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Designing for Adaptation in Workers' Individual Behaviours and Collective Structures with Cognitive Work Analysis: Case Study of the Diagram of Work Organisation Possibilities

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Complex Sociotechnical Systems



Need for Adaptation in the Workplace

- Workers adapt their individual behaviours and organisational structures to the evolving task demands

(e.g., Bigley & Roberts, 2001; Bogdanovic et al., 2015; Hutchins & Klausen, 1998; Luff & Heath, 2000; Lundberg & Rankin, 2014; Rochlin et al., 1987; Ziegert et al., 2006)

Behavioural Adaptation

- e.g., Emergency management (Bigley & Roberts, 2001)



Structural Adaptation

- e.g., Naval operations
(Rochlin et al., 1987)



Existing Design Frameworks

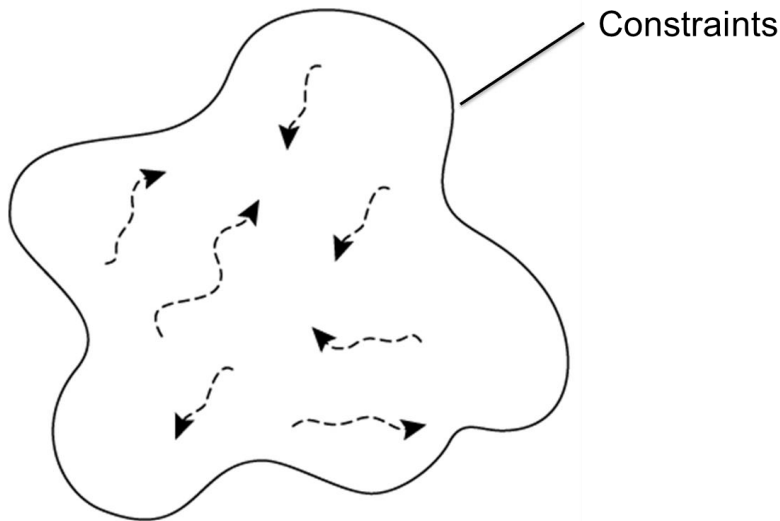
- Resilience engineering (e.g., Hollnagel et al., 2006)
- Sociotechnical systems theory (e.g., Clegg, 2000)
- Cognitive systems engineering (e.g., Hollnagel & Woods, 1983)
- Computer-supported cooperative work (e.g., Schmidt & Bannon, 1992)

Work Analysis Approaches

- Normative approaches:
 - e.g., sequential flow or timeline task analysis (Meister, 1985)
- Descriptive approaches:
 - e.g., naturalistic (Zsombok & Klein, 1997) or ethnographic (Suchman, 1987) studies

Cognitive Work Analysis (CWA)

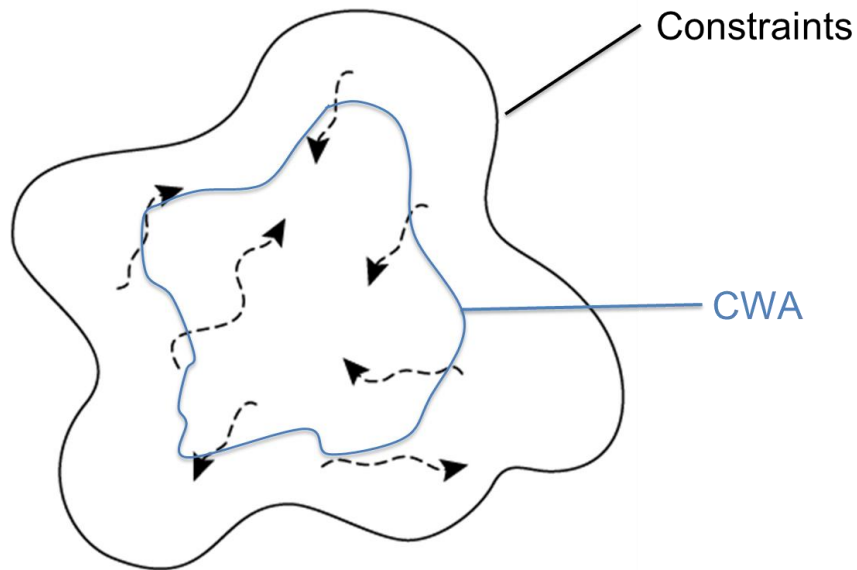
- Formative approach (Rasmussen et al., 1994; Vicente, 1999)



CWA Dimensions	Constraints
Work domain analysis	Work domain
Activity Analysis	Activity
Strategies analysis	Strategies
Social organisation and cooperation analysis	Work organisation
Worker competencies analysis	Workers

Cognitive Work Analysis (CWA)

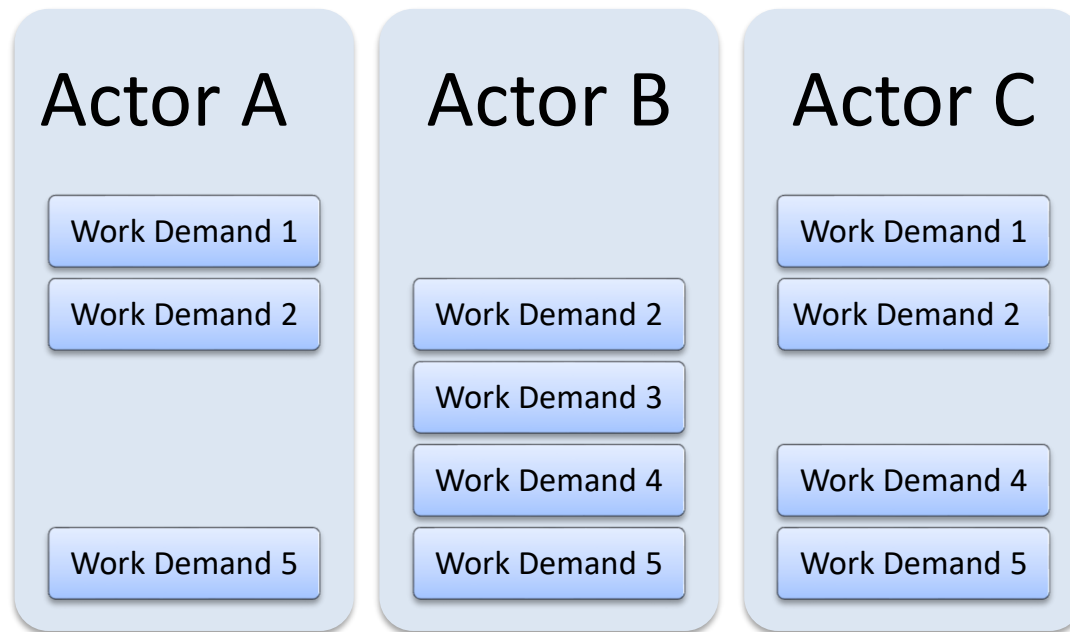
- Experimental studies (e.g., review by Vicente, 2002)



CWA Dimensions	Constraints
Work domain analysis	Work domain
Activity Analysis	Activity
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Social organisation and cooperation analysis	Work organisation
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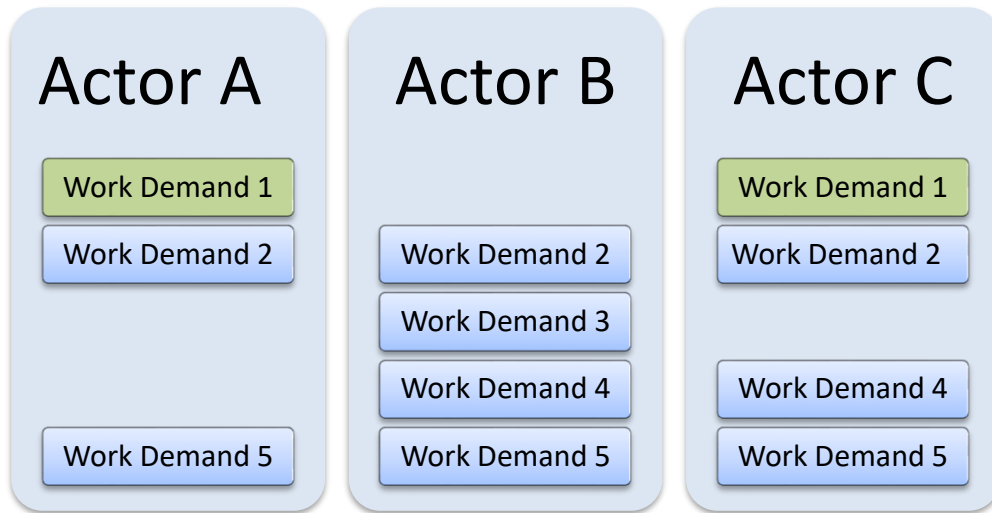
Diagram of Work Organisation Possibilities

(Naikar & Elix, 2016)



Constraints, not Possibilities

Constraints



Possibilities

Actor A

Actor C

Actors A and C

Work Organisation Criteria

(Rasmussen et al., 1994; Vicente, 1999)

- Compliance
- Safety and reliability
- Access to information/controls
- Coordination
- Competency
- Workload

Case Study

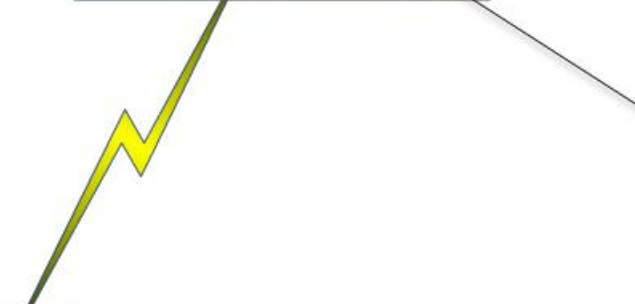
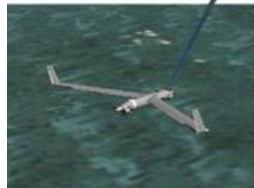
P-8A



Crew



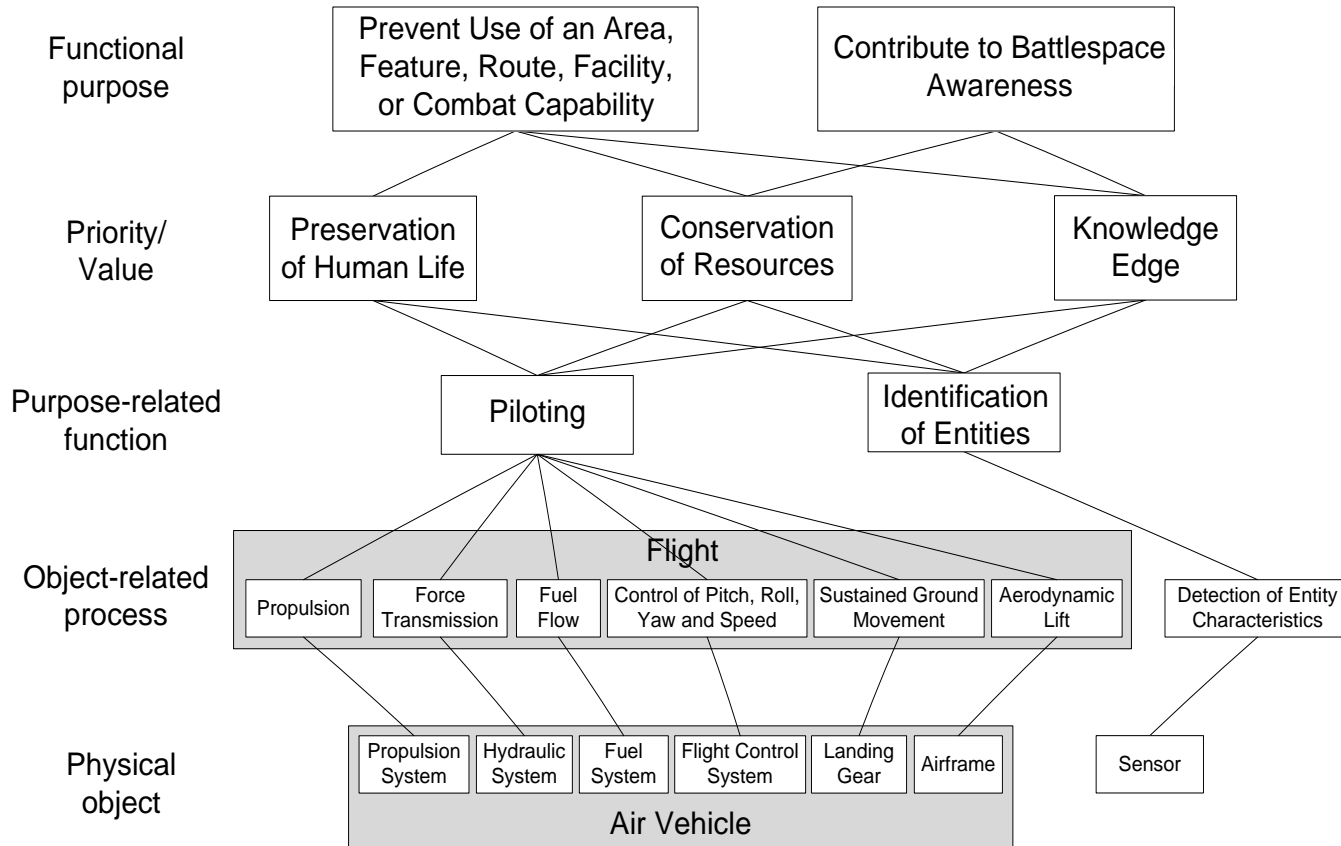
UAS



Work Demands

- First two CWA dimensions:
 - Work domain analysis
 - Activity analysis

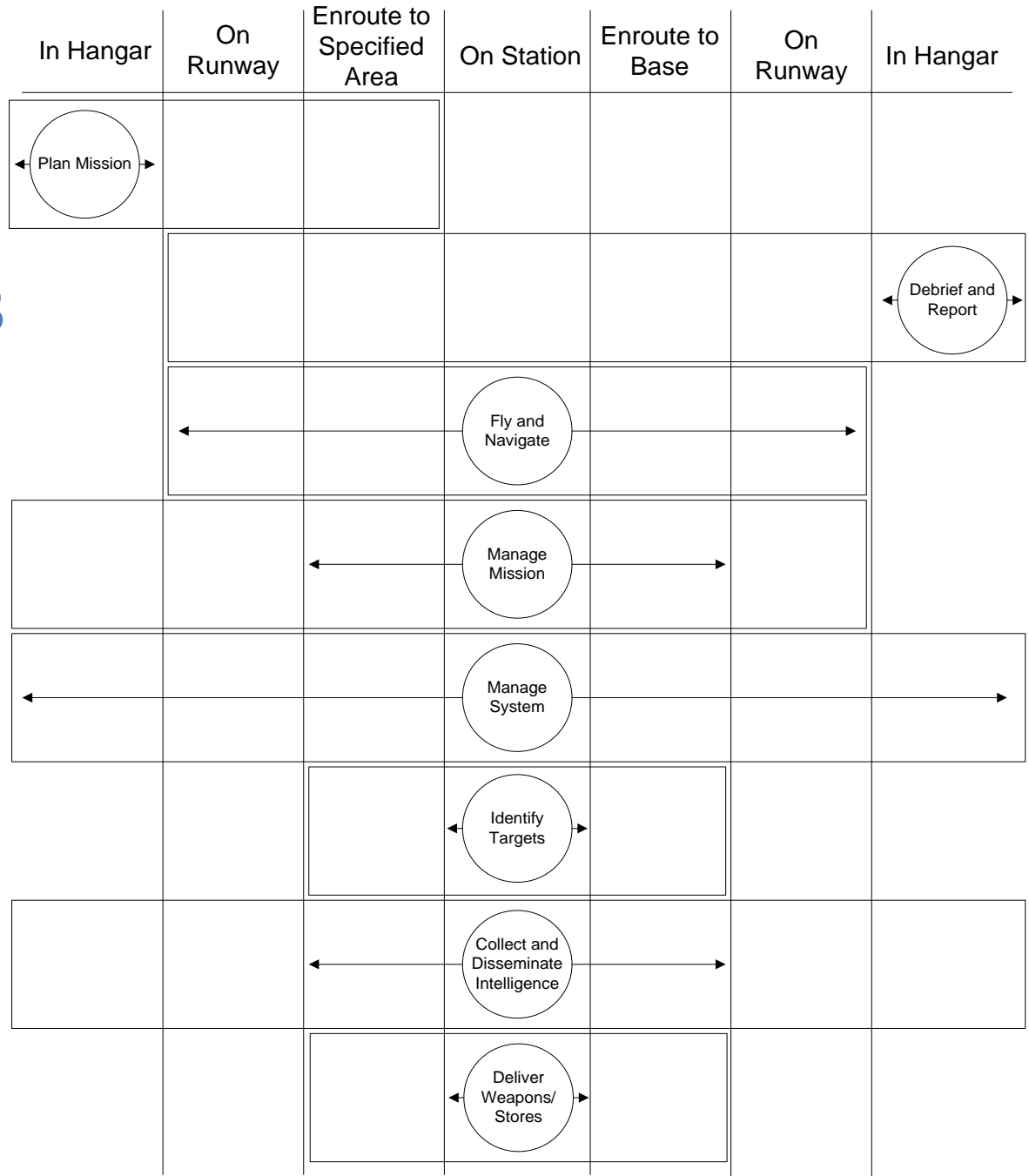
Work Domain Analysis



Abstraction hierarchy

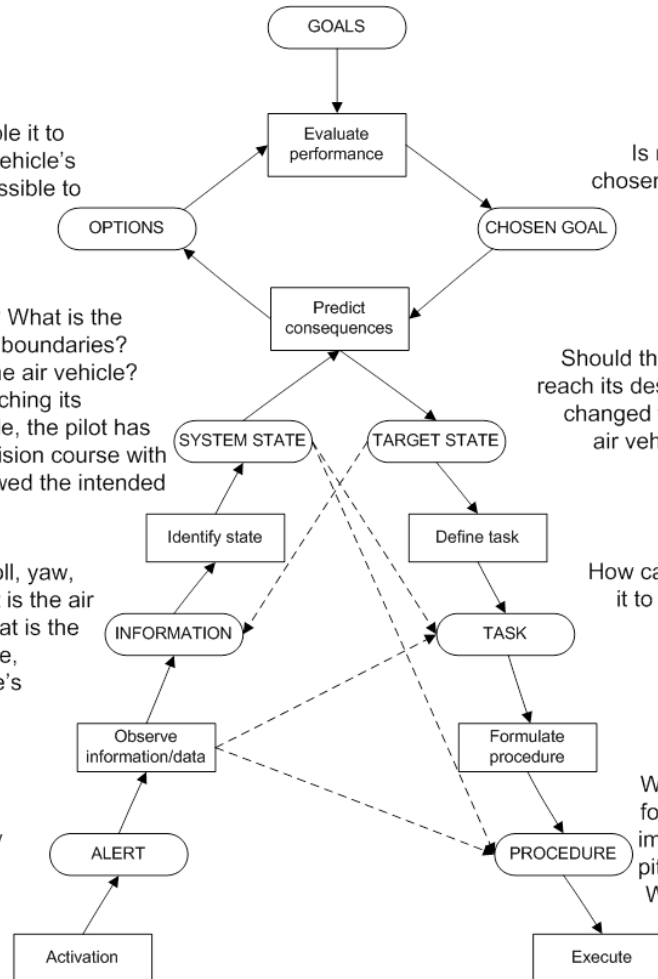
Activity Analysis

Contextual Activity Template



Activity Analysis

To reach the air vehicle's destination
safely, efficiently, and lawfully



Is it possible to change the air vehicle's status to enable it to reach its destination? Is it possible to change the air vehicle's behaviour to enable it to reach its destination? Is it possible to change the air vehicle's route to enable it to reach its destination?

Is reaching the air vehicle's destination safely my chosen goal? Is reaching the air vehicle's destination efficiently my chosen goal? Is reaching the air vehicle's destination lawfully my chosen goal?

Where is the air vehicle? What is the air vehicle doing? What is the location of the air vehicle relative to the location of any boundaries? What is the effect of the environmental conditions on the air vehicle? What is inhibiting or preventing the air vehicle from reaching its destination (e.g., the enemy has engaged the air vehicle, the pilot has lost control of the air vehicle, the air vehicle is on a collision course with the terrain or another air vehicle, the pilot has not followed the intended route)?

Should the air vehicle's status be changed to enable it to reach its destination? Should the air vehicle's behaviour be changed to enable it to reach its destination? Should the air vehicle's route be changed to enable it to reach its destination?

What is the air vehicle's behaviour (e.g., pitch, bank, roll, yaw, speed, heading, rate of descent, rate of ascent)? What is the air vehicle's status (e.g., lat/long, altitude, fuel level)? What is the lat/long of the boundary (e.g., missile engagement zone, territorial waters)? What is the lat/long of the air vehicle's destination?

How can the air vehicle's status be changed to enable it to reach its destination? How can the air vehicle's behaviour be changed to enable it to reach its destination? How can the air vehicle's route be changed to enable it to reach its destination?

Is there a problem (e.g., crew error, software glitch, hardware malfunction, environmental condition, enemy action) inhibiting or preventing the air vehicle from reaching its destination?

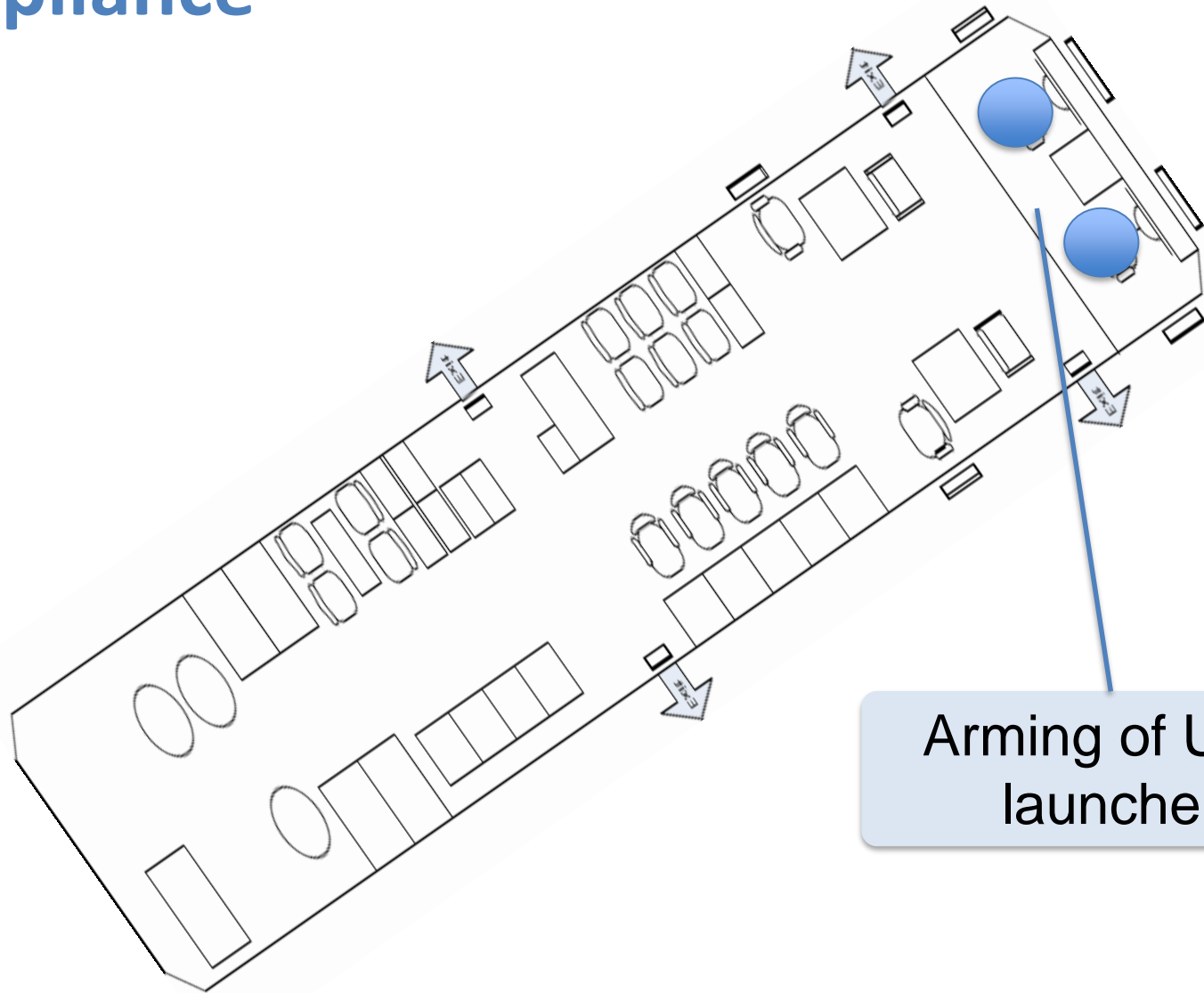
What steps are needed to prepare the air vehicle for ascent or descent? What steps are needed to implement the air vehicle's required bank, speed, pitch, heading, rate of ascent, or rate of descent? What steps are needed to adopt the air vehicle's selected route to its destination?

Decision Ladder for *Fly and Navigate*

Limits on Distribution of Work Demands

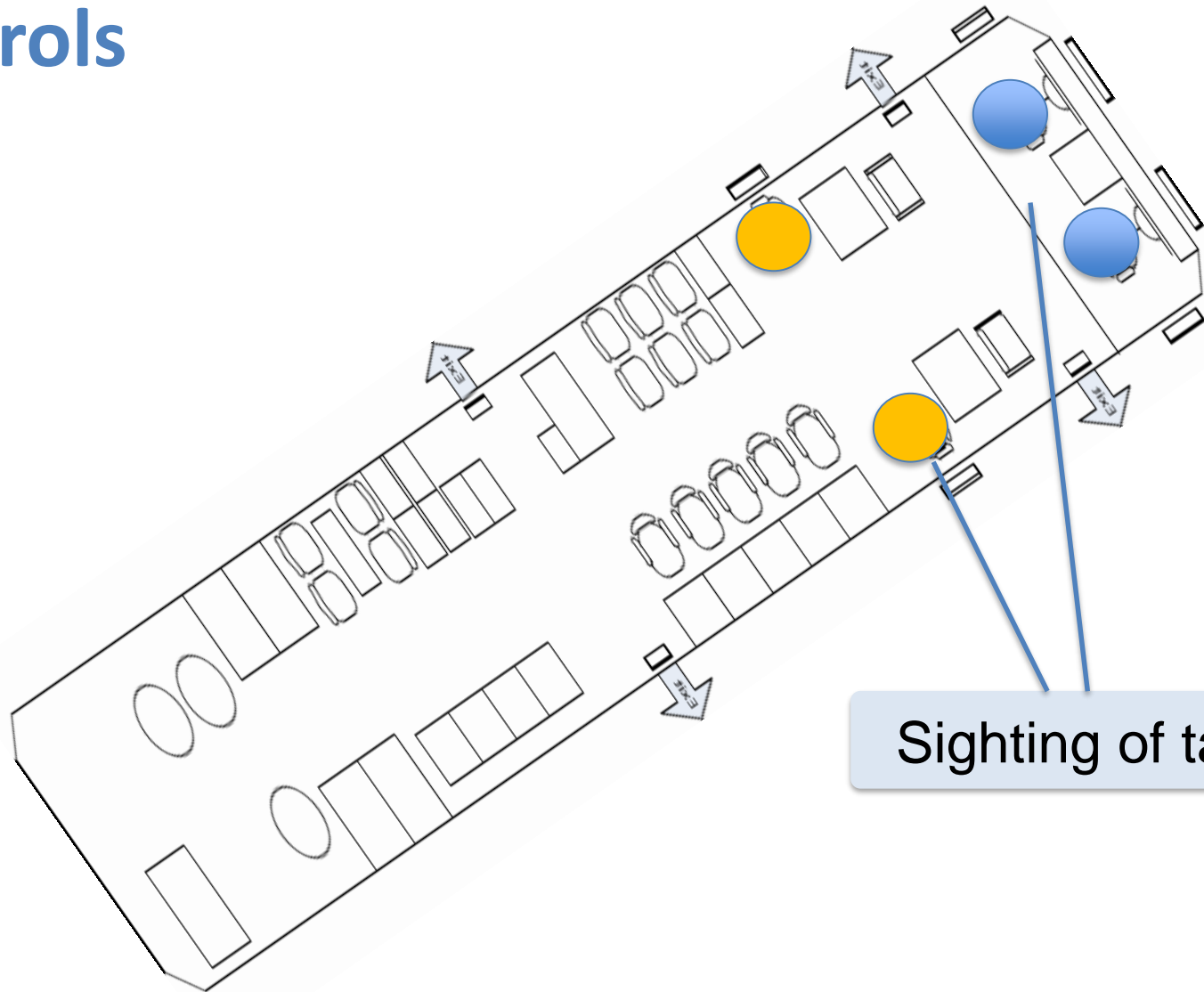
- Work organisation criteria:
 - Compliance
 - Safety and reliability
 - Access to information/controls
 - Coordination
 - Competency
 - Workload

Compliance



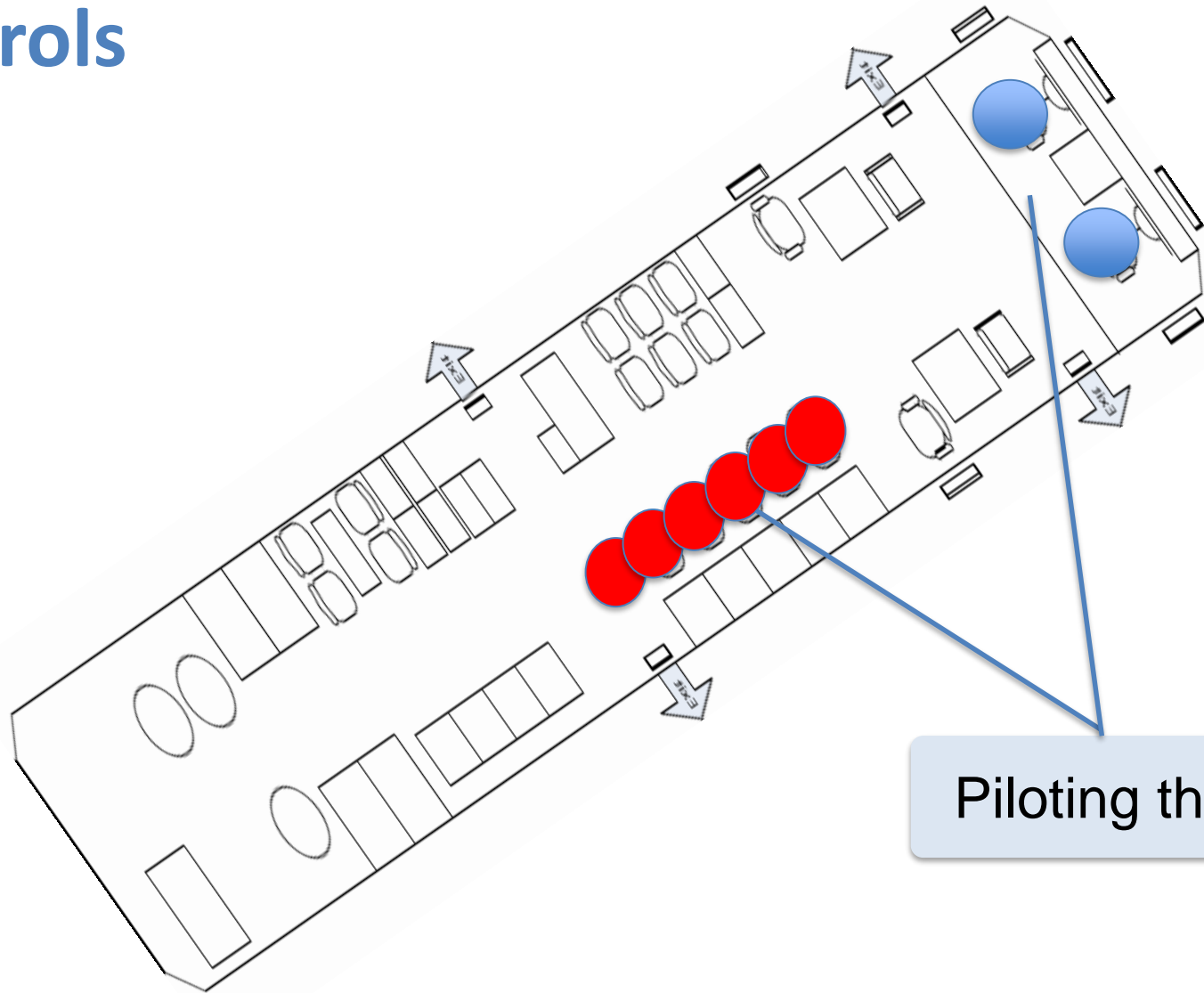
Arming of UAS
launcher

Access to information and controls



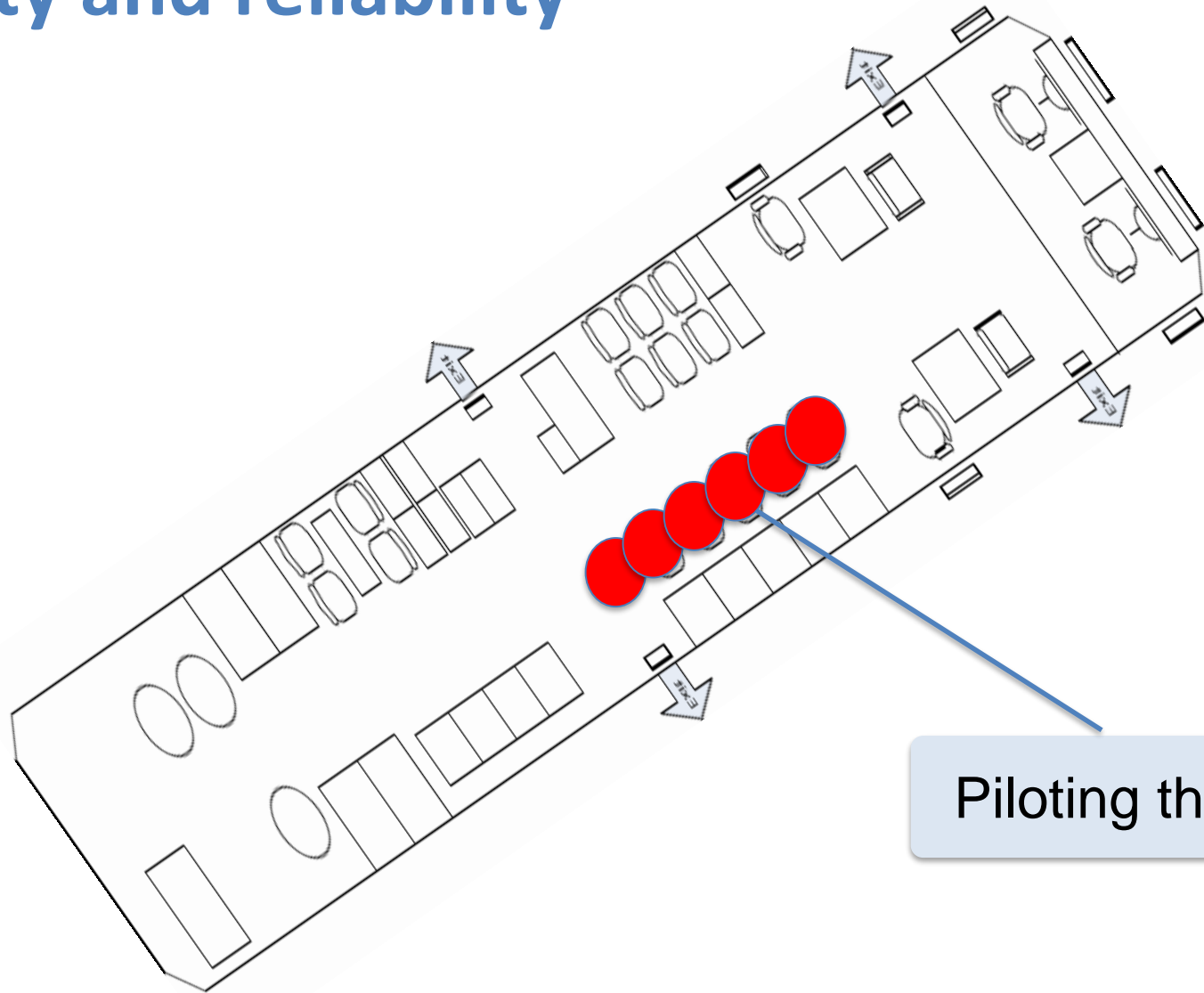
Sighting of targets

Access to information and controls



Piloting the UAS

Safety and reliability

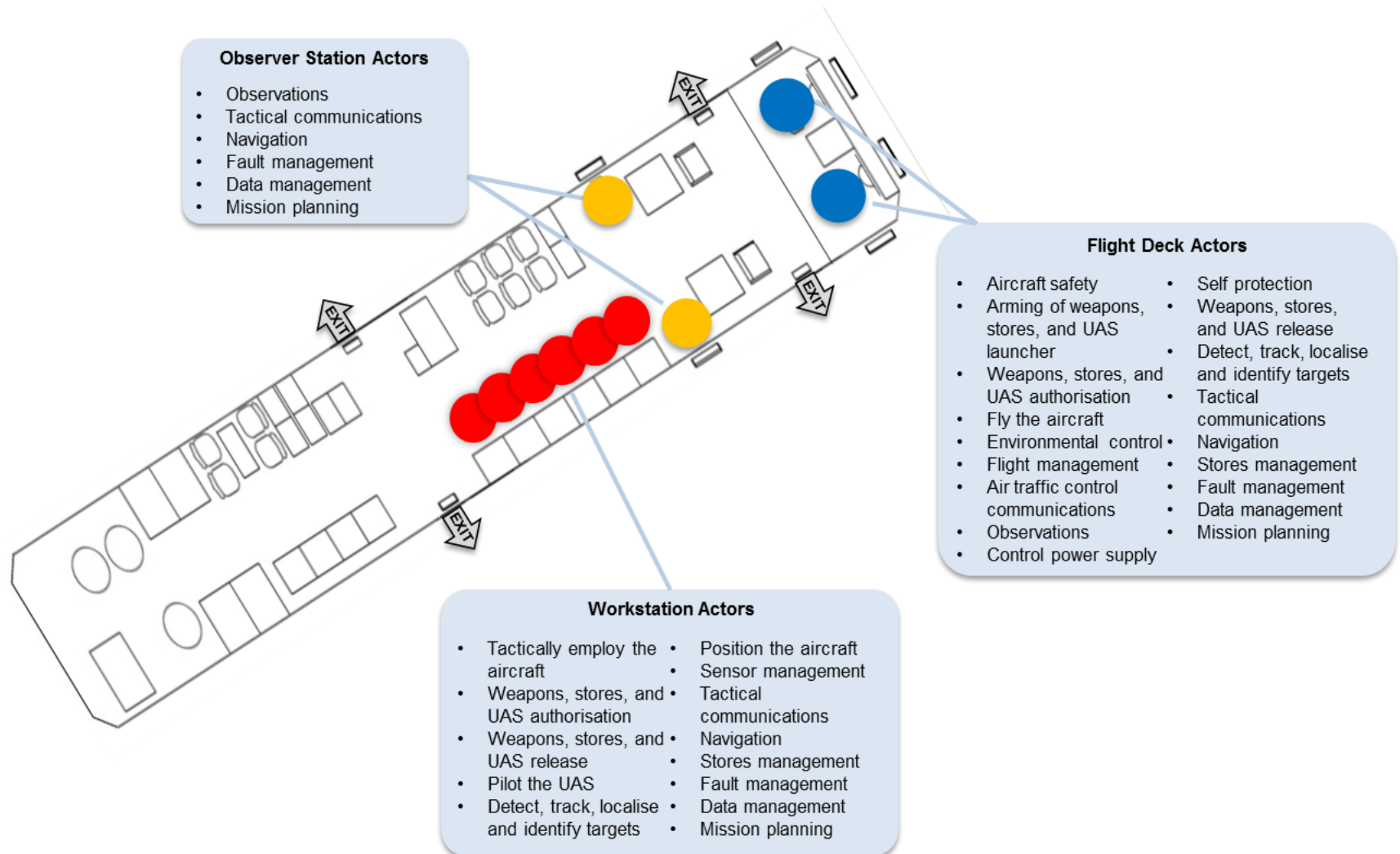


Piloting the UAS

Coordination, Competency, Workload

- e.g., Workload

Work Organisation Possibilities Diagram of Future Maritime Surveillance System



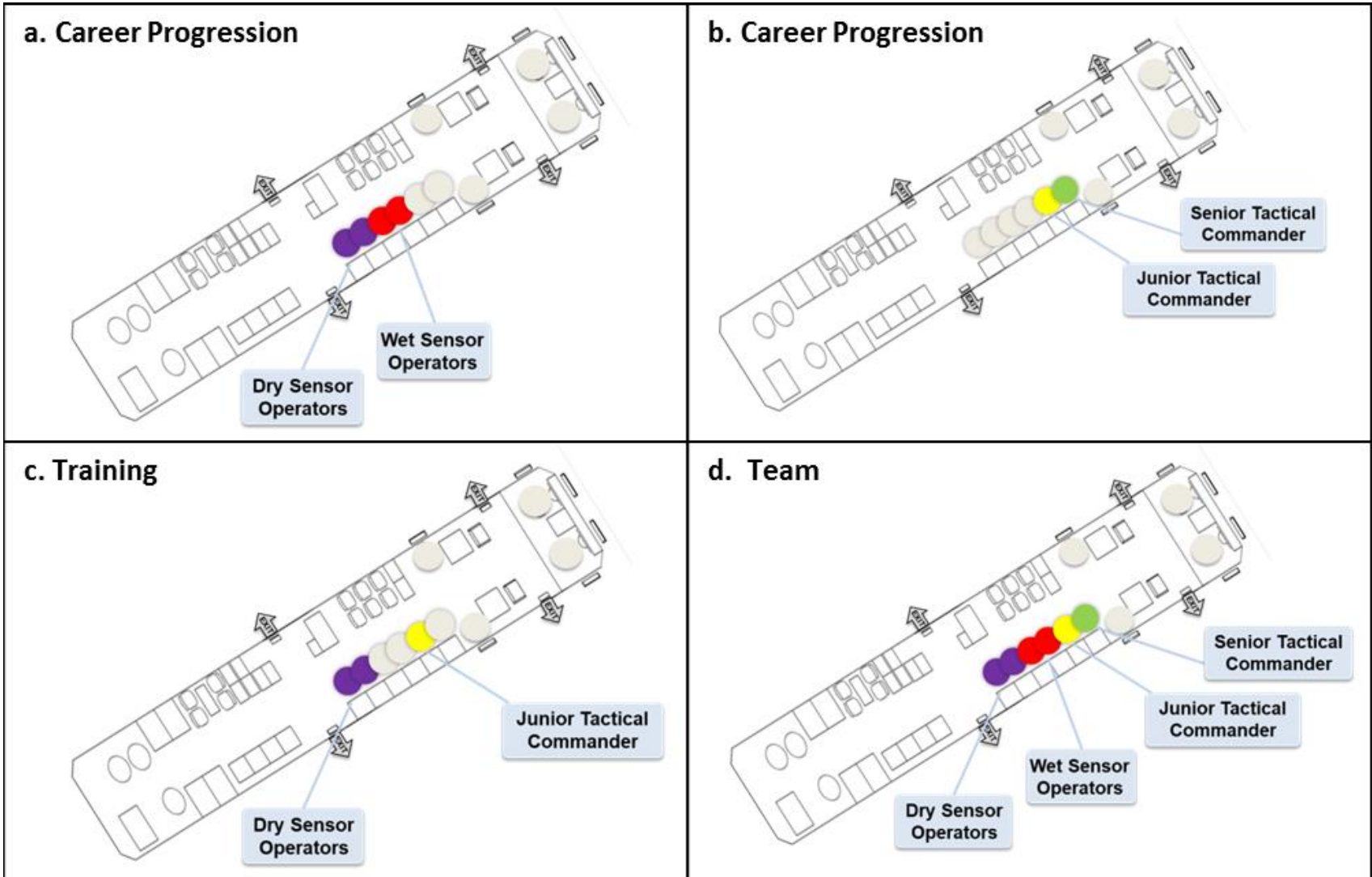
Design Problem

- 6 workstation actors: pilot the UAS; detect and localise targets with UAS sensor
- 2 flight deck actors: detect and localise targets with UAS sensor
- 2 observer station actors: only if tactical interfaces provided at these stations

Potential Design Solutions

- Most obvious solution: Enable all crew members to operate the UAS
- Most obvious alternative: Enable only one or two crew members to operate the UAS

Proposed Design Solution



Integration of Team, Training, and Career Progression

- “The progress of various team members through the career cycle of navigation practitioners [on naval vessels] produces an overlapping distribution of expertise that makes it possible for the team to achieve training and job performance in a single activity”

(Hutchins, 1990, p. 191).

Criteria	Senior Tactical Commander	Junior Tactical Commander	Wet Sensor Operators	Dry Sensor Operators
Compliance				
Safety and Reliability	<ul style="list-style-type: none"> • Big picture perspective (Beneficial If the UTAS leaves the area of operations) • Big picture perspective (Problematic if having to focus in on the UTAS) 	<ul style="list-style-type: none"> • Less of a requirement to have a big picture perspective of operations (as compared to the Captain, Co-pilot, and TACCO) 	<ul style="list-style-type: none"> • No requirement to have a big picture perspective of operations • The risk of the track being lost (on acoustics) because the Sensor Operator (acoustics) is distracted by operating the UTAS may not be acceptable 	<ul style="list-style-type: none"> • Less of a requirement to have a big picture perspective of operations (as compared to the Captain, Co-pilot, and TACCO)
Access to Information/ Control	<ul style="list-style-type: none"> • Has some ability to control the P-8A to the UTAS release point 			
Coordination	<ul style="list-style-type: none"> • Best suited to formulate the UTAS release point • Coordinates with the Sensor Operator (acoustics) • Already involved with the release of the UTAS • Added communications (e.g., ATC) 	<ul style="list-style-type: none"> • Could be involved with the release of the UTAS • Monitors the surrounding air traffic • Added communications (e.g., ATC) • Added coordination with the Sensor Operator (acoustics) • Added coordination with the TACCO (and potentially Captain/Co-pilot) 	<ul style="list-style-type: none"> • High coordination between the two Sensor Operator (acoustics) • Comprehensive understanding of the target status and behaviour • Required to monitor surrounding air traffic • Not involved in releasing the UTAS • Added coordination with the TACCO (and potentially Captain/Co-pilot) 	<ul style="list-style-type: none"> • High coordination between the UTAS operator and the radar operator • Comprehensive understanding of the terrain and/or surface traffic • Not involved in releasing the UTAS • Added coordination with the TACCO (and potentially Captain/Co-pilot)
Competencies	<ul style="list-style-type: none"> • Competent to tactically employ an aircraft • Competent to navigate an aircraft • Competent to perform communications • Competent to release the UTAS • Not competent to fly an aircraft • Not competent to operate any sensors 	<ul style="list-style-type: none"> • Some competencies associated with tactically employ an aircraft • Competent to navigate an aircraft • Competent to perform communications • Competent to release the UTAS • Not as experienced as the TACCO tactically employing an aircraft • Not competent to fly an aircraft • Not competent to operate any sensors 	<ul style="list-style-type: none"> • Experience operating sensors and may be competent in sensor management • Not competent to tactically employ an aircraft • Not competent to fly or navigate an aircraft • Not competent to perform communications • Not competent to release stores 	<ul style="list-style-type: none"> • Competent to operate other sensors • Competent in collision avoidance • Least experienced crew member • Not competent to tactically employ an aircraft • Not competent to fly or navigate an aircraft • Not competent to perform communications • Not competent to release stores
Workload	<ul style="list-style-type: none"> • May reduce during recovery • Workload may be high at times 	<ul style="list-style-type: none"> • May reduce during recovery • Workload may be high at times 	<ul style="list-style-type: none"> • May reduce during recovery • Able to share workload • Workload may be high at times 	<ul style="list-style-type: none"> • Lowest of any crew member • May reduce during recovery • May need to rotate through different sensors

Industrial Criteria

(e.g., Whitefield et al., 1991)

- Impact:
 - Design accepted by the RAAF for further development
- Uniqueness:
 - Formative versus normative and descriptive approaches
- Feasibility:
 - Achieved within schedule, financial, and personnel constraints

Conclusion

- Future Research

Final Points

- Elix and Naikar (2019). Accepted for publication in *Human Factors*.
- Extension to workforces or teams with human and artificial agents:
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