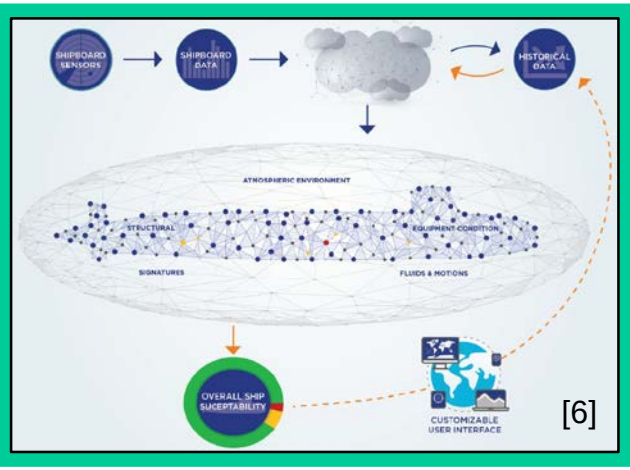

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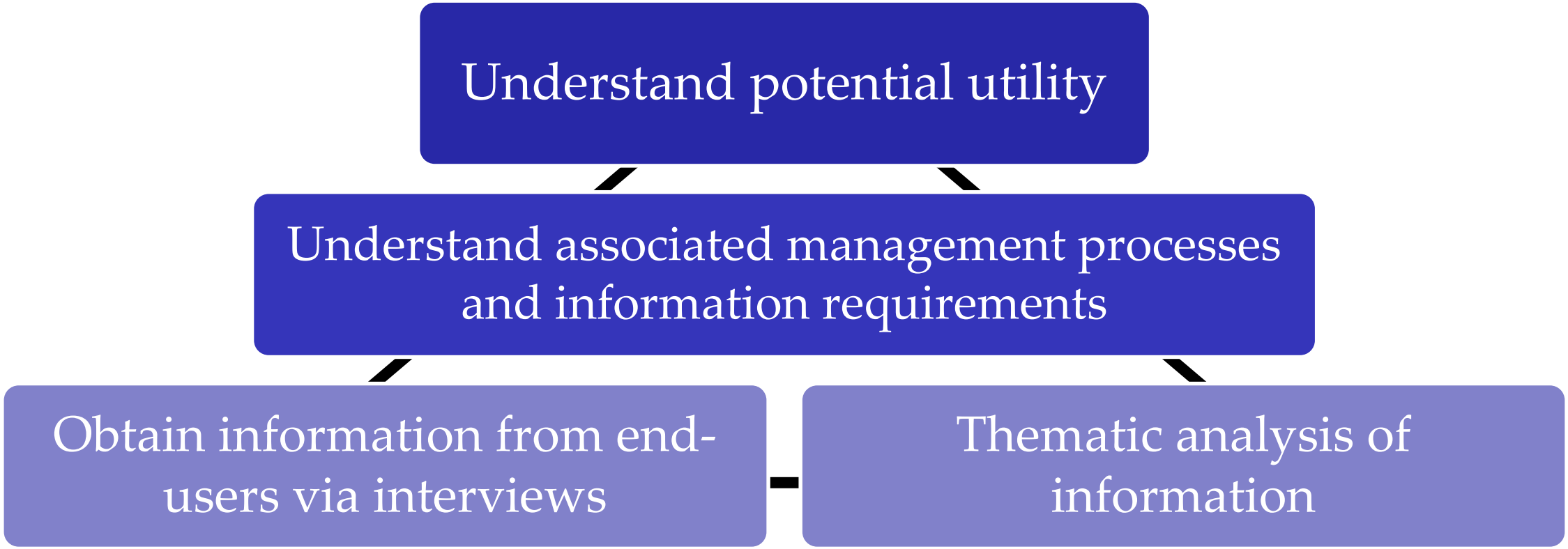
BAE Systems - Digital Twin of Canadian Surface Combatant	Navantia - Digital Twin Life Cycle	Office of Naval Research (ONR) – Navy Platform Digital Twin

- Used for visualisation, virtual prototyping, design across time zones, build, and delivery
- Link/fusion between physical and virtual environment of product
  - Data obtained over life-cycle can be analysed in virtual environment, e.g. in physics-based modelling
- Enables:
  - identification of corrective measures, and recommendations for preventive actions
  - prediction of optimum performance, and susceptibility of a naval ship
  - enhanced resource allocation, and in-situ decision-making

Digital Twin in Support of Naval Platform and Operations

Aim: to identify processes that could be enabled or enhanced by a Digital Twin



Study Method

Scenario Development

Collection of interview data

Processing of interview data

Journey Map development

- Identify gain and pain points (what does/does not work well)

Workshops

- Identification of concepts supporting the scenarios
- Ranking of concepts
- Pros and cons of concepts

Thematic Analysis

Study Method

Scenarios

1. Platform Selection and Readiness
   processes for selection and readiness of suitable ship for six-month task force deployment
2. Platform Class Life-of-Type Management
   management of fleet of mid-life ships for remaining years of service
3. Underway Management
   understand provision of operational guidance
4. Survivability
   decision-making during damage control and recovery of a ship after a damage event

Semi-Structured Interviews

Scripted questions with allowance for follow-up questions (e.g. to seek clarification):

i. Demographics
   e.g. *How long have you been in the navy?*

ii. Role identification
   e.g. *With respect to your job role, what procedures would you change to make it easier or faster?*

iii. Decision-making
   e.g. *What is the greatest source of uncertainty that affects your decision-making?*

iv. Information requirements
   e.g. What information, not normally available to you, might help you make a decision or make a decision quicker?

Thematic Analysis

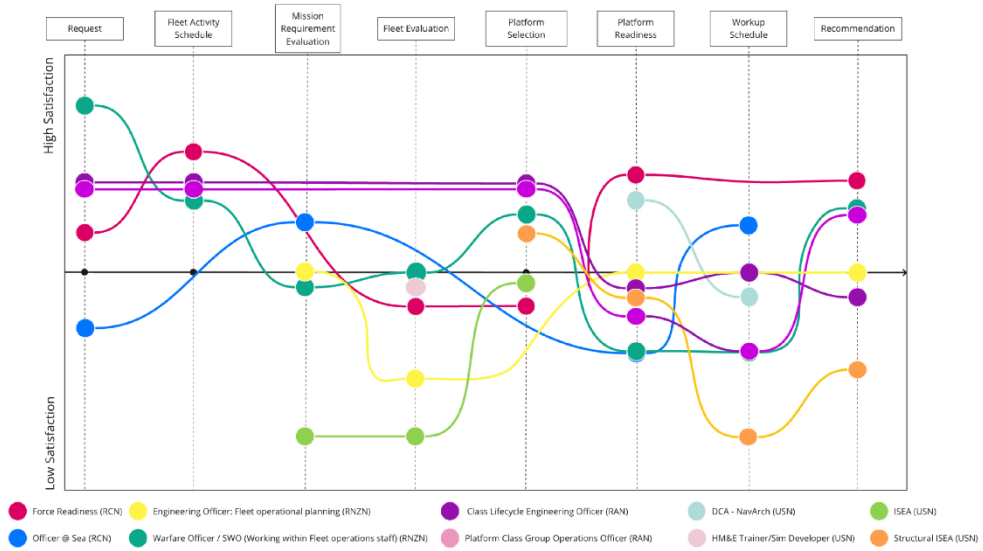
- Allows identification of themes, or patterns of meaning, from raw data
- Can inform key features and requirements of a future technology, product, process etc

Deductive coding (derived from theoretical framework)

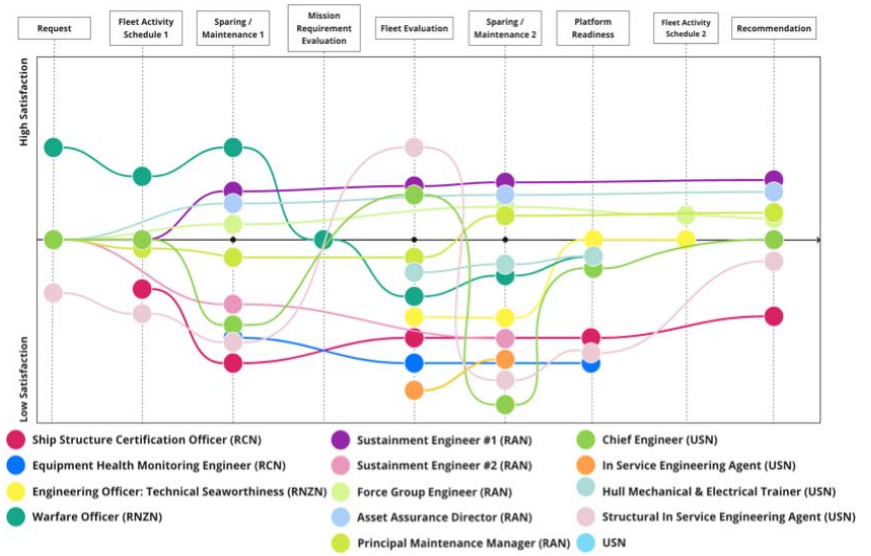
Inductive coding (themes emerge from interviews)

- Inductive analysis via workshops and mathematical analysis

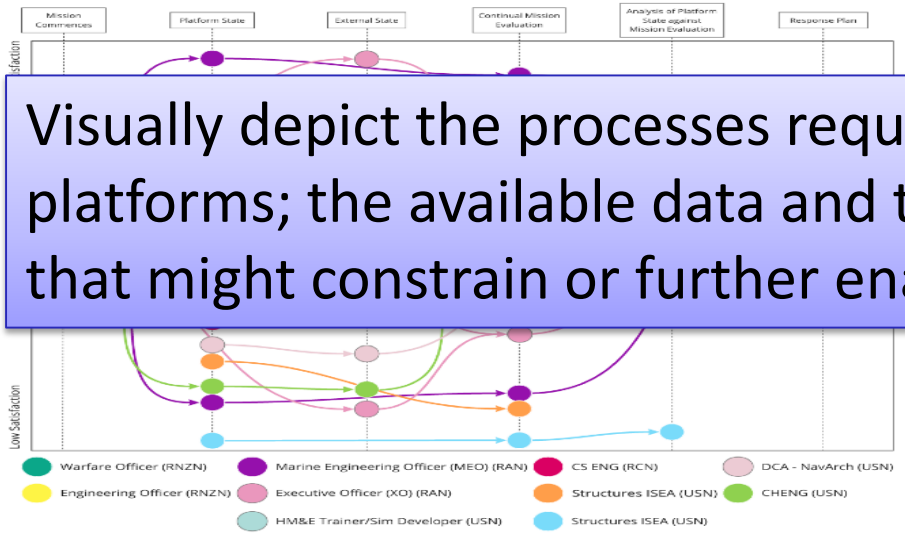
Journey Maps



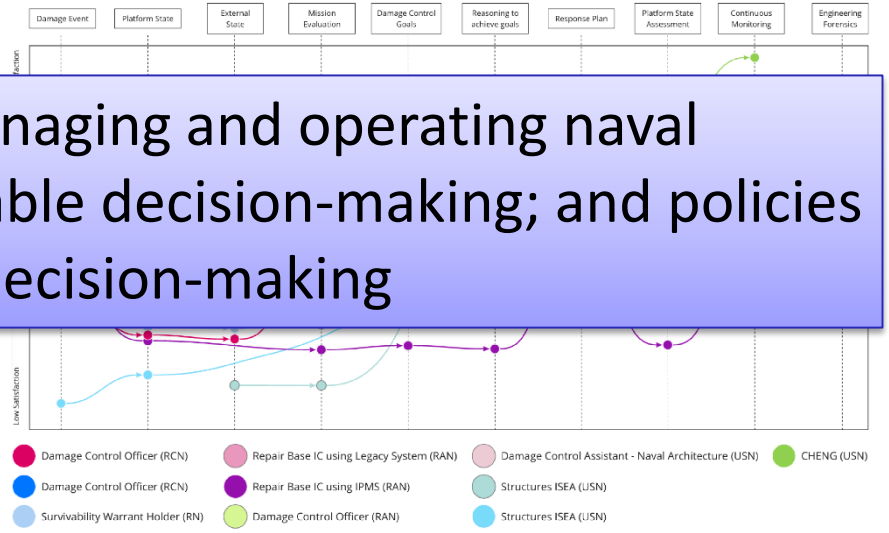
Scenario 1 – Platform Selection and Readiness



Scenario 2 – Platform Class Life-of-Type Management



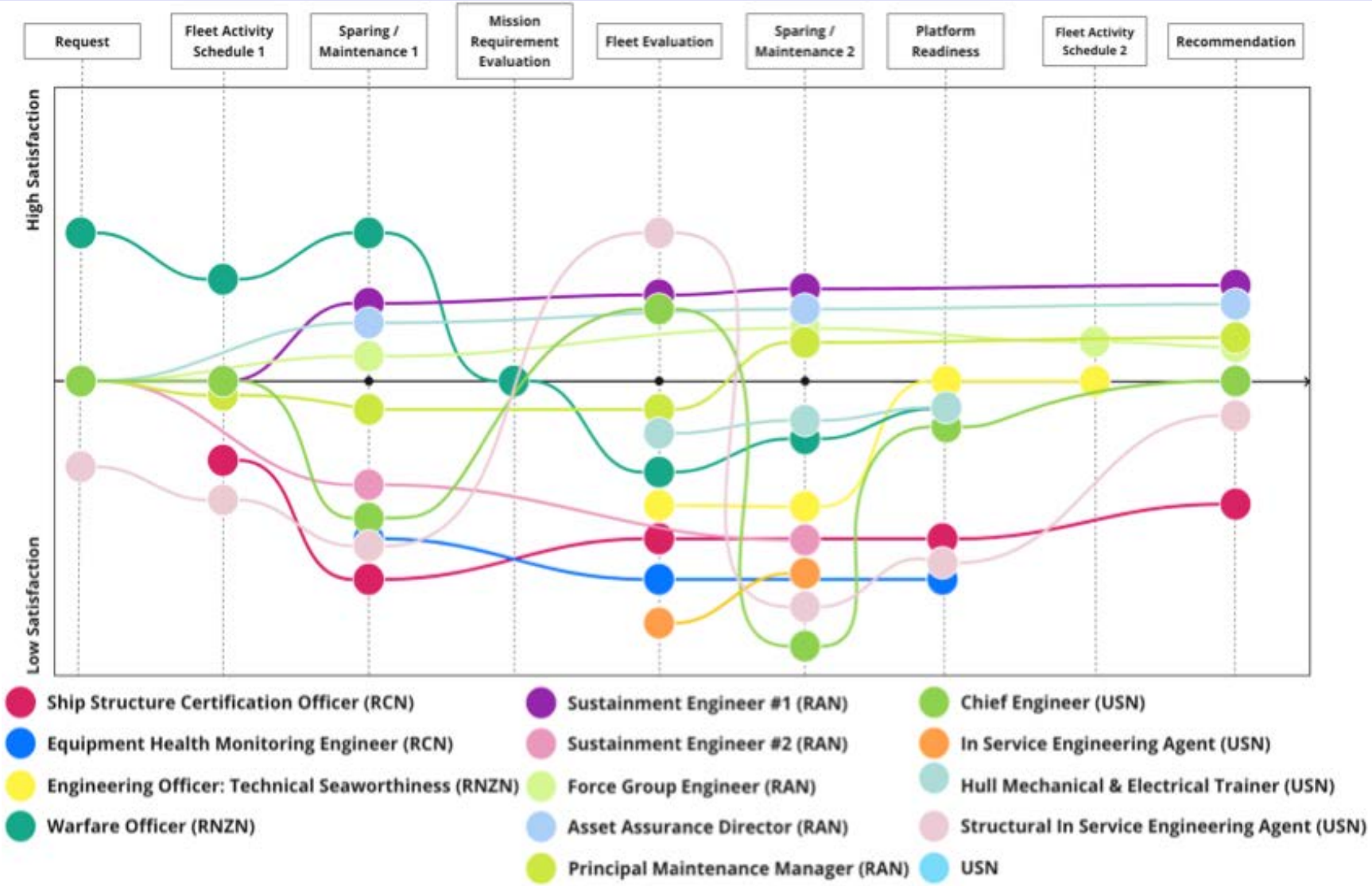
Scenario 3 – Underway Management



Scenario 4 – Survivability

Visually depict the processes required for managing and operating naval platforms; the available data and tools to enable decision-making; and policies that might constrain or further enable their decision-making

Journey Map *Scenario 2 – Platform Class Life-of-Type Management*



Workshop Overview

- present scenario description
- definition of the Digital Twin concept (Prof. Matt Collette video: https://www.youtube.com/watch?v=emmzycj_rf0)
- Breakout Session 1: Journey Map discussion, validation, and identification of domains suited and not suited to Digital Twin application
- Journey Map Share Out to discuss key point identified during Breakout Session 1
- Breakout Session 2: identification of concept applications supporting the scenario
- cohort discussion of concepts identified during Breakout Session 2
- cohort vote to identify top three concepts (voting criteria: most feasible; and most impactful)

- Breakout Session 3: teams identify advantages/disadvantages for their respective concept making the case: each team champions the concept to which they were assigned
- cohort vote to identify top two concepts (voting criteria: most feasible; and most impactful)

Workshops – End User Understanding for Application of Digital Twin

What a Digital Twin needs to address

- method of data collection (automation versus manually entered);
- connectivity between data sources, sensors, systems, models;
- data validation and verification; and
- trust and uncertainty in decision-making
- legacy systems and the fleet-in-being
- integration of the Digital Twin into current procedures
- deployment aboard platforms

Applications for which a Digital Twin might not be suitable

- when there is over-reliance on Digital Twin output for decision-making without physical verification
- cost-benefit of implementing the Digital Twin
- inability to validate/verify the data and outputs
- when data aggregation becomes a security risk
- quantifying the state of the crew

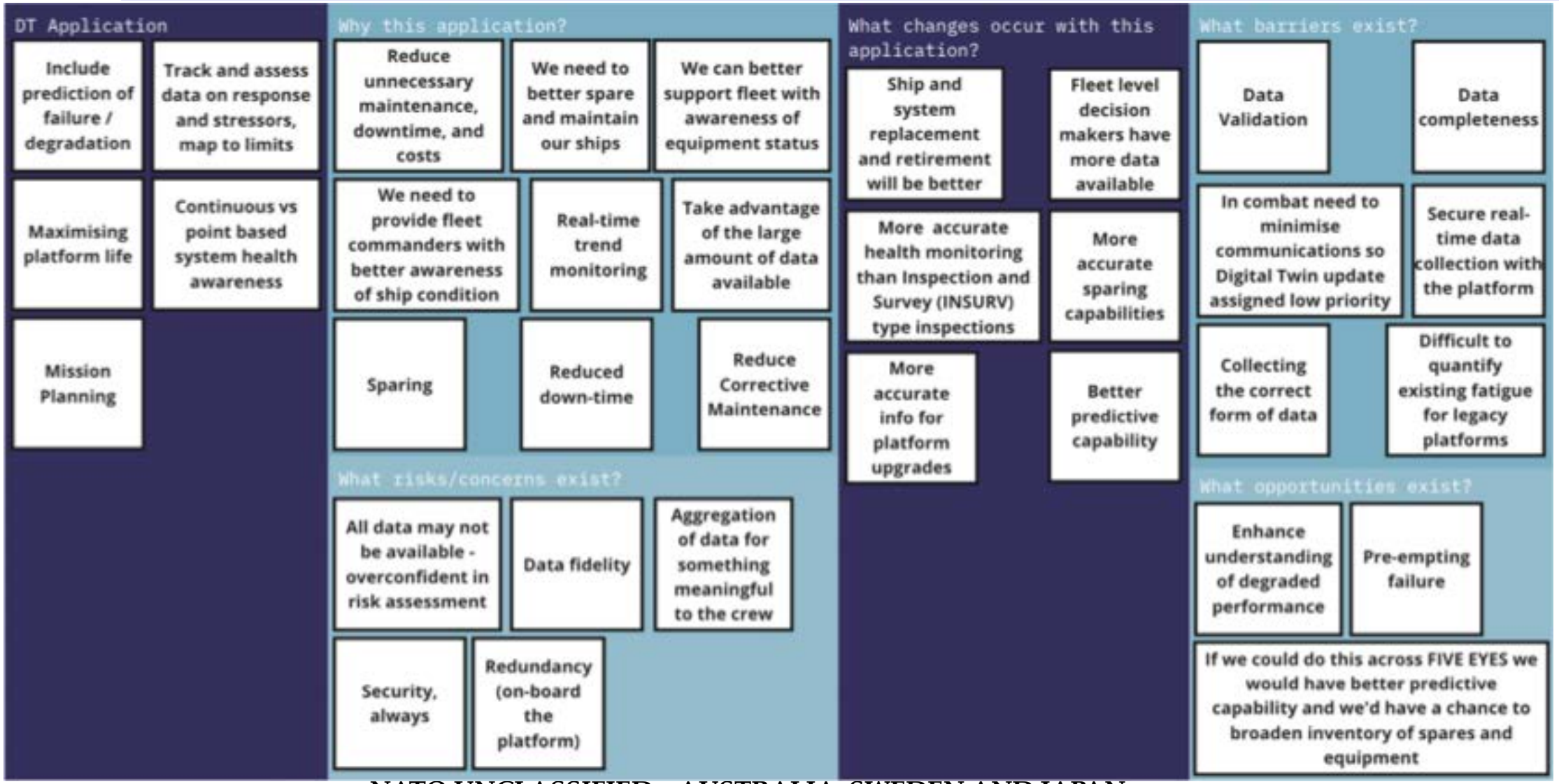
Applications for which a Digital Twin might be suitable

- master data repository
- quantifying platform health
- risk analysis and remediation
- defect forecasting
- fleet evaluation

Affinity Clustering for Theme Identification

Scenario 1 *Platform Selection and Readiness*	*Scenario 2* *Platform Class Life-of-Type Management*	*Scenario 3* *Underway Management*	*Scenario 4* *Survivability*
• Quantifying Platform Health • Forecasting Platform State and Defect Prediction • Master Data Repository • Monitoring Crew Readiness • Risk Management	• Condition Monitoring/Health and Usage Monitoring • Defect Trend Analysis • Sparing and Inventory Analysis • Platform Capability Management • Fleet Evaluation • Maintenance Regime Change / Optimisation / Prioritisation • Risk Evaluation and Verification • Performance Verification • Modernisation / Upgrade Planning • Fatigue Life Tracking • Disposal Planning	• Condition Monitoring/Health and Usage Monitoring (HUM) • Defect Trend Analysis • Sparing and Inventory Analysis • Platform Capability Management • Fleet Evaluation • Maintenance Regime Change / Optimisation / Prioritisation • Risk Evaluation and Verification • Performance Verification • Modernisation / Upgrade Planning • Fatigue Life Tracking • Disposal Planning	• Information synthesis • Situation Awareness • System performance prediction • Ensuring a shared mental model • Risk predication and prioritization • Connectivity with shore bases • Resilience of the Digital Twin (stand-alone aboard the platform) • GUI • Prioritisation of human life • Training • Assimilation with vulnerability assessment to forecast damage • Containment boundaries • Forensic analysis

Making the Case *Condition Monitoring / HUM*



Workshops – Identification of Important Themes

Scenario 1 *Platform Selection and Readiness*	*Scenario 2* *Platform Class Life-of-Type Management*	*Scenario 3* *Underway Management*	*Scenario 4* *Survivability*

• Most impact
  • *Forecasting Platform State and Defect Prediction*
• Most feasible
  • *Quantifying Platform Health*
	• Most impact
	  • *Condition Monitoring/HUM*
	• Most feasible
	  • *Fatigue Life Tracking*
		• Most impact
		  • *Rapid Evaluation of Alternatives for Mission Planning*
		• Most feasible
		  • *HUM*
			• Most impact
			  • *Situation Awareness of Platform and System State*
			• Most feasible
			  • *Connectivity to Shore Bases*

Thematic Analysis: Processing of Interview Data (aka the Corpus)

- Qualitative data analysis to identify patterned meaning/themes in corpus.

- Corpus pre-processed to de-identify interviewees and ensure extraction of meaningful words and phrases, including:
  - sanitisation of data e.g. simplifying names of directorates and groups to 'office'
  - removal of punctuation and words such as 'a', 'and', and 'the'
  - normalising words to their singular form, and acronyms where appropriate
  - reducing number of synonyms e.g. budget, cost

Thematic Analysis: Coding of Significant Words and Phrases

Shore-based

Sea-based

dc = Damage Control

Word cloud

2-word-phrase cloud

- Significance determined by statistic 'term frequency – inverse document frequency' (tf-idf)
  - Calculates frequency of a word/phrase appearing in a dataset, weighted by number of interview records in given dataset containing that word/phrase

Theme Identification

Shore-based			Sea-based		
Code	**Theme**	**Key Features**	**Code**	**Theme**	**Key Features**
Seaworthiness Risk Assessment Risk Deployment Maintenance	*Ability to Deploy Platform*	• quantitative seaworthiness assessment • policy manuals (tracking & connectivity)	Command Risk Capability Communication	*Maintain Mission Capability*	• capability impact statements • system monitoring, requirements & reconfiguration • defect tracking, risk identification & acquittal
Upkeep Cycle Usage Maintenance Availability Contractor Risk Defect	*Provision of Maintenance*	• predicting & planning maintenance requirements against the state of the platform • accessing detailed technical data for equipment • balance between platform maintenance & platform upgrades	DC DC Board DC Huddle Repair Base IPMS Fire Command Priority Communication	*Platform Survivability*	• situation awareness & assessment • identification & restoration of capability baseline • explainable decision-making • response planning & prioritisation
People	*Experience of People*	• tracking & provision of training • workforce management.	People Training Management Communication	*People at Sea*	• tracking of training, skills, experience requirements • personnel deficiency reports & filling of vacancies

Thematic Analysis: Theme Analysis

- A common thread was 'connectivity and continuity'
  - Facilitates audit tracking and justifiable decision-making
    - Connecting disparate policy documents to ensure robust process and clear Capability Impact Statement
    - Data amalgamation, including data validity and providence → important for planning and risk assessments
  - On-board ship, data contributes to situation awareness e.g. data needed during Damage Control
  - For shore-based ship management, data represents state of ship and systems
    - Used in maintenance planning, parts sparing, and monitoring of remaining life of hull & other systems

Thematic Analysis: Theme Analysis (cont.)

- 2 themes related to people identified in corpus
  - Whilst leadership and interpersonal skills are important, they cannot be enabled by a Digital Twin → not represented in themes
  - A Digital Twin can support management of people e.g. tracking of technical skills when filling personnel deficiency on-board ships
    - People gain experience through achievement of their job roles
    - Skills can enable people to adapt to new situations and ease transition into new job roles
    - Difficult to quantify personal experience as actionable information for use in a Digital Twin, but knowledge elucidation techniques are available

Converting Features to Functional Requirements

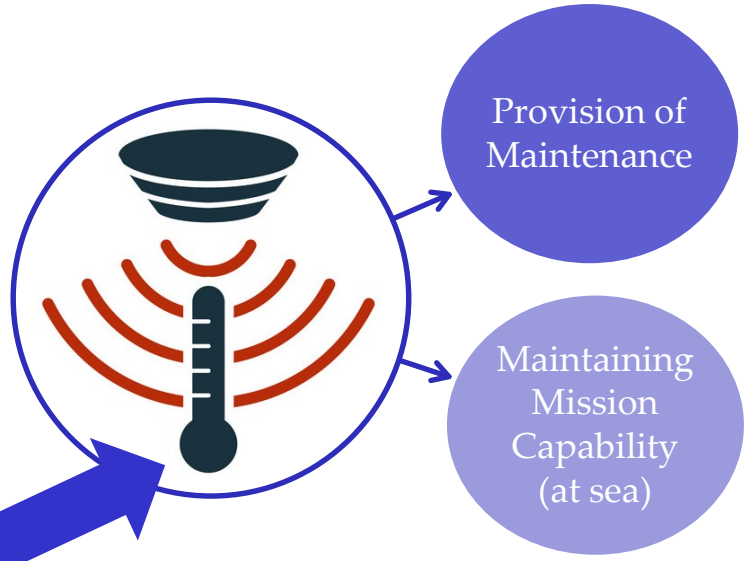
- Found overlaps in functional requirements e.g. 'data validation'
  1. 'data validation and completeness checking' (Ability to Deploy the Platform)
  2. 'data validation and trend monitoring' (Maintaining Mission Capability)
  3. 'data validation and integration' (Platform Survivability)
- Need to ensure key features convey functional requirements

To assess platform state, need to monitor platform systems and perform trend analysis

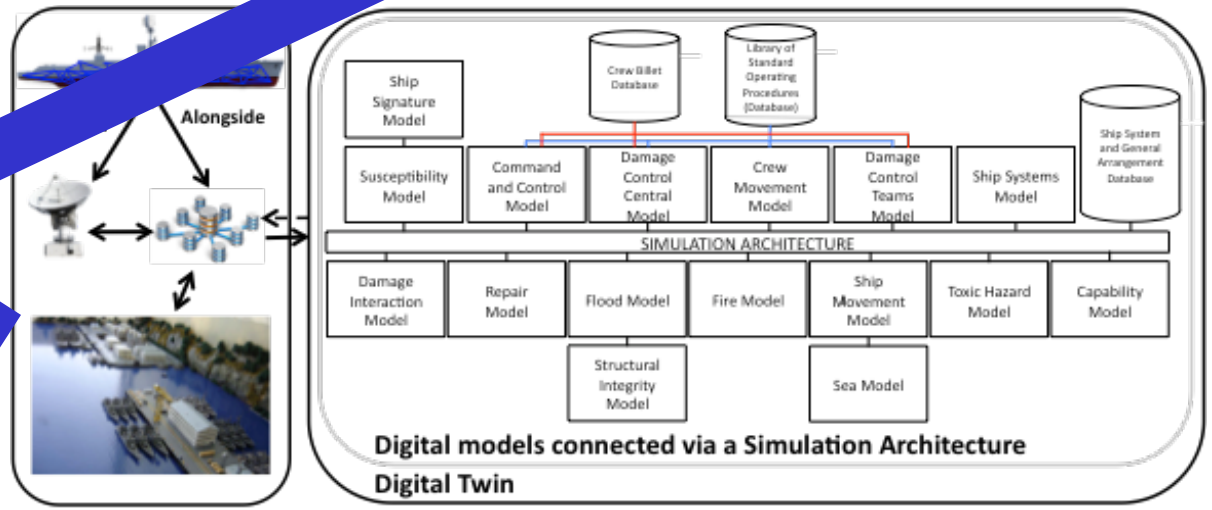
Key feature	'predicting and planning maintenance requirements against the state of the platform' (*Provision of Maintenance*)	
Requirements	Explicit	Implicit
	• 'ability to predict maintenance requirements' • 'ability to plan maintenance'	• 'ability to assess the platform state'

Implementation of a Digital Twin

- Identify the problem to be solved with the implementation of a digital engineering solution.
- Is a Digital Twin the optimal solution?
- Cost-benefit analysis of implementing the solution.
- Identification of off-the-shelf technologies satisfying the requirements.
- Is R&D of bespoke software and hardware tools required?



- Some techniques may suit several functional requirements
- May be implemented as specific modules



Implementation of a Digital Twin (cont.)

- Data is a key enabler → processing and validation of data are important
  - Data collection frequency, fidelity, and security are tied to modelling requirements
  - Can utilise edge (local) computing, but data processing more likely to occur closer to modelling & simulation architecture for legacy ships
- Need to assess computing infrastructure to enable requirements setting

Internal to ship, for decision-making at sea

Between ship and shore-based facilities, for shore-based support & ship management

Between shore-based facilities, to effectively use data from disparate sources

CONNECTIVITY

Conclusion

- A navy must be resilient and adaptable to evolving operational & threat environments and maintain ship & fleet readiness → exploit advancements in digital engineering …

Which processes could be enabled or enhanced by a Digital Twin of a physical system?

- Conducted thematic analysis of data collected during interviews with potential DT end-users, and derived functional requirements

'data validation and completeness checking'

Shore-based Themes	Sea-based Themes
1. Ability to Deploy Platform	4. Maintain Mission Capability
2. Provision of Maintenance	5. Platform Survivability
3. Experience of People	6. People at Sea

'data validation and trend monitoring'

- For a Digital Twin to enable/enhance processes within a specific application, need to:
  - Respect importance of data (processing, validation and relationship to modelling & simulation)
  - Assess computing infrastructure (e.g. internal to ship, between shore-based facilities)

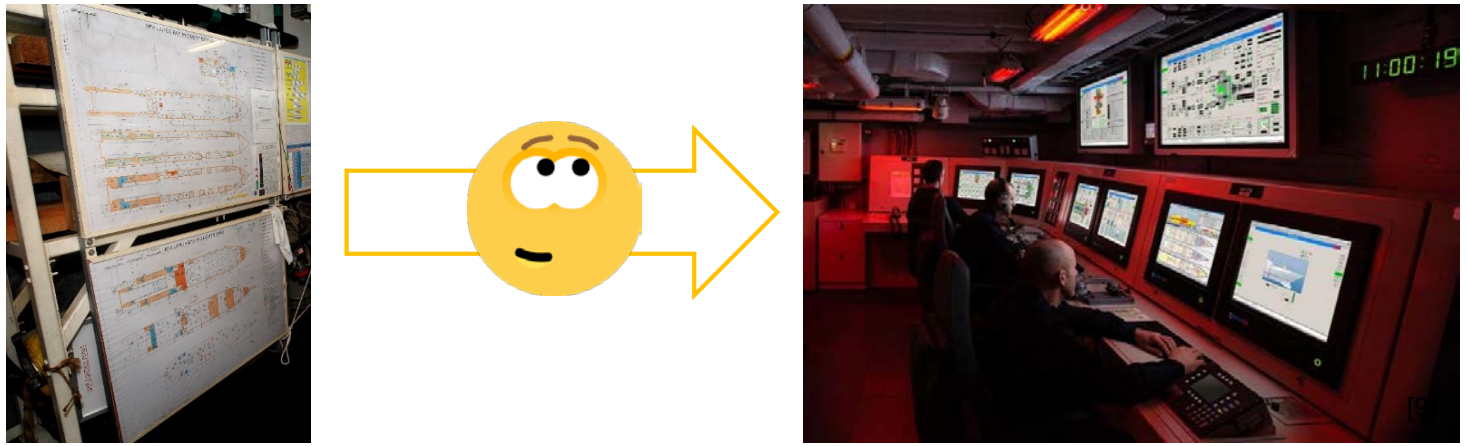
Acknowledgements

- The TTCP Digital Twin CoI thank the interview respondents for giving their time and sharing their knowledge and expertise during the interviews.
- The TTCP Digital Twin CoI also the workshop participants, also giving their time to share their knowledge and experience.
- Thank you to Associate Professor Matthew Collette, Naval Architecture and Marine Engineering, University of Michigan, for providing an overview of the Digital Twin concept to the TTCP Digital Twin CoI.
- Thank you to Sondra Laughlin, David Schiff, Michael Lavery, and Lauren Hanyok, NavalX, United States Navy, for guidance in ethnographic interviews and the visualisation of interview data; creating detailed workshop programs; and hosting of the workshops, ensuring a safe environment for participants to contribute in free discussion.

- Ethical clearance for RAN involvement was provided by the DSTG Low Risk Ethics Panel (protocol: MD 06-20).

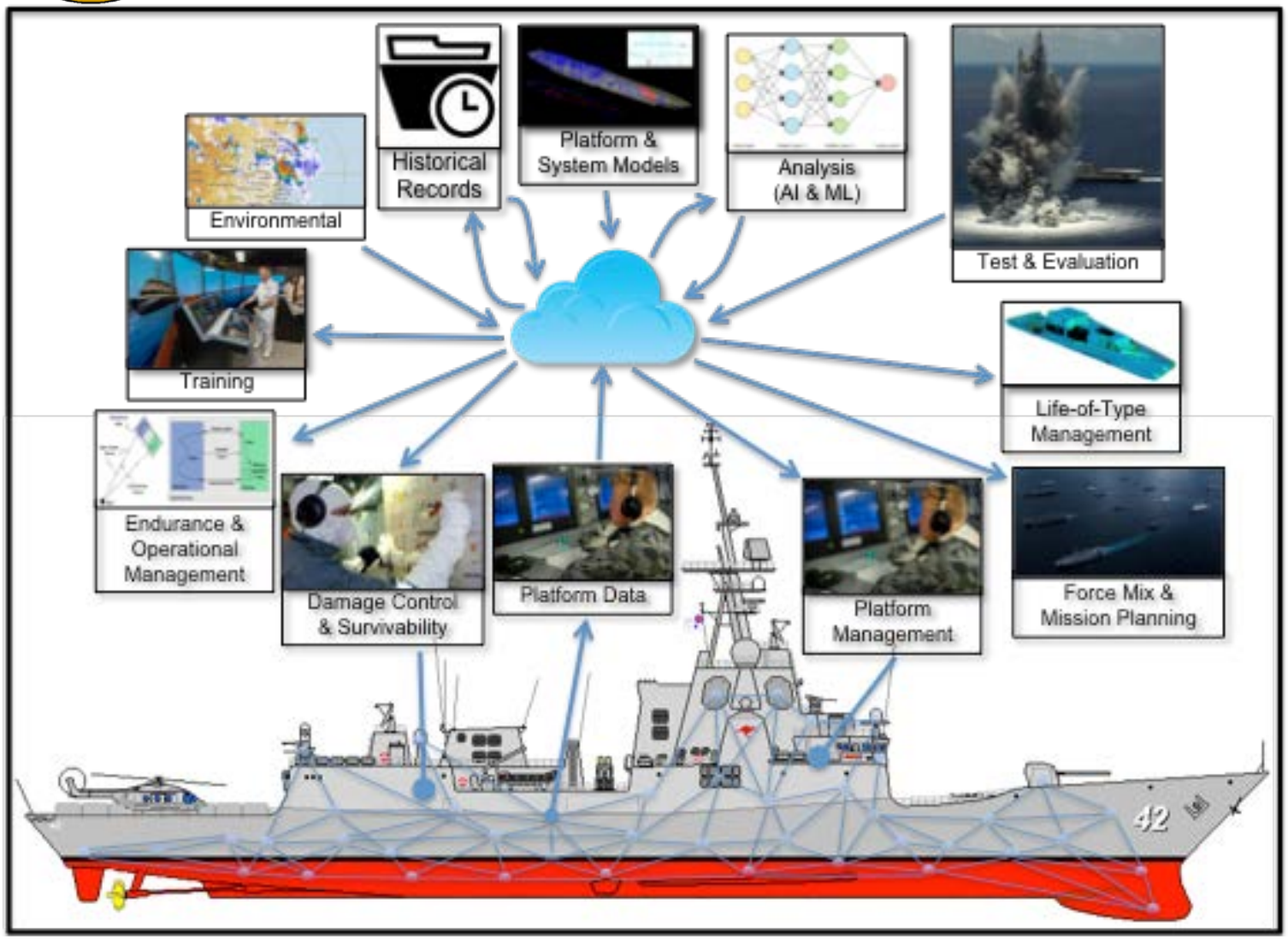
Future Work

- Implementation of a DT is application-specific (not-standardised) → need to identify/develop:
  - computing infrastructure (communications, databases, hardware requirements) to ensure connectivity and security
  - modelling software to fill gaps not supported by legacy systems



- Broaden the study: interview more end-users → capture diversity of issues encountered by personnel supporting naval platforms

Summary – Digital Engineering Support to Naval Operations



Expectation

- To provide a process for monitoring, optimising and forecasting the needs of enduring platform and fleet capability performance in support of the navy mission.

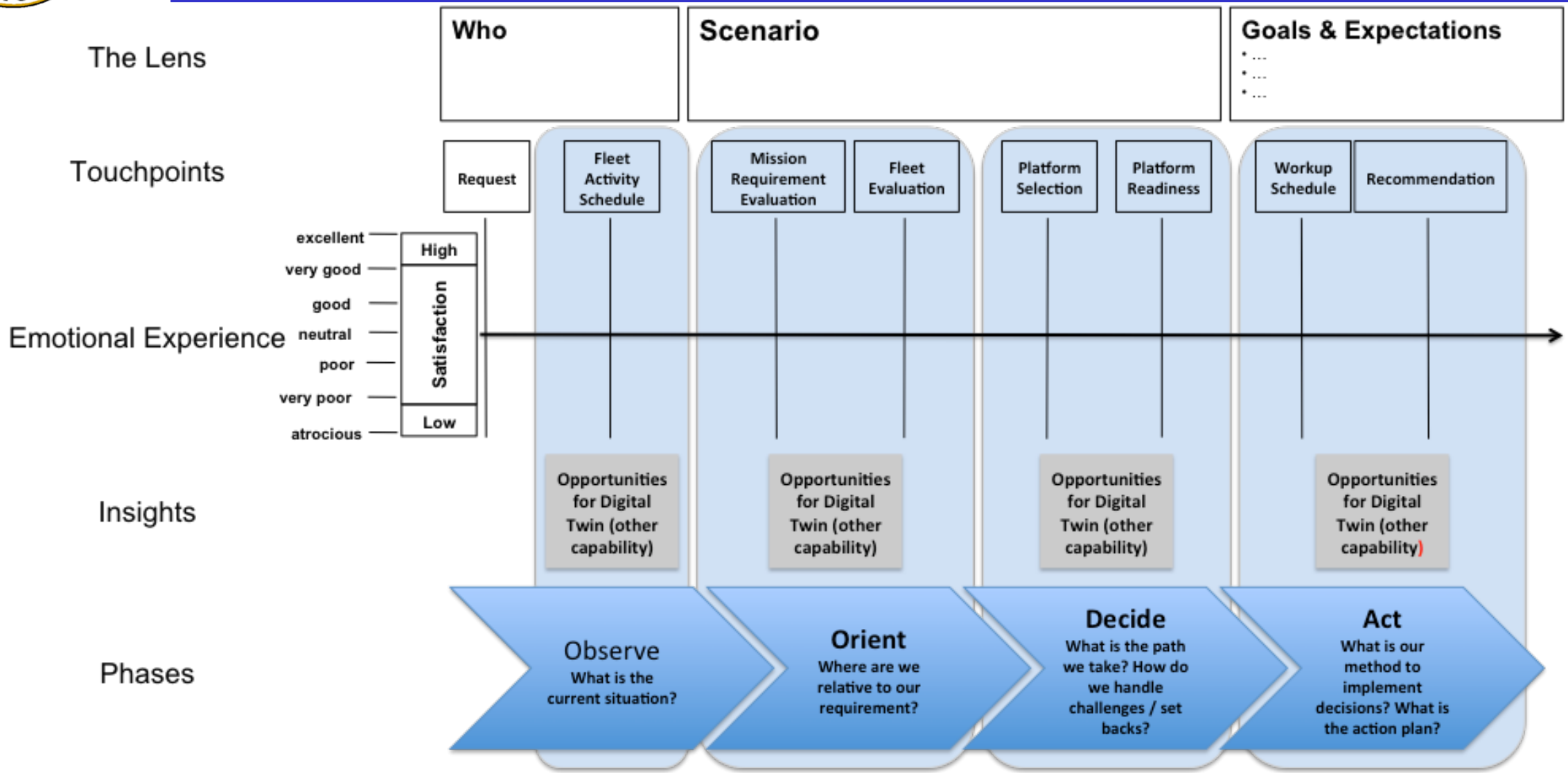
Application

- Sustainment management / Life-of-Type
- Endurance
- Energy management
- Survivability
- Operations Analysis
- Readiness
- Training

Issues / Limitations

- Size of problem could be overwhelming
- Secure real-time data transmission
- Data storage
- Data quality management
- Data processing capacity
- Endurance of DT (and related) technology
- Ongoing support (from leadership) for development and management of digital engineering technologies

Journey Maps



Collection of Interview Data

Demographics

- To understand interviewee's experience
- Identify statistical spread of respondents

Role Identification

- To identify interviewee's role
- To identify interviewee's duties in relation to the scenario
- To identify tools and policies to perform those duties

Goal Identification

- To identify the intent of the interviewee's role
- To identify what the interviewee needs to achieve in fulfilment of the role

Decision-making

- To identify decisions required in achievement of the goal(s)
- To identify time constraints associated with achievement of the goal(s)

Information Requirements

- To identify information needs in support of the decision-making