Identifying Human Factors Considerations Associated with Command, Control and Communication (C3) of Autonomous Vehicles in the Maritime domain

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ABSTRACT

As part of an ongoing program of research looking at autonomous vehicles in the maritime domain (i.e., Maritime Autonomous PLatform Exploitation (MAPLE) – Phase 4), this paper describes an approach to identifying human factors considerations associated with Command, Control and Communication (C3) of unmanned vehicles (UxV). This approach utilises the Human Factors Integration domains as a framework for conducting an Early Human Factors Analysis.

This paper describes the data capture process, as well as the context of the source / baseline data and the Early Human Factors Analysis (EHFA) workshop from which the main findings are derived. Additionally, this work provides the rationale for the EHFA tool selection, as well as the Human Factors Integration (HFI) domains which acted as a framework for the data collection. Following this, all Risks, Assumptions, Issues, Dependencies and Opportunities (RAIDO) are reported and summarised and a number of key recommendations and conclusions are provided, which will inform future work within the MAPLE programme, as well as future in-service C3 systems for autonomous vehicles.

The main findings are presented in terms of their impact per HFI domain. Specifically, this work identifies Human Factors considerations associated with 'Social and Organisational' (particularly for legislative and regulatory frameworks), as well as 'Manpower', 'Training' and 'System Safety' HFI domains. A key finding is that capability developers will need to overcome cultural resistance and inaccurate / inappropriate expectations before Unmanned Vehicles (UxVs) are fully deployed. Furthermore, there will be considerable effort involved in identifying training requirements, and incorporating new training technologies / methodologies, whilst not increasing the training burden (a key MoD requirement).

Additionally this paper will describe the next steps in the ongoing MAPLE research program. Specifically an upcoming series of experiments, which will further inform and guide human machine tasking / role allocation and elucidate the HF considerations associated with UxV C3.

1.0 INTRODUCTION

The MAPLE (Maritime Autonomous PLatform Exploitation) programme is focussed on the deployment and operation of Unmanned Vehicles (UxVs) in the maritime domain, in terms of a circa 2030 timeframe. The MAPLE programme is being considered in advance of established doctrine or regulatory requirements,

however ultimately, UxV deployment will be governed by the legislative / regulative frameworks developed specifically for their use. On completion of MAPLE 4, Defence Science and Technology Laboratory (Dstl) will have a roadmap describing a recommended approach for bringing UxVs into service, and integrating them within the Command Chain of a Royal Navy (RN) platform. This work contributes to the RNs understanding of the UxV Command, Control and Communication (C3) space and builds on research themes, which have developed throughout previous phases of the MAPLE programme.

1.1 Scope of analysis

The scope of this work covers the C3 associated with UxV management and control. Specifically, this work uses an Early Human Factors Analysis (EHFA) approach (described fully in section 2.2) to capture the Human Factors (HF) considerations (i.e., risks, issues, assumptions, dependencies and opportunities) associated with the C3 of UxVs. Notably, UxV operation and physical control (i.e., manual control of UxVs) are outside the scope of this current work.

1.2 Context (previous work in MAPLE programme)

The following subsections describe the research and analysis that has informed and guided this current work.

1.2.1 Autonomy Strategy and Roadmap

The Autonomy Strategy and Roadmap [1], developed under MAPLE 4, concentrates on identifying some of the more significant considerations that may assist (enable) or obstruct (constrain) the introduction of the capability implied by MAPLE. It also identifies the Dstl and MoD programmes that provide the exploitation and deployment opportunities to start to realise the capability envisaged. Future iterations of this work will further develop and refine the strategies and interactions between the various activities to form a roadmap for the deployment of autonomous capabilities. Relevant HF related material was extracted from [1] as an input to the materials used for the EHFA stakeholder workshop.

1.2.2 Functional decomposition

In order to model and capture the tasks, subtasks and enablers anticipated for UxV C3, MAPLE 4 (HF activity), extended the HF Elements of the Persistent Architecture [5] and thereby produced a functional de-composition and data flow depiction. Initially this effort was informed by work undertaken in MAPLE 2.5 [2], and further shaped by data collected during Unmanned Warrior 2016 (UW 16) [3].

During UW 16, observers were tasked with recording observed tasks / subtasks, equipment used to enable task and level of autonomy associated with each task (drawn from the MAPLE 2 and 2.5 workshops). The nature of the UxV Command and Control (C2), observed during UW 16, provided a unique opportunity for comprehensive data capture in relation to UxV activities undertaken in the current timeframe.

The MAPLE 4 work focussed on those areas that were outstanding from the MAPLE 2.5 work, as well as capturing any final changes required to the dataflow diagrams and functional de-compositions [4]. The revised depictions are provided for both realistic (feasible and desirable) and high autonomy in the circa 2030 timescale. These are being used in MAPLE 4 as the baseline for developing the experimental investigations such as those associated with level of autonomy, multiple assets and adaptable autonomy.

1.2.3 Wider HF issues

The wider HF issues that were incorporated in the Critical Architecture Review (CAR) at the end of MAPLE 2.5 included a number of slides describing the wider HF issues associated with truly autonomous systems

[5]. This material was also used as an input to develop the materials for the EHFA stakeholder workshop.

2.0 METHOD

This section describes the approach taken to data collection and analysis, as well as the rationale for selecting these methods. Additionally this section describes the context of the analysis and the Human Factors Integration (HFI) domains to which this current work applies.

2.1 Description of EHFA

EHFA is a key HFI tool, and is an essential part of initial project development activities. The main purpose of an EHFA is to identify high-level HF considerations, which are then classified by probability and impact, linked to an action plan where appropriate, and recorded in a Human Factors Issues Register (i.e., RAIDO log). The RAIDO log is intended to be updated iteratively as the programme develops in maturity, and thereby acts as an audit trail for HF governance.

The four explicit stages of the EHFA process, adapted from generic risk management protocols, are as follows:

- Identify – find, list and characterise HFI considerations;
- Assess – analyse and prioritise HFI considerations against agreed criteria;
- Plan – develop, analyse and recommend response actions to address HFI considerations; and
- Implement – implement, monitor, report and review response actions against objectives. Escalate risks where required.

The level of detail and content of an EHFA will depend on the level of information available (typically determined by the maturity of the project), as well as who performs the analysis and the end customer for whom the analysis is intended. As described in Joint Services Publication (JSP 912), the convening of a workshop is an effective way of conducting the EHFA together with an appropriately mature HFI baseline dataset acting as a preliminary input. Also, the EHFA process requires early engagement with relevant stakeholders, which greatly improves the quality and accuracy of the human-centric risks and potential inputs to the RAIDO. Given the level of maturity of this current work programme, which is at a research stage, a high level EHFA was conducted in accordance with the mandated EHFA methodology guide and toolset [6], but was appropriately tailored for the MAPLE programme. The wider HF issues identified under MAPLE 2 and relevant work within MAPLE 4 also provided an input to this work (see sections 2.3.2 – 2.3.4 for further detail).

The use of EHFA is recommended for the purpose of ensuring HF involvement at the earliest possible point in the Concept, Assessment, Demonstration, Manufacture, In-Service and Disposal (CADMID) lifecycle, and is used to identify, quantify and manage HF considerations, which influence safety, human performance and / or cost. Additionally, EHFA provides a framework through which to capture, monitor and review programme risks (as well mitigation strategies), thus ensuring that HF risks and issues are considered iteratively throughout the CADMID lifecycle.

2.2 HFI Domains

The EHFA approach sits within the broader context of HFI, and as such is bounded by the same HF domains. The HFI domains utilised as a discussion framework in this current work are as follows:

- Manpower – the number of military and civilian personnel required and potentially available to

operate, maintain, sustain and provide training for [C3 of unmanned systems];

- Personnel – the cognitive and physical capabilities required to be able to train for, operate, maintain and sustain [C3 of unmanned systems];
- Training – the instruction or education, and on-the-job or unit training required to provide personnel their essential job skills, knowledge, values and attributes;
- HF engineering – the integration of human characteristics into system definition, design, development, and evaluation to optimise human-machine performance under operational conditions;
- Health hazards – short or long term hazards to health occurring as a result of normal [C3 of unmanned systems];
- System safety – safety risks occurring when the system is functioning in either a normal or abnormal manner;
- Social and organisational – organisational practices (including doctrine), the culture associated with information sharing, centralised / distributed teamwork, information management and communication.

2.3 RAIDO Definitions

The definitions of the different elements that constitute a RAIDO are detailed below:

- An issue is a significant, unplanned event or situation that has already occurred, or will definitely happen;
- A risk is a significant uncertain event or situation;
- An assumption is a statement that is taken as being true for the purposes of planning or other decision making;
- A dependency defines the relationship between products or activities;
- An opportunity is, in effect, a risk with potentially beneficial consequences.

2.4 Scoring Criteria

The following subsections provide a breakdown of the descriptors, for probability of occurrence and potential impact, as well as breakdown of the scoring criteria and coding scheme.

2.4.1 Descriptors for likelihood of occurrence and impact

Figure 1 provides the descriptive criteria used in the EHFA tool to assess likelihood of risk / issue, as well as the impact following occurrence. Whilst the examples given in Figure 1 will not be relevant to all design / manufacturing programmes, they are provided here for reference purposes.

Likelihood of risk/issue occurring	Confidence in information on which cause is based (example guidance)
High	No evidence of risk/issue being addressed in previous system(s) or analysis/prototyping performed to understand or assess impact. New unproven technology, task or procedure is required.
Medium	Technology, task or procedure is similar to that used for previous system(s), but no evidence of analysis/prototyping performed for this system.
Low	Some evidence of risk/issue being considered in previous fielded system(s) or prior analysis/prototyping performed to demonstrate performance in an operational scenario.

Potential Impact	Description of impact in relation to HFI (example guidance)
High	Failure to resolve the issue or fully mitigate the risk will prevent the system achieving specified performance, safety requirements, usability and/or maintainability/ supportability requirements.
Medium	Failure to resolve the issue or fully mitigate the risk will prevent the system achieving specified performance, usability, safety requirements, and/or maintainability/ supportability requirements, but can be managed within the performance margin for the system.
Low	Failure to resolve the issue or fully mitigate the risk will impact system performance, usability, safety and/or maintainability/supportability requirements, but is contained within the performance margin for the system.

Figure 1: Descriptive criteria for probability of occurrence (top panel) and impact on programme, if risk / issue / opportunity occurs (bottom panel)

2.4.2 Breakdown of scoring criteria

Figure 2 shows each Probability + Impact (P+I) score, as well as its associated colour code, and a descriptor of the scoring criteria for each P+I score. As can be seen in the descriptors provided in Figure 2, issues are scored differently to risks and opportunities, in order that the certain probability of issues can be appropriately weighted. Additionally the lowest and highest scores are given nominal P+I scores (1 and 9 respectively) in order that a continuous (i.e. scalar) distribution is provided.

P+I Score	Descriptor
9	Only given to issues which have a high impact (i.e., for issues which are given an impact rating of high, a P+I score of 9 is assigned)
6	Either a risk / opportunity with high probability (P = 3) and high impact (I = 3), or an issue with medium impact (i.e., for issues which are given a medium impact rating (I = 2), a probability rating of 4 is assigned)

5	This P+I score can be achieved in several ways. First, either a risk / opportunity with high probability (P = 3) and medium impact (I = 2), or a risk / opportunity with medium probability (P = 2) and high impact (I = 3). Additionally, a P+I score of 5 is also given to an issue with a low impact rating (I = 1; P = 4)
4	A risk / opportunity with medium probability (P = 2) and medium impact (I = 2)
3	Either a risk / opportunity with medium probability (P = 2) and low impact (I = 1), or a risk / opportunity with low probability (P = 1) and medium impact (I = 2)
1	A risk / opportunity with low probability and low impact is given a nominal rating of 1

Figure 2: Overview of P+I scoring criteria, together with colour coding scheme

2.4.3 EHFA workshop

The majority of the content contained in the RAIDO log described in this work was derived from discussions with SMEs during an EHFA themed / HFI guided workshop. The format of which, as well as emergent HF considerations, are described in this subsection.

The overarching aim of the MAPLE 4 EHFA workshop was to highlight the key HF related considerations that will need to be addressed to enable UxV capabilities/technology to be introduced into service without increasing manning / training overheads. Additionally the output from the EHFA workshop informed development of the issues to be addressed within the MAPLE 4 HF experimental programme. A suitable agenda was agreed with the customer, which included top level discussions covering the HFI domains and their effect on the introduction of autonomous vehicle capabilities, assumptions and notable considerations. Discussions were recorded for the purposes of populating the EHFA report and RAIDO log and stakeholders were invited to provide further comments / suggestions and validate the workshop outputs.

The main output of this workshop was an endorsed and validated set of HF considerations, organised by HFI domain. The validation process took the form of recorded workshop comments and subsequent feedback, being incorporated into the HFI domains, and thereafter disseminated for further validation and final endorsement.

Attendees were a representative panel of domain experts and military advisors, which included SMEs from Dstl as well as senior members of the RN. All pertinent comments were transcribed and subsequently sent to attendees for validation and endorsement. All considerations and descriptors contained in this work are either direct quotes or very close paraphrasing of validated and endorsed commentary.

3.0 FINDINGS AND RESULTS

This section describes the main findings which emerged from the EHFA workshop.

3.1 EHFA Findings

The following subsections contain information pertaining to key risks, assumptions, issues, dependencies and opportunities, as well as a summary of the distribution of these HF considerations across the seven HFI domains (see Tables 2 – 8). Additionally, a summary table is provided which includes a Probability + Impact score for the key risks, issues and opportunities (see Table 8).

3.2 Key Programme Risks, Issues, and Opportunities

The following sub-section describes risks, issues and opportunities associated with the C3 of UXVs. The following subsections (3.4 – 3.6) groups the HF considerations thematically and provides an overview and descriptor for each risk, issue and opportunity.

3.2.1 Summary of issues

This sub section reports all of the issues captured during the EHFA workshop. According to [6], "an issue is a significant, unplanned event or situation that has already occurred, or will definitely happen, which is certain to affect at least one project or programme activity, or business objective. As such the probability of an issue occurring is scored as 'Certain' [achieving a score of 6 in the EHFA tool]".

3.2.2.1 Training considerations

There are a group of issues pertaining to the understanding of the training requirements for UxV C3 (associated with the 'Personnel' and 'Training' HFI domain), these issues are described in Table 1. Three of these issues (I-0001 – I-0003) were given the highest P+I score (certain probability + highest impact), and as such are a high priority consideration for the MAPLE programme.

Table 1: Summary of issues associated with training and personnel, together with P+I score

Issues (ID and title)		Descriptor	P+I
I-0001	No Target Audience Description (TAD)	"Currently it is unknown who (which roles and at what seniority) will be responsible for UxV C3, therefore there is no Target Audience Description (TAD), and a lack of understanding regarding tasks/roles, changes to competencies, and what Knowledge Skills and Attitudes will be required"	9
I-0002	Training requirement	"Bespoke training will be required for UxV C3. Entirely new operator tasks, skills and competencies will need to be understood. Planning and delivering this training requirement (from training needs analysis, to designing course content and establishing appropriate standards) will be a high priority"	9

I-0003	Training requirement (weaponisation)	As per I-0002 except with specific focus on issues associated with C3 of weaponised UxVs.	9
I-0004	Maintainer's KSAs	"Maintenance crews will need to be equipped with skills and knowledge to support C3 for UxV platforms and payloads"	5

3.2.2.2 Frameworks and protocols

There are also a group of issues related to the adoption of a common set of standards for UxV design (particularly for communication and networking protocols), associated with the 'HF Engineering', 'System Safety' and 'Social and Organisational' HFI domains. These issues are shown in Table 2, and as can be seen this group of issues also attracted the highest P+I score throughout (certain probability + highest impact), and similarly are a high priority consideration for the MAPLE programme.

Table 2 All issues associated with frameworks and protocols, together with P+I score

Issues (ID and title)		Descriptor	P+I
I-0005	Open architectures	"It will be crucial for system designers to adopt a modular approach, using open architectures (i.e. using principles of service oriented architectures) and standards (including for communication and networks)"	9
I-0006	Emergency recovery protocols	"Emergency recovery protocols must ensure that unmanned systems can be stopped and recovered at any time during operations"	9
I-0007	Legislative and regulative frameworks	"The development of legislative and regulative frameworks will be a high priority"	9

3.2.3 Summary of risks

This sub section reports all of the risks captured by the EHFA workshop. According to [6], "A risk is an uncertain event for which the probability of occurrence should be assessed".

3.2.3.1 Manning and training methods

A key group of risks, which emerged from the EHFA workshop, pertain to both manning levels and training methodologies (associated with the 'Manpower', 'Training' and 'Social and Organisational' HFI domains) are shown in Table 3. Only one of these risks attracted the highest P+I score (R-0001), however R-0017 (inappropriate expectation) was rated as high probability + medium impact (P+I = 5). Consequently, both of these risks are a priority for mitigation planning.

Table 3 All issues associated with frameworks and protocols, together with P+I score

Risks (ID and title)		Descriptor	P+I
R-0001	Current manning levels	"There is a risk that current manning levels may not support change to tasking"	6
R-0017	Inappropriate expectation	"There is a risk of inappropriate expectations that using UxV systems will reduce manning levels"	5
R-0002	Government directive to reduce manning levels	"There is a risk that UK government will issue a(nother) directive to reduce manpower, in which case manning levels will be insufficient"	4
R-0004	Training technologies	"Emerging training technologies (e.g., VR / AR / AI) may have a negative impact (e.g. through disconnection and disorientation) on the development of operator's knowledge, skills and attitudes (KSA)"	4

3.2.3.2 Human-machine interaction

There are a number of risks associated with human-machine interaction and the human machine interface (associated with the 'HF Engineering', 'Health Hazards' and 'System Safety' HFI domains), listed below in Table 4. Only one of these risks attracted the highest probability + impact score (R-0008), however a group of three risks (R-0005, R-0010 and R-0011) were rated as either high probability + medium impact or medium probability + high impact (P+I = 5). Consequently, these four risks are priorities for appropriate mitigation.

Table 4 All risks associated with human machine interaction, together P+I score

Risks (ID and title)		Descriptor	P+I
R-0008	Operator Overload	"There is a risk that managing large numbers of unmanned systems, particularly during novel scenarios, will result in overload"	6
R-0005	HMI development	"As unmanned systems are developed a corresponding development of HMIs may also be necessary (e.g., incorporating AR / VR / AI), with design features to enhance trust"	5
R-0010	Reduced situation awareness	"There is a risk of reduced SA, as well as impaired decision making capabilities, due to increased automation"	5

R-0011	Task disengagement	"There is a risk that long vigilance / monitoring periods will result in task disengagement"	5
R-0006	Trust	"There is a risk that trust / confidence in automated systems will be low, impacting deployment and efficacy"	3
R-0007	Over confidence	"There is a risk of over confidence in UxV systems, thereby impacting on mission delivery and safety"	3

3.2.3.3 Safety considerations

Table 5 illustrates two risks reported pertaining to the system safety HFI domain. One of these risks (R-0012) attracted the second highest P+I score, medium probability + high impact (P+I = 5), the other (R-0013) attracted the third highest P+I score, medium probability + medium impact (P+I = 4). R-0012 will be a priority for appropriate mitigation.

Table 5 All risks associated with system safety, together with P+I score

Risks (ID and title)		Descriptor	P+I
R-0009	Safety checks	"Safety critical factors (including weaponisation and use of sensors for targeting) will affect the time required to perform safety checks of the C3 system"	5
R-0012	Information accuracy	"There is a risk that the UxV provides incorrect information, driving inappropriate / incorrect response from C3 operators"	5
R-0013	Maintenance	"If UxV C3 systems are classified as safety critical then additional / higher levels of maintenance will be required"	4

3.2.3.4 Organisational structures

The final group of risks pertains to the potential impact on organisational structures as shown in Table 6. Two of these risks (R-0014 and R-0016) attracted the second highest P+I score, medium probability + high impact (P+I = 5), the other two (R-0015 and R-0018) attracted the third highest P+I score, medium probability + medium impact (P+I = 4). Clearly then R-0014 and R-0016 will be priorities for appropriate mitigation, as will R-0015 and R-0018 although with a slightly lower priority.

Table 6 All risks associated with system safety, together with P+I score

Risks (ID and title)		Descriptor	P+I
R-0014	Platform organisational structures	"The introduction of unmanned systems will impact on platform organisational structures"	5
R-0016	Cultural resistance	"There is a risk of considerable cultural resistance to UxV uptake"	5
R-0015	RN organisational structures	"There is a risk that the introduction of unmanned systems will impact on RN organisational structures / career pyramids"	4
R-0018	Job satisfaction and motivation	"There is a risk that using UxV systems will negatively impact job satisfaction and motivation"	4

3.2.4 Opportunities

This sub section reports all of the opportunities captured by the EHFA workshop. According to [6], "An opportunity is, in effect, a risk with the possibility of positive consequences. The process for managing opportunities is very similar to that for managing risks and issues".

As can be seen in Table 7, there are two opportunities in the training domain (O-0002 and O-0003), an opportunity to address the manning levels (O-0001), and a related opportunity to introduce operator monitoring protocols (O-0004) to improve effectiveness of team / role allocation management. Additionally there is an opportunity to improve operational procedures (O-0005) and job satisfaction (O-0008), as well as continue with autonomous vehicle research (O-0006), particularly for multi-platform coalitions (O-0007). The majority of these opportunities were rated as medium probability + medium impact (P+I = 4), however the highest rated opportunity (autonomous vehicle research O-0006) was rated as high probability + medium impact (P+I = 5), and consequently ought to be the primary focus for future business.

Table 7 All reported opportunities, together with P+I score

Opportunities (ID and title)		Descriptor	P+I
O-0006	Autonomy research	"The autonomous vehicles space is well funded and is a priority for UK defence spending"	5
O-0002	Emerging training technologies	"The potential of emerging training technologies (e.g. VR/AR/AI) to enhance understanding of a systems plan/decision/action should be harnessed and used to help develop Operator trust/acceptance of new technology"	4

O-0003	On-board training	"There is an opportunity to use emerging technologies (e.g., VR/AR) to conduct training on-board platforms in order to keep pace with rapid technological development"	4
O-0004	Operator monitoring	"Human psychophysiological monitoring technologies can be embedded into UxV control hardware, and used to monitor operator engagement/task loading/awareness and reaction time and optimise C3 human machine teaming"	4
O-0005	Operational procedures	"Incorporating UxV C3 capability will lead to changes to operational procedures, which will enable every ship to have access to all deployed assets / capabilities"	4
O-0007	Multi-platform coalitions	"There is an opportunity to improve targeting and sensor performance, through multi-platforms coalitions"	4
O-0008	Job satisfaction and motivation	"There is an opportunity that to use UxV systems to positively impact job satisfaction and motivation"	4
O-0001	Manning levels	"Additional study will be required in order to address overall manning issues (this should be included in the roadmap)"	1

3.2.5 Summary of key risks, issues and opportunities

Shown below in Table 8 are the highest rated risks, issues and opportunities, ranked according to P+I scores.

Table 8 Top seven rated risks, issues and opportunities. Ranked according to P+I score, with colour coding shown

Rank	Risks			Issues			Opportunities		
1st	R-0001	Current manning levels	6	I-0001	No Target Audience Description (TAD)	9	O-0006	Autonomy research	5
2nd	R-0008	Operator overload	6	I-0002	Training requirement	9	O-0002	Emerging training technologies	4

3rd	R-0009	Safety checks	6	I-0003	Training requirement (weaponisation)	9	O-0003	On-board training	4
4th	R-0002	Government directive to reduce future manning levels	5	I-0005	Open architectures	9	O-0004	Operator monitoring	4
5th	R-0005	HMI development	5	I-0006	Emergency recovery protocols	9	O-0005	Operational procedures	4
6th	R-0010	Reduced situation awareness	5	I-0007	Legislative and regulative frameworks	9	O-0007	Multi-platform coalitions	4
7th	R-0011	Task disengagement	5	I-0004	Maintainer's KSAs	5	O-0008	Job satisfaction and motivation	4

3.2.6 Assumptions and dependencies

The following sub-section describes assumptions and dependencies associated with the C3 of UXVs. Assumptions and dependencies are not given a P+I score, consequently no ratings or rankings are provided.

3.2.6.1 Assumptions

This sub section reports all of the assumptions captured by the EHFA workshop. According to [6], an assumption is “a consideration that is set as true to enable a project to proceed”. Table 9 shows all of the assumptions which will likely act as constraints on UxV capability development. As can be seen in Table 9, there are a number of training / manning assumptions (A-0001, A-0002, A-0004, A-0008), as well as group of assumptions pertaining to recruitment (A-0005), career structures / staff roles (A-0006 and A-0007) and technical / regulatory based assumptions (A-0009 – A-0013).

Table 9 All reported programmatic assumptions

Assumptions (ID and title)		Descriptor
A-0001	Current manning levels	There will be no increase in overall manning
A-0002	Manning levels (holistic)	Manning levels will be considered holistically (i.e. adding in new roles or changing the responsibilities of existing roles will impact multiple interconnected functions)

A-0003	C3 hub in operations room	In 2030 timeframe the Operations room will still be the C3 hub
A-0004	Skills and competencies	Skills and competencies will be developed to support UxV tasking
A-0005	Recruitment strategy	Recruitment strategy / levels will either change or will be made sufficient to support UxV operations
A-0006	Career pyramids	Career pyramids and structures will remain unchanged / unaffected by new capability
A-0007	Staff roles	Staff roles which currently cover C3 decision making tasks will remain the same. However operator level roles and responsibilities will change
A-0008	Training burden	It is assumed that it will be possible to broaden expertise of existing personnel without increasing training pipeline burden
A-0009	C3 HCI	It is assumed that interface for the C3 of UxVs, will conform to appropriate HF standards and guidance materials
A-0010	Safety case	A robust safety case is required that covers human-centred issues, risks and constraints
A-0011	Failure modes	User reactions to failure modes need to be considered during the design process
A-0012	Rules of Engagement (ROE)	ROE will need to keep pace with developing UXV system capabilities
A-0013	Regulation and legislation	RN will utilise UxVs in advance of regulation and legislation catching up with UxV operations

3.2.6.1 Dependencies

This sub section reports all of the dependencies captured by the EHFA workshop. According to [6], a dependency is "a consideration that must be met to enable a project's delivery. Dependencies must be identified and tracked as they will impact on the projects delivery". Table 10 shows all of the dependencies which will likely act as constraints on UxV capability development. As can be seen in Table 10, the dependencies captured during the EHFA workshop are distributed across the HFI domains (with the exception of the 'System Safety' domain, for which no dependencies were recorded). For examples, 'Manning' and 'Personnel' (D-0001 and D-0002 respectively), 'Training' (D-0003), 'HF Engineering' (D-0004), 'Health Hazards' (D-0005), and 'Social / Organisational' (D-0006 and D-0007).

Table 10 All reported programmatic dependencies

Assumptions (ID and title)		Descriptor
D-0001	Manning levels are dependent	Before manpower requirements can be specified it will be necessary to specify the level of automation of individual UxVs (i.e., minimum / mandatory levels of autonomy, legislative boundaries of autonomous decision making, maximum number of autonomous assets under command)
D-0002	Competencies and Knowledge, Skills and Attitudes (KSAs)	Personnel will need to be kept aware of the impact that the C3 unmanned systems may have on future roles, competencies and KSAs
D-0003	Training Audience Description (TAD)	Training requirements must be considered sufficiently early to ensure training pipeline needs are met. A Target Audience Description (TAD) is needed to support MAPLE, and this will enable a Training Needs Analysis to be developed
D-0004	Evaluation and assurance	There is a dependency on appropriately specified test, evaluation and assurance procedures, including those related to the human element
D-0005	Task loading	Task loading associated with UxV C3 will need to be understood in order to put appropriate mitigations in place to avoid overloading
D-0006	Tactical doctrine	New tactical doctrine will need to be produced to incorporate unmanned systems
D-0007	Expectation management	There will be a need to build trust with RN stakeholders, by providing education (to all levels of RN structure) on what autonomy does and does not provide

3.2.5 HFI considerations totals per HFI domain

For summary purposes, Figure 3 shows the distribution of HFI considerations per HFI domain. As can be seen in Figure 3, all considerations are summed together and percentage totals per HFI domain are shown. Whilst the HF considerations are (for the most part) evenly distributed, the largest proportion of HFI considerations was reported for the ‘Social and Organisational’ domain (25% of total HFI considerations). ‘Manpower’, ‘Training’ and ‘System Safety’ each accounted for ~15% of the total, whilst ‘Personnel’ accounted for 12%. The least frequently occurring HFI consideration pertained to ‘Health Hazards’, accounting for only 4% of the total.

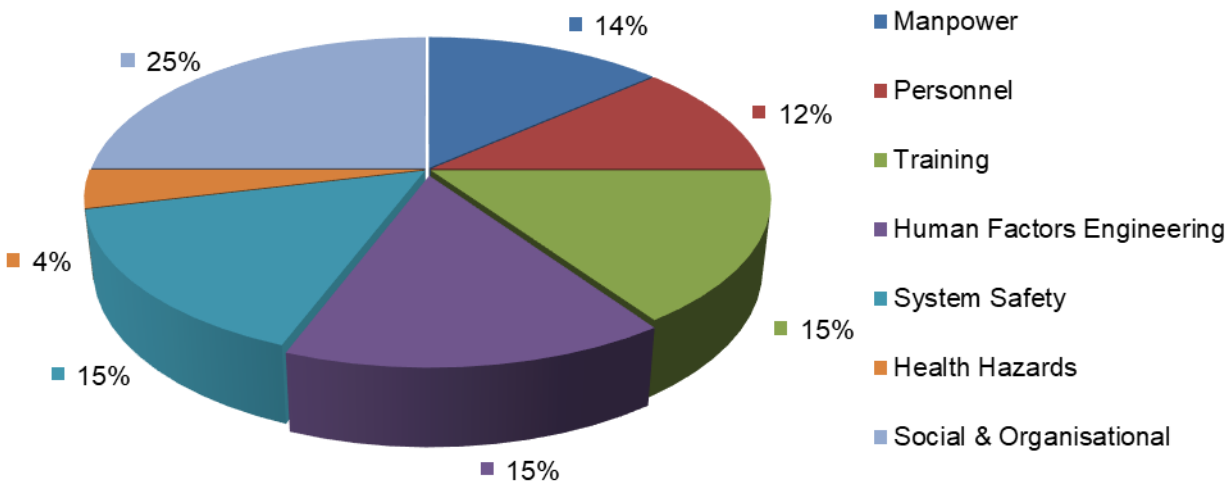

Figure 3 Distribution of HF considerations across HFI domains

4.0 Conclusions and recommendations

4.1 Conclusions

The main conclusion of this current work is that in order to achieve successful integration of UxVs into the maritime domain there will be a considerable amount of 'Social and Organisational' change needed. Essentially, this will include changes to legislative and regulative frameworks, platform organisational structures and RN organisational structures. Additionally, capability developers will need to overcome cultural resistance and inaccurate / inappropriate expectations (e.g., the expectation that UxVs will reduce manning levels, or at least not increase them).

In addition, the other key conclusion which emerges from this current work, and which aligns with previous findings, is there will be considerable effort involved in identifying training requirements, and incorporating new training technologies / methodologies, whilst not increasing the training burden. This may also qualify as an 'inappropriate expectation', particularly if (as seems likely) additional recruitment will be needed to support this new capability. A Target Audience Description (TAD) is needed to support MAPLE, and this will enable a Training Needs Analysis to be developed.

4.2 Recommendations

Taken together this mix of issues, risks, assumption and dependencies, associated with training and manning levels, as well as legislative / regulatory frameworks, indicates that further work is required to fully understand these HFI considerations and appropriately specify mitigation where required. This requirement for further research is captured by opportunity O-0006, which posits that: "the autonomous vehicles space is well funded and is a priority for UK defence spending".

It is recommended that RAIDO logs (i.e. risk registers) are considered live documents, and should therefore

be re-visited and updated with respect to any new considerations as they emerge throughout the CADMID lifecyle. For the MAPLE programme the RAIDO log will be updated again after a series of experiments investigating levels of automation and control of multiple assets in a synthetic environment. Once updated, the output of this work will provide a high level reference point for the procurement and integration of UxVs in the Maritime domain.

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