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UAV operator decision-making in a Search and Rescue Application

UAV Operator Decision-making in a Search and Rescue Application

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Abstract

Uncrewed Aerial Vehicles (UAVs) within Search and Rescue (SAR) applications can improve the effectiveness and safety of individuals working on the ground. However, the task of detecting a human within the images collected by UAVs is challenging. For this reason, the development of automated image classification aids have the capability to improve the effectiveness of target identification. Such automated technology can be viewed as part of a Decision Support System (DSS) with the potential to improve the decision-making processes of the individuals responsible for analysing UAV imagery in real time. Until now, research looking at the integration of automated functionality has focused on the complexities of piloting and navigating UAVs. As a result, the role of the operator has been somewhat neglected. Given that DSS are yet to be integrated within SAR applications, there is an opportunity to ensure their design meets the user requirements of the operators. This research seeks to understand the decision-making processes employed within a UAV team, comprising a Payload Operator and Pilot, when searching for a missing person.

Three types of decision models were investigated: the Recognition Primed Decision Model; the Perceptual Cycle Model, and Decision Ladders. To generate the models, five in-depth interviews were conducted with UAV operators currently working within SAR teams across the UK. The different decision models identified the aspects of decision-making that could be supported with decision aids. From this understanding, each model was used to propose unique design recommendations for a future DSS capable of guiding a Payload Operator's decision-making process. Suggestions for future work are made to ensure DSS development continues to involve the end-user as part of a user-centred design approach.

Keywords: Uncrewed Aerial Vehicles (UAVs); Search and Rescue (SAR); Decision Modelling; Decision Support System (DSS); Automated Imagery Analysis; Payload Operator

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Having returned to do a post-grad after a year and a half of working full-time, I was doubtful about doing an MRes - so doubtful that I procrastinated filling out the application until my big sister and saviour, Chloe, sat me down and made sure that I did (contrary to belief, she did not force me to write that). I am immensely thankful that she did, and for her continuous support throughout the MRes. Another person I credit for encouraging and preparing me for this experience is Kiome – and for that I am grateful. To my younger sister, Poppy, thank you for always being there for an impromptu FaceTime call whenever I need to talk about something (or in most cases, nothing). To my future brother-in-law, Alex, thank you for answering any of my stupid academic questions. Maybe one day we will collaborate on a paper. Finally, I'd like to thank my Mum and Dad for providing an endless supply of crumpets, a roof over my head, and for supporting me throughout the year.

Author's Declaration

I declare that the work in this dissertation was carried out in accordance with the requirements of the University's *Regulations and Code of Practice for Research Degree Programmes* and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, the work is the candidate's own work. Work done in collaboration with, or with the assistance of, others, is indicated as such. Any views expressed in the dissertation are those of the author.

SIGNED: …………….Sophie Hart……………………… DATE: ……………..02/03/2023…………………….

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Acronyms & Abbreviations

Acronym	Definition
BU	Bottom-up
CAA	Civil Aviation Authority
CDM	Critical Decision Method
CTA	Cognitive Task Analysis
CWA	Cognitive Work Analysis
DSS	Decision Support System
GPS	Global Positioning System
HF	Human Factors
HFI	Human Factors Integration
HMI	Human Machine Interface
INS	Inertial Navigation System
MISPER	Missing Person
MREaW	Mountain Rescue England and Wales
MRT	Mountain Rescue Team
MWL	Mental Workload
NDM	Naturalistic Decision-making
ODD	Operational Design Domain
OESD	Operator Event Sequence Diagram
PCM	Perceptual Cycle Model
PNF	Pilot Not Flying
PoD	Probability of Detection
RPDM	Recognition Primed Decision Model
SA	Situation Awareness
SAR	Search and Rescue
SAW	Schema World Action
SDF	Systems Design Framework
SRK	Skills, Rules, Knowledge
SME	Subject Matter Expert
SoA	Sense of Agency
SOP	Standard Operating Procedure
SVP	Serial Visual Presentation
SWARM	Schema World Action Research Method
TD	Top-down
UAV	Uncrewed Aerial Vehicle
UK	United Kingdom
UxV	Uncrewed Vehicle
WK	Watchkeeper

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Chapter 1 Introducing automation within the SAR environment: implications, challenges, and research directions

1.1 Introduction

Plant and Stanton (2016a) described Search and Rescue (SAR) as "the task of searching for missing persons or locating and recovering persons in distress and delivering them to a place of safety" (p. 1355). In the United Kingdom (UK), the skill and experience of voluntary SAR organisations are leveraged by the police to support the planning and execution of SAR missions (Greene & Alys, 2016). Mountain Rescue England and Wales (MREaW) represents one of the five organisations accessed by the police (Greene & Alys, 2016). Each year, Mountain Rescue teams respond to hundreds of callouts, with the number of deployments showing little sign of decreasing in the near-future (see Figure 1).

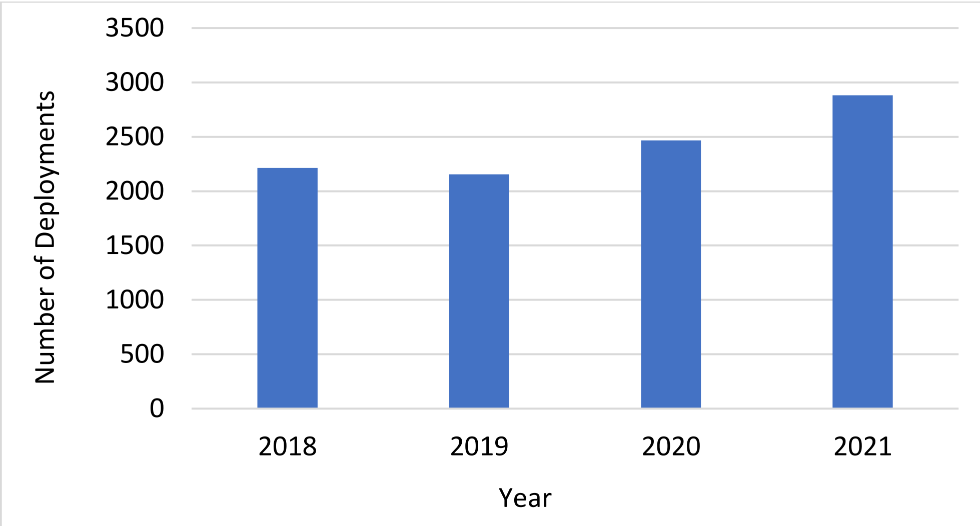

Figure 1. *Frequency of SAR deployments by MREaW (MREaW, 2019, 2020, 2021, 2022a)*

During each mission, SAR responders work within hazardous climates and terrain, often putting their lives in danger in pursuit of the rescue effort (Lois, 2003). They also frequently work under temporal pressure due to the limited survival time of the victim and dynamically changing environmental conditions (J.L. Adams et al., 2007; Waharte & Trigoni, 2010). More recently, Uncrewed Aerial Vehicle (UAV) technology are being sought to minimise the risk exposed to SAR responders and increase the lifesaving capability of SAR teams (Maritime & Coastguard Agency, 2020). This is owing to the numerous benefits offered by their deployment, including, but not limited to:

- rapid surface area coverage (Goodrich et al., 2007; Karaca et al., 2018);
- ability to investigate difficult-to-reach locations (e.g., Van Tilburg, 2017);
- provide evidence to inform the allocation of resources (Anderson et al., 2021);

- supplement knowledge of the environment (Tuśnio & Wróblewski, 2022);
- restore signal lost from communication devices (McRae et al., 2021);
- deliver lifesaving equipment to victims (Bäckman et al., 2018; Van Tilburg, 2017);
- and provide the capability to communicate with the injured or missing persons using onboard speakers (C. Burke et al., 2019).

However, these benefits can only be achieved when the UAV is interacted with efficiently. This interaction applies to the way in which the UAV is flown, and the analysis of the payload data by the team of human operators responsible for managing the UAV (Murphy, 2004). Section 1.2 and 1.3 explore the composition of current UAV teams within the SAR context. In order to support these UAV teams, automation is being viewed as a key facilitator for extending the capabilities of a system by managing the limited resources available within the human team (Chiou et al., 2022). Section 1.4 discusses the implications of automatic imagery analysis and identifies the potential pitfalls of integrating automated functionality within a SAR application. In an effort to manage these issues, section 1.5 suggests directions for future work that seek to leverage existing HF methods to support the development of systems designed with the decision-making processes of the human operator in mind.

To that end, the questions that will be examined in this thesis are as follows:

1. What are the decision-making processes of SAR teams when deploying UAVs to support a SAR mission?
2. In what ways can insight into these decision-making processes be used to design a user-centred Decision Support System (DSS) to assist the Payload Operator?

1.2 UAVs for SAR: a tale of success and complexity

Already UAVs have demonstrated their capability to save lives. In a recent incident, coastguards in the Mediterranean deployed a UAV to locate and transport lifesaving equipment to a drowning person, which, in turn, bought valuable time for lifeguards to rescue and treat the individual (Hahn, 2022). There are some notable points to take away from this particular event. Firstly, the UAV did not remove the requirement for human involvement as lifeguards ultimately recovered the victim and provided the critical medical attention. Secondly, the manoeuver carried out by the UAV team to reach the victim was complex due to the heavy ocean waves, highlighting the skill and centrality of the human operator throughout the UAV mission. Lastly, within the SAR environment there were multiple social and technological agents operating alongside one another to achieve a common goal, to rescue the individual in danger. Together, these three points elucidate the nature of the UAV as additional system tool, rather than a replacement for the human responder. This is because the skill and presence of human operators were both critical components for securing the success of the rescue effort. It is therefore important to establish a partnership between the UAV and human operator to manage the tasks and constraints involved during a UAV-equipped SAR response (Mouloua et al., 2001).

This case study also demonstrates that a rescue response, be it with or without a UAV, is not the output of any one individual. Instead, every responder within the SAR service works interdependently to achieve an overall goal. Within this systemic structure, both human and non-human agents complete loosely coupled tasks to achieve sub-goals that ensure for safe and efficient SAR operations (Plant & Stanton, 2016a). To that end, the SAR environment can be viewed as a sociotechnical system (Walker et al., 2008).

1.3 Teamwork makes the dreamwork

Typically, SAR teams operate small UAV models that are available 'off the shelf', commonly known as drones (C. Burke et al., 2019). For the sake of consistency, the term UAV will be used here. To control and monitor the data incoming from the UAV, a team of human operators work together to achieve the objective of the UAV mission (Goodrich et al., 2008). Within this UAV team there are typically two human operators present: a UAV Pilot and a Payload Operator[1] (Khan et al., 2020; Peschel et al., 2022). Table 1 provides a high-level overview of the responsibilities of each operator in the UAV team.

Table 1. Responsibilities of the human UAV operators

Operator role	Responsibilities
Pilot	• Navigate the UAV via a rudder and/or control stick within line of sight (Peschel & Murphy, 2013; Murphy et al., 2008) • Maintain awareness of UAV health and air worthiness (Murphy, Pratt & J.L. Burke, 2008) • Monitor the environment for other aircraft users (Murphy et al., 2008) • Safely launch and land the UAV (Drury et al., 2006)
Payload Operator	• Interpret data obtained by the UAV payload sensors (e.g., aerial imagery) (Calhoun et al., 2006) • Direct the UAV Pilot to navigate the vehicle to points of interest (Peschel & Murphy, 2013) • Confirm when the UAV mission is achieved (Peschel & Murphy, 2013)

[1] There is little consistency on the terminology used to describe the operator responsible for aerial imagery analysis. In some applications the role is referred to as an observer, sensor operator, or mission specialist. The term 'Payload Operator' is used in the current work.

The roles of the Pilot and Payload Operator are akin to the role of a traditional aircraft Pilot and Pilot Not Flying (PNF) respectively (Plant & Stanton, 2013b, 2016a). Where a UAV Pilot is responsible for navigating the aircraft (cf. traditional Pilot) the Payload Operator monitors the incoming data from the UAV payload sensors and cross-checks the actions of the UAV Pilot, much like the PNF (Murphy et al., 2008). This adds further evidence of the interdependencies between each operator role within the sociotechnical system.

The challenges associated with operating UAVs from a distant location, also known as teleoperation, has prompted a body of work looking at the implementation of automated functionality (e.g., Chen, 2010) and the design of usable Human Machine Interfaces (HMI) to support the UAV Pilot (e.g., Lercel & Andrews, 2021; Neville et al., 2012). Whilst these research contributions have been revolutionary for improving the user experience of the Pilot, the role of the Payload Operator has mostly been neglected (Peschel & Murphy, 2013). This is despite the skill required to manually interpret and extrapolate information from the payload sensors (Daud et al., 2022; Silvagni et al., 2017).

1.3.1 Examining the role of the Payload Operator

The task of visually searching aerial imagery for a target should not be underestimated. The process is heavily dependent on the capabilities of the Payload Operator for perceptually selecting and identifying objects of interest (Wolfe & Gray, 2007; Woodman & Luck, 2003). In the context of SAR missions, these objects can manifest as sightings of a missing person (MISPER) or hazards in the environment that require careful navigation to prevent damaging the UAV (e.g., National Science Foundation, 2005). Failure to identify either of these items could compromise the benefits of equipping UAVs within SAR environments.

There are, however, several challenges associated with visually searching aerial images. First, the difficulty of the Payload Operator's task is often compounded by the state of the aerial image itself. Given that UAVs collect and transmit aerial images in-flight, the stability of the UAV can result in obscured, blurry images (Murphy, 2014). This can reduce the operator's ability to detect sightings of interest within the imagery in real-time whilst also impoverishing the aggregation of any emergent findings with other available sources of data [e.g., Global Positioning System (GPS) information]. Further, environmental factors such as the weather and complexity of the terrain can further heighten this task difficulty (Humann & Spero, 2018; Rosenholtz et al., 2007). The Payload Operator must manage these constraints whilst ensuring the influx of UAV imagery is being sufficiently attended to, even when the acquisition rate of the sensor payloads surpasses the attentional resources of the Payload Operator (Morison et al., 2015).

Whilst humans are exceptional at detecting targets within their 3D environments, the teleoperation of UAVs means that all aerial images must be viewed on a 2D display (Hopper, 2000). This configuration decouples the Payload Operator from their natural 3D environment and can constrain their relatively high perceptual capabilities due to a lack of sensory cues and temporal delays in the feedback of data received from the UAV (McCarley & Wickens, 2005). The display technology must therefore support the tasks and responsibilities of the Payload Operator; however, concerns have been raised over the appropriateness of current UAV interfaces for meeting this requirement. Peschel and Murphy (2013) argued that the robustness of the Payload Operator's performance could be limited by their HMI display which is often mirrored from the UAV Pilot's interface. The user requirements for the Payload Operator may not be encapsulated within the Pilots' interface, indicating that current technology could hinder the analysis of incoming UAV data (Peschel et al., 2022). A recent UAV incident involving the crash of a Watchkeeper (WK) over West Wales airport provides some support for this (Lynch et al., 2022). During a routine exercise, a team of UAV operators incorrectly assumed their vehicle had landed based on environmental cues displayed within the aerial imagery. In response, the UAV team manually aborted the UAV landing, resulting in the vehicle crashing ~40 feet from the ground (Lynch et al., 2022). This misperception demonstrates the poor decision-making that can ensue following inaccurate imagery analysis and indicates that further support is required to assist with the comprehension of the UAV's environment.

It appears that both Off the Shelf and military UAV systems place a high reliance on the Payload Operator to manually search for features within the aerial imagery in real-time. However, human error is an inevitable by-product within any complex system (Dekker, 2017; Peters & Peters, 2006). Even with the best of intentions, the visual cognitive system can contribute to false alarms and misses during object identification tasks (Chan & Chan, 2022; Harris et al., 2012). Such error can partially be attributed to the saliency (Fincannon et al., 2013), prevalence (Godwin et al., 2015; Wolfe et al., 2007), and state of the objects contained in the imagery (Lygouras et al., 2019). It is also possible for the expectations of the Payload Operator to impact the detection of a sighting (Chen & Zelinsky, 2006). In that sense, top-down processing represents an influential factor when identifying potential sightings within an aerial image. For example, the visual search of the Payload Operator can become prejudiced due to their pre-conceived expectations surrounding a SAR mission; this is a phenomenon known as confirmation bias (Nickerson, 1998). The repetitive nature of visually scanning a set of stimuli for an extended period of time is a mundane, yet mentally taxing task. In that sense, confirmation bias serves as a strategy for managing the limited pool of cognitive resources available to the Payload Operator (Rajsic et al., 2015).

Evidently, there is a high reliance on the Payload Operator to act with rigour and accuracy when feature searching the aerial imagery collected by the UAV. In order to reduce the burden placed on the Payload Operator, automated functionality is widely viewed as a tool that could facilitate progress by assuming aspects of the human operator's tasks (Pawełczyk & Wojtyra, 2020). The development of such technology could serve to optimise the decision-making processes within the UAV team through the acquisition of information, which, in turn, would benefit the wider SAR effort.

1.4 Considering the Implications of Automated Aerial Imagery Analysis

Rapid advances in Artificial Intelligence are enabling the development of support systems to assist with the task of imagery analysis. The functionality for current support systems typically includes automatic object detections, classifications, and confidence intervals that estimate the automated systems accuracy in its output (Sun et al., 2016; Zhao et al., 2019). Nevertheless, there have been technical challenges with developing fool-proof automated imagery analyst systems (Jain et al., 2021; Yu et al., 2020). The unreliable nature of these automated systems means that the Payload Operators' involvement is not redundant. Therefore, future systems developed with functionality for automated imagery analysis should be designed with the human operator in mind (Banks & Stanton, 2017). This is especially true given that system designers seek to leverage these autonomous functions to introduce novel concepts of operation, such as merging the roles of the UAV Pilot and Payload Operator (Cooper & Goodrich, 2008) and multi-UAV teams (Waharte et al., 2009).

1.4.1 Changing the Role of the Payload Operator

Presently, the majority of tasks carried out by the Payload Operator are conducted manually (C. Burke et al., 2019). Yet, as the integration of automated functionality takes place, so too does the evolution of the Payload Operator's responsibilities. Embedding automated actors within a UAV system shifts their current role from a manual to a supervisory position, with little to no control inputs being exerted by the Payload Operator (Sheridan, 1992, 2016). Under this supervisory role, physical intervention by the human operator would, in theory, only be required when the automated system's Operational Design Domain (ODD) is compromised. The ODD refers to the conditions that an autonomous or automated system is designed to operate under (Colwell et al., 2018). When these conditions are no longer met, a transfer of control is required from the automated agent to the human operator (Banks, Eriksson, et al., 2018). However, the diagnosis of these automation failures can be complex and leaves the human as a last line of defence for preventing critical events (e.g., UAV collisions) (Li & Greaves, 2014; Ramos & Mosleh, 2021).

The continued importance of the human operator as a 'safety barrier' or key decision-maker, implicates the need to keep the Payload Operator in-the-loop; essentially working in a partnership with the autonomous system (Kaber, 2018). In light of this newfound partnership, it is important to understand the emergent human-automation interaction issues introduced by the integration of automated functionality (Banks & Stanton, 2017; Parasuraman et al., 2008).

1.4.2 Human-Automation Interaction Issues

Human Factors (HF) research has shown continuous trends on the types of human-automation interaction issues that emerge within automated systems (Banks & Stanton, 2017; Parasuraman et al., 2008). However, current research has not yet considered the way in which these issues could impact a Payload Operator. Therefore, the following sections provide an overview of these issues and how they could impact a Payload Operator when provided with functionality for automated imagery analysis.

Managing Mental Workload. Mental Workload (MWL) is defined as "the perceived relationship between the amount of mental processing capability or resources and the amount required by the task" (Hart & Staveland, 1988). The task of manually analysing imagery is considered to be cognitively demanding due to the considerable amount of attentional resources that must be expended over time (Bertuccelli et al., 2010). It is widely accepted that automation holds the potential to reduce an operator's MWL (Balfe et al., 2015; Dadashi et al., 2013). Indeed, Rogers et al. (2019) revealed that UAV systems supported with automatic object detection technology decreased the MWL of the Payload Operator. However, Banks et al. (2014) argue that the introduction of automated agents within pre-existing systems can increase the number and complexity of the interactions required between the human and automated agents. This alteration can place higher cognitive demands on the human operator, resulting in inadvertent increases in workload (Banks et al., 2014). High levels of MWL are associated with issues such as operator stress (Szalma et al., 2004; Wohleber et al., 2018) and fatigue (Gore, 2018; Szalma et al., 2004).

Conversely, the reduction in workload enabled by automated systems introduces the issue of work under-load (Young & Stanton, 2002). The supervisory role likely to be undertaken by the Payload Operator is characterised by tasks that require extensive periods of attention, such as system monitoring to determine where small adjustments to the system may be necessary (Banks & Stanton, 2019; Young et al., 2015). However, the monotonous nature of such tasking can result in performance degradation and errors. Young and Stanton (2002) explained that a human operator's attentional resource shrinks and grows in relation to the level of demand being faced in a given situation. In turn, when an operator is under stimulated, their attentional resource shrinks or is allocated to alternative tasks; essentially disengaging them from the activities of the automated system and increasing the likelihood of errors and lapses. Therefore, work under-load is equally problematic as work over-load, leading system designers to procure systems that aim to balance the MWL of the human operator. Prewett et al. (2010) implicated the need for optimal visual displays, multimodal feedback and reliable automation that fosters team work between the human operator and their associated technological agent (i.e., the automated system). This ensures that any abnormalities in performance can be detected and ameliorated for without overwhelming the human operator from sharp increases in workload. Equally, the attributes of the sociotechnical system should be considered when designing novel technologies in order to manage the uncertainty and unreliability which will inevitably be present within the work domain (Prewett et al., 2010). As such, the attributes of the SAR environment and its key constraints should be determined to ensure any future UAV systems are designed to assist the human in the management of these operational limitations.

Calibration of Trust. Researchers have continuously debated the meaning of trust owing to its complicated and multifaceted nature (Parnell, Fischer, et al., 2022). However, the general consensus is that trust represents an operator's subjective perception of the automated agent's performance relative to how well it is achieving the goal of the system (Lee & See, 2004; Sheridan, 2019). For an automatic classification algorithm, the Payload Operator could utilise the accuracy of object classification as an indicator of trust. The concept of trust can also be considered in relation to a generic system (e.g., trusting a UAV to execute control inputs; Parnell, Fischer et al., 2022) but it is more commonly associated with the level of trust delegated to automation (Lee & See, 2004; Mishler & Chen, 2023; Nam et al., 2018). This is because the level of trust placed within an automated system can guide the subsequent interactions between the human and the automated agents (Lee & See, 2004).

Trust is often described as something that can be calibrated, indicating that it is not a set construct and can be modified relative to users' perceptions of the system's performance (Hussein et al., 2019; Mishler & Chen, 2023). For this reason, trust is heavily associated with system reliability (Avril et al., 2022; Lee & Moray, 1992; Parasuraman & Miller, 2004). In order to develop effective partnerships within a human-automated system, trust must be calibrated appropriately (Chen et al., 2018; Tomsett et al., 2020). When an automated system is perceived to be performing reliably without fault, high levels of trust may be delegated to the automated agents, resulting in over-reliance on automation (Lee & See, 2004). Indeed, Lu and Sarter (2019) showed that participants monitoring aerial imagery with the support of reliable automatic object identification support displayed a tendency to monitor their HMI less, something that is indicative of operator complacency (Parasuraman & Riley, 1997). Conversely, a system deemed to be performing imperfectly could deplete the operators' trust in the automation and result in its disuse (Parasuraman & Riley, 1997).

As automation becomes more widely available for imagery analysis, system designers should seek to understand visualisations and design strategies that lend themselves towards appropriately calibrating trust (Helldin et al., 2013; Lee & See, 2004). Equally, training paradigms should ensure the functions and capabilities of the automated system are fully understood before it is utilised within a real-world context (Chavaillaz et al., 2016; Merriman et al., 2021).

Luggage screening at security checkpoints is a safety critical task that requires human personnel to visually scan X-ray images of baggage for potential weapons and explosives. This is achieved by distinguishing between a target (i.e., the weapon) and the visual background comprised of generic objects (e.g., newspaper) (Rieger et al., 2021). In that sense, the role of the security scanner shares similarities with the Payload Operator insofar that targets of interest (e.g., the MISPER, landmarks) are separated from the terrain. Airport scanners must exercise sustained periods of attention under increasing temporal pressures whilst also balancing the need for safety. As a result, the benefits for automation have already been explored within this domain to assist with the detection of weapons (Chavaillaz et al., 2018; Huegli et al., 2022; Rieger et al., 2021; Wiczorek & Meyer, 2019). The integration of automated systems within this domain has been found to improve the detection rate for explosive materials and weaponry (Chavaillaz et al., 2019; Huegli et al., 2022). However, the operators displayed complacent tendencies towards reliable automated systems. This resulted in a greater miss rates for weapons concealed within the passenger's baggage due to overreliance on the information provided by the automated system (Chavaillaz et al., 2018; Huegli et al., 2022). The benefits of automation were also diminished as the difficulty of the task increased (Rieger et al., 2021; Wiczorek & Meyer, 2019). This suggests that human operators are unwilling to relinquish control to the automated system during complex situations where ambiguity is higher. It is important that operators are able to calibrate trust in a way that manages the constraints of the automated technology and pressures imposed within the work domain. Within the context of baggage security scanning, Chavaillaz et al. (2018) cited the need for directive and reliable cues that guide attention when searching baggage. For this reason, when integrating automated functionality within a UAV system, the presentation of information should be designed to carefully to support the decision-making processes and behaviours of the SAR operator. This requires an understanding of what they are looking for and how this would be achieved using the current UAV system.

Sense of Agency. An emerging concept that is beginning to gain traction within the study of human-automation partnerships refers to an operator's Sense of Agency (SoA). Haggard and Chambon (2012) define SoA as the "experience of controlling one's own actions, and, through them, events in the outside world" (p. 1.). In other words, it is the sense of control that the human operator perceives within a given context, and the understanding that the control exerted will produce consequences. The passivity of the supervisory role is thought to reduce the human operator's SoA due to the reduced requirement for active input (Caspar et al., 2016; Ciardo et al., 2020; Limerick et al., 2014). However, recent findings suggest that hybrid autonomous team that divide operator responsibilities between the human and automated agents improved the users' SoA in comparison to a highly automated system (Ueda et al., 2021; Vantrepotte et al., 2022; Zanatto et al., 2021).

The relationship between SoA and objective task performance has been of less focus within the literature. However, Ueda et al. (2021) revealed that hybrid autonomous teaming improved task performance and maintained the users' SoA. It is thought that SoA can be leveraged to define the sweet spot for the optimal allocation of function when designing a human-automation system in a way that manages the MWL of the human operator, whilst still yielding the maximum benefits of automation (Barden et al., 2022; Vantrepotte et al., 2022). Nevertheless, the relationship between SoA and performance within a human-automation team requires further clarification. In particular, validation of SoA is required within a naturalistic setting as much of the available research on SoA has been conducted in a laboratory setting, limiting the generalisability of the findings. Even so, the implementation of automation appears to reduce the perceived control an operator has within the decision-making process (Starke & Baber, 2020). The removal of control is something designers should be cognisant of when developing DSS, such as image classification modules to ensure the Payload Operator does not perceive the automated system as a replacement for their role (Steane et al., 2023).

Degraded Situation Awareness. Endsley (1995) defined Situation Awareness (SA) as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future" (p. 36). The SA held by a human operator is viewed as a critical component for informing effective decision-making processes, and, by way of extension, their performance given that decision-making precludes the operators' subsequent behaviours and actions (Endsley et al., 2003). However, automated systems often lead to reductions in SA as the human operator becomes removed from the control loop (Endsley, 2017; Kaber & Endsley, 1997). When an operator experiences degraded SA, they are considered to be out-of-the-loop (Camblor et al., 2022; Endsley & Kiris, 1995). The higher the level of automation implemented, the greater the risk of an operator falling out-of-the-loop (Endsley & Kiris, 1995; Parasuraman & Riley, 1997). This can lead to a reduction in the human operators' awareness of the automated systems state and mode of operation due to impairments to their cognitive processing (Lee & See, 2004; Sarter & Woods, 1995; Young & Stanton, 2004).

It appears that the out-of-the-loop problem is also present when interacting with unmanned vehicle (UxV) technology. Indeed, degraded SA has been cited as an antecedent for deficient performance when using autonomous UxV technology during simulated SAR operations (J.L. Burke & Murphy, 2004; Murphy, 2004). Camblor et al. (2022) also identified degraded SA to be a contributory factor across 45 incidents involving robotics. To address this, the HMI that bridges the human operator to the vehicle is thought to be central for combatting the out-of-the-loop conundrum (Prewett et al., 2010; Riley et al., 2010).

An effective HMI must display the right information at the right time (Riley et al., 2010). To date, information requirements have been specified for UAV systems capable of autonomous navigation (e.g., Drury, et al., 2006). However, there has been less focus on the requirements for future imagery analyst systems and the way in which such technology can support the decision-making processes of UAV teams. In order to improve the SA of image analysts, such as Payload Operators, much effort has been placed on improving the manner in which aerial imagery is displayed to the human operator. Mardell et al. (2014) compared the impact of displaying the UAV's sensor payload data as a live video feed against a Serial Visual Presentation (SVP) mode wherein the UAV data was displayed as a set of static images. It was found that participants were significantly more accurate at a target identification task with the SVP mode, yet, an increase in false alarms was also observed (Mardell et al. 2014). In the context of a real-life SAR mission, the occurrence of a false alarm could result in the inappropriate re-allocation of team resources. Clearly, simply altering the presentation mode of the payload data does not provide an all-encompassing solution for improving the detection rate of the Payload Operator. Alternative approaches have sought to leverage 3D visualisation techniques (Lauterbach et al., 2019; Verykokou et al., 2016). System designers predict that the provision of 3D models would provide the impetus for improved strategic planning, structural inspections, and enhanced SA (Lauterbach et al., 2019). However, the practicality of such design solutions in a real-world context requires further exploration to understand how this visualization should be presented and what the end-user would extrapolate from such a resource. More importantly, the cues and information utilised by the Payload Operator should be understood to ensure any design interventions capture these requirements.

Human-automation interaction issues: a combined problem. Whilst the human-automation interaction issues were outlined independently, it is important that the intertwined nature of these issues are understood. Figure 2 presents the set of challenges identified within the literature and demonstrates the relationships between these human-automation interaction issues. The intertwined nature of human-automation interaction issues therefore warrants a careful design approach to appropriately and efficiently integrate functionality that facilitates automatic imagery analysis.

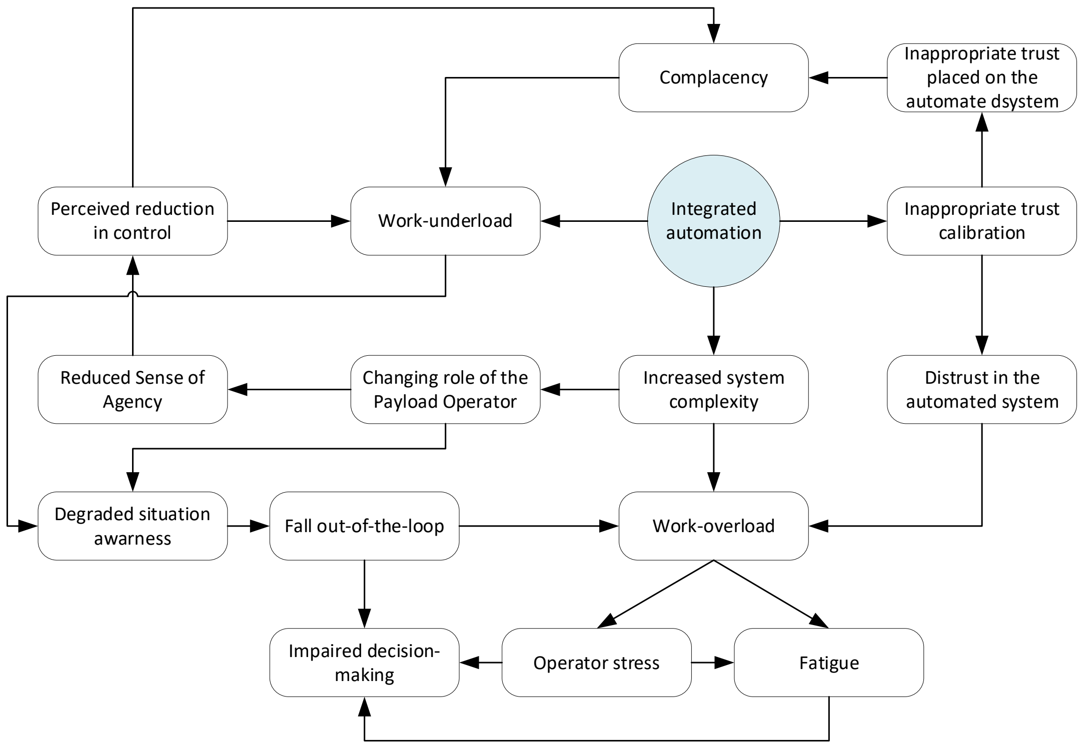

Figure 2. Human-automation interaction issues and their intertwined links

1.5 Managing System Complexity through Design

There are promising results regarding the development of novel visualisation strategies and automated technologies for imagery analysis (e.g., Lygouras et al., 2019; Macdonald, 2019). However, Dolata and Aleya (2022) assert that all too often designers focus on the technical aspects of the UAV and automated system capabilities, rather than the interaction between UAV systems and the human operator working at the ‘sharp end’ of the system. Whilst novel intervention strategies have been identified in this review, there has been little to no mention of researcher engagement with the end-users to understand their requirements and expectations for future UAV systems. Failure to involve the end-user at an early point of the design lifecycle has often culminated in systems associated with usability problems (Banks et al., 2018a).

An exemplary case study that demonstrates the need for Human Factors Integration (HFI) is the Predator UAV system currently used by the United States Defence Sector for Intelligence Surveillance and Reconnaissance missions (Boyne, 2009). Since its deployment in 1994, a number of HF issues have emerged as contributory factors across several UAV accidents; in particular, design errors (Carrigan et al., 2008; Williams, 2004). Indeed, 89% of predator accidents made reference to issues with the HMI (Williams, 2004). The displays were reportedly difficult to monitor due to the cluttered and distributed nature of information presented on the HMI. In addition, the display did not provide sufficient indication of the autopilot's mode of operation. This can give rise to issues such as mode error wherein the human operator performs inputs for the assumed system mode, as opposed to the actual system mode (Sarter et al., 1997; Banks & Stanton, 2017). In turn, when the system starts executing functions that violate the expectations of the user, the human operator is said to experience 'automation surprise' (Woods et al., 1994). Given that automation surprise has been implicated within previous critical incidents (e.g., Colgan AirFlight 3407; Geiselman et al., 2013) the importance of interfacing the state and mode of the system should be prioritised. Giese et al. (2013) argued that the ergonomic aspects of manned system HMI for the Predator UAV were overlooked to meet the demand for the vehicle's rapid integration within the Air Force. It is therefore not surprising that HF issues were found to be the most common causal factor among Predator UAV incidents, and evidently implicates the importance of HFI to mitigate for expensive design issues at latter stages of the design life cycle (Cullen, 2007).

In order to support the design and development of UAV systems and procedures, a sociotechnical systems approach has been advocated (Charalampidou et al., 2020; Dolata & Aleya, 2022; O'Neill et al., 2020). The systems approach prescribes a number of methods that have been widely used to inform the design of usable technology (Stanton et al., 2013). Within the approach, differing levels of analyses are available. Higher levels of analysis examine the system as a whole to identify each agent within the system and the interactions that take place among them (i.e., macro processes) (Foster et al., 2020). Conversely, lower levels of analyses models system interaction at an individual level in a way that is inclusive of the end-users' behaviour and cognition (i.e., micro processes) (Hamim et al., 2022). Given that the aim of the current work was to determine where the Payload Operator could be better supported, it seems reasonable to explore the utility of micro level analyses. One such method involves decision modelling. Decision models have been widely used in the HF domain to model the micro-level processes of human operators within the context of their sociotechnical system (e.g., Plant & Stanton, 2012). Their application has been used to ascertain design recommendations for automated decision aids in an effort to improve the decision-making processes of crewed aircraft Pilots (e.g., Banks et al., 2021; Parnell, Wynne, Griffin, et al., 2021). As such, the use of decision modelling to understand UAV operator decision-making in a SAR application will be investigated in the current work to support the design of a user-centred DSS that assists with the task of aerial imagery analysis.

1.5.1 Decision Modelling

Redish and Mizumori (2015) defined decision-making as the process of selecting an action that will have consequential effects in the world. This is a fairly simplistic definition and does not fully explain the way in which multiple human and non-human agents work collaboratively in a team to respond to a situation. Bicho et al. (2011) offered a more nuanced definition of decision-making, describing it as a joint task that occurs across a time continuum using information regarding the goals of the system, knowledge on what the response should comprise, and contextual information contained within the environment. Gaining an understanding of these processes is integral to ascertain 'why' and 'how' decision-making can become faulty (Banks et al., 2020). It follows the view that decision-making should be investigated with respect to the circumstances and factors that lead an operator to make a decision (Dekker, 2017).

Decision models provide an exploratory mechanism for acquiring insight on the processes and behaviours of human operators during both routine (e.g., McIlroy & Stanton, 2011, 2015) and non-routine (e.g., Plant & Stanton, 2012) situations. Several types of decision models exist within the HF domain. Broadly speaking, these models can be categorised as belonging to the Naturalistic Decision Making (NDM) approach or the formative approach (Hart et al., 2022).

1.5.2 The NDM Approach

The field of NDM has produced several models since its inception, however, there is much discourse surrounding the optimal decision model (Lipshitz, 1993). Even so, in recent years, only a subset of the original nine models outlined by Lipshitz (1993) have been used to explore decision-making within complex sociotechnical systems (Hart et al., 2022). Such models include the Recognition Primed Decision Model (RPDM; Klein, 1989) and the Perceptual Cycle Model (PCM; Neisser, 1976). The RPDM asserts that decision-making is grounded in the knowledge of the decision-maker that is obtained through experience and training (Klein, 1993). This knowledge enables the decision-maker to draw parallels between their current situation and events experienced in the past to identify an appropriate response plan (Klein, 1989). Yet, the model has been widely criticised for focusing on the cognitive processes of the human operator and neglecting the interaction between these internal knowledge structures and the operational environment (Plant & Stanton, 2012, 2015).

The limitations associated with the RPDM have led researchers to explore the utility of the PCM for modelling decision-making (e.g., Banks et al., 2021; Parnell, Wynne, Griffin, et al., 2021). The PCM contains three cyclically interacting components: "Schema", "World", and "Action" (Neisser, 1976; Plant & Stanton, 2012). The concept of a Schema refers to the internally held knowledge structures that are formed through experience over time and provide a mental template that guides the interpretation and exploration of information in the world (Plant & Stanton, 2012). The inclusion of the schemata component means the PCM captures the interaction between the decision-maker and their environment, whilst the RPDM reduces decision-making to a process that occurs solely 'in the head' of the decision-maker (Banks et al., 2021; Plant & Stanton, 2015).

Both the RPDM and PCM have been used to describe decision-making from numerous temporal perspectives. For example, the PCM has been used to elicit insight on decision-making retrospectively following an incident or event (e.g., Banks et al., 2018b; Debnath et al., 2021; Lynch et al., 2022; Plant & Stanton, 2012, 2015; Revell et al., 2020) and prospectively using Subject Matter Expert (SME) input on their typical approach to hypothetical scenarios (e.g., Banks et al., 2021; Parnell, Wynne, Griffin et al., 2021). The RPDM has mostly been applied retrospectively (Klein et al., 1989; Neville et al., 2016). However, the model was recently used to prospectively conceptualise Pilot decision-making processes during a dual-engine failure (Parnell, Wynne, Griffin, et al., 2021). The flexibility of the NDM models represents a major benefit alongside their ability to provide a platform that enables the identification of design recommendations for novel technology (Hamim et al., 2022; Parnell, Fischer, et al., 2022).

1.5.3 Formative Decision Making

Formative models seek to encapsulate the tasks, goals, and constraints existent within a work domain without attributing the processes to any one actor (Vicente, 1999). This differs from the NDM approach which outlines the decision process from the point of view of the human decision-maker. Within the domain of HF, several formative models are used to conceptualise decision-making processes within sociotechnical systems. For instance, the second phase of the Cognitive Work Analysis (Cognitive Task Analysis; CTA) specifically focuses on decision modelling by extending existing task analysis techniques to include representations of human cognitive processing (McIlroy & Stanton, 2011; Stanton et al., 2017).

Several methods are prescribed to conduct a CTA (see Wei & Salvendy, 2004). One seminal method used widely within the systems approach involves the application of Decision Ladders (Rasmussen, 1974). A Decision Ladder provides a theoretical framework that captures the information processing tasks used to analyse a situation and form a response (Rasmussen et al., 1994; McIlroy & Stanton, 2015). The uptake of the Decision Ladder in previous work have led to design recommendations for automated systems (Banks et al., 2020), training programmes (Jenkins et al., 2010), novel HMI designs (Jenkins, 2017; McIlroy & Stanton, 2015) and information requirements for decision support aids (Salim et al., 2022; van der Kleij et al., 2022). In addition, Decision Ladders have been used to develop an understanding on the role of UAVs for supporting ground operations within a military application (Jenkins, 2012). Further, J.A. Adams et al. (2009) identified several recommendations to improve the current UAV team configuration and HMI for UAV used within SAR contexts; however, the benefits of applying the NDM models in tandem with formative decision models was not exercised. This is despite the widely accepted notion that Decision Ladders provide complementary insights when applied alongside NDM models owing to their normative account of decision-making (Jenkins et al., 2010; Lintern, 2010; Naikar, 2010; Parnell, Wynne, Plant, et al., 2021).

1.6 Conclusion

The availability of automated functionality for imagery analysis is already being leveraged within military applications in the form of automatic threat detection systems (Defense Advancement Reporter, 2021). It is only a matter of time before it is disseminated within civil applications, such as SAR. The array of human-automation interaction issues poses some important implications for the way in which such automation is integrated; in particular, how it is designed. The discussed benefits of decision modelling present a useful avenue of investigation for identifying design recommendations for a DSS intended to aid the Payload Operator, and by way of extension, the UAV team. Hart et al. (2022) proposed that the RPDM, PCM, and Decision Ladder should be applied together to capture the complimentary insights offered when modelling the decision-making processes of Payload Operators in a SAR context. To do so, the involvement of the end-user is integral to ensure that any outputted design concepts are derived from their processes, tasks, and needs (Parnell, Wynne, Griffin, et al., 2021). In doing so, a user-centred design approach is taken to ensure the end-user is considered at an early stage of the design lifecycle in accordance with best practice (Stanton & Young, 2003).

Chapter 2 Exploring the use of the Schema World Action Research Method to measure UAV operator decision-making

2.1 Introduction

Chapter 1 identified the need to apply a systems approach to understand the decision-making processes of SAR teams. In order to gain insight into these processes, it was decided to conduct operator interviews that could be used to populate each decision model. The following chapter describes the methodology used to understand and validate the decision-making processes of SAR personnel with reference to the Systems Design Framework (SDF) (Banks & Stanton, 2017) (see Figure 3). Banks and Stanton (2017) designed the SDF to examine the complex interactions between human and non-human agents (Banks & Stanton, 2017).

2.1.1 SDF: A methodological approach

The SDF proposes that distributed cognition can be measured and understood using several steps: design a concept, allocate functions between system agents, model the system's interactions using Operator Event Sequence Diagrams (OESDs), conduct user trials, and propose novel design solutions (see Figure 3) (Banks & Stanton, 2017). The user trials serve as a validation measure that verify the accuracy of the assumptions generated within the theoretical models, from which design solutions can be identified to improve the initial design concept (Banks & Stanton, 2017).

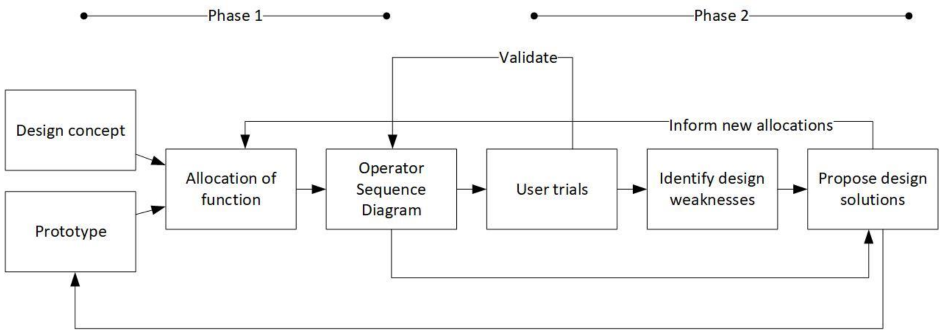

Figure 3. *Outline of the SDF proposed by Banks and Stanton (2017)*

Given that decision models were used in the place of OESDs, the SDF was adapted to reflect the different modelling strategy (see Figure 4). The SDF was also modified to include the preparation required for conducting operator interviews which provided the data needed to populate the decision models (see Figure 4). When conducting operator interviews, a degree of preparation is necessitated to ensure the dataset effectively elicits information that meets the objective(s) of a study (Stanton et al., 2013). The purpose of this chapter is to outline the design process used to develop the interview protocol for use with SAR personnel (see Chapter 3). Therefore, Chapter 2 covers the initial aspects of the SDF (see Figure 4).

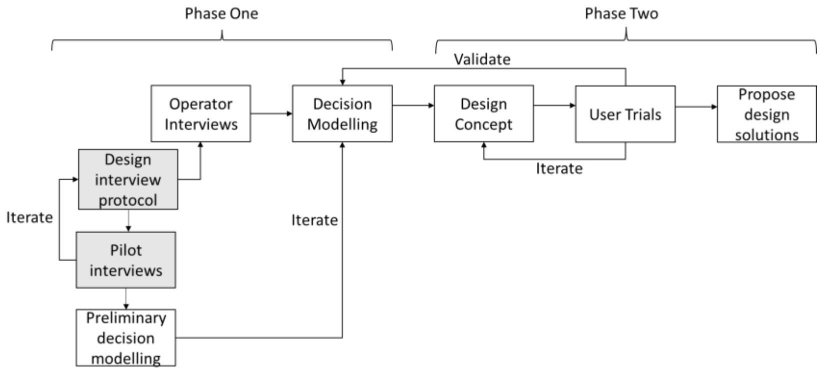

Figure 4. *Adapted version of the SDF (Banks & Stanton, 2017). Aspects of the SDF conducted during chapter three, as shown in grey*

2.2 Designing the interview protocol

Stanton et al. (2013) suggested that the first step for designing an interview protocol is to identify the objectives of the interview. To that end, the following objectives were identified:

- Understand the tasks, interactions, and processes SAR teams undertake during a traditional ground search and UAV-equipped response.
- Investigate perceptions towards automated systems for imagery analysis.

The questions used within the interview protocol were therefore designed with these objectives in mind.

In order to facilitate the design of interview protocols, researchers have developed several methods within the field of HF. For instance, the Critical Decision Method (CDM) uses cognitive probes to construct a timeline that depicts the structure of an incident experienced by the decision-maker. Specifically, the CDM aims to identify the environmental cues that are leveraged by the decision-maker to recognise and select an appropriate response (Klein et al., 1989). However, the method has received criticism for providing inadequate insight into the schematic processes embedded within decision-making activities (Plant & Stanton, 2013b). In addition, the CDM relies on the recall ability of the interviewee when discussing a specific event, which is subject to inevitable bias due to memory alteration and decay (Plant & Stanton, 2016b).

In order to address these limitations, Plant and Stanton (2016b) developed and validated the Schema World Action Research Method (SWARM) as an extension of the CDM. Plant and Stanton (2016b) designed SWARM to gather information on the interactional relationships between internal knowledge structures (i.e., schemata; Neisser, 1976) and the information available within the environment (Plant & Stanton, 2016b). Since its development, SWARM has been used to elicit insight on the perceptual processes of a decision-maker, something that is extremely complex to capture (Banks et al., 2021).

The uptake of SWARM has enabled the generation of several human-system interaction models, including the PCM (e.g., Parnell, Fischer, et al., 2022), Decision Ladder (e.g., Banks et al., 2020) and the RPDM (e.g., Parnell, Wynne, Plant et al., 2021). It has also been used to conduct human error identification methods, such as the Systemic Human Error Reduction and Prediction Approach (e.g., Parnell et al., 2019). Therefore, the flexibility in which researchers can analyse the data elicited using SWARM presents a significant benefit. Although SWARM was developed to measure aeronautical decision-making, the authors intended that the method to be utilised within different research contexts (Plant & Stanton, 2016b). Its application beyond the aeronautical domain has been demonstrated by its recent uptake to understand trust requirements for multi-agent operations (i.e., UAV swarms) (Parnell, Fischer, et al., 2022). In addition, SWARM has successfully been applied to analyse decision-making prospectively using a hypothetical scenario to identify design requirements for future flight deck technology (Banks et al., 2021; Parnell, Wynne, Plant, et al., 2021). Therefore, the flexibility and adaptability of SWARM and its output warranted its use in the current work over the CDM to understand UAV operator decision-making in a SAR application.

As with the CDM, SWARM also uses cognitive probes to elicit data from SMEs. However, the prompts belonging to SWARM are categorised into the three components of the PCM, namely, schema, world, and action (Neisser, 1976; Plant & Stanton, 2016b). Each PCM category comprises of several subtypes; each of which contain a set of interview prompts. In total, 95 prompts are contained in the complete SWARM repository. A full description of each SWARM subtype and their associated prompts is given in Appendix A. When developing an interview protocol using SWARM, Plant and Stanton (2016b) advised the down-selection of SWARM prompts based on their relevance to the research objective. To that end, the work presented in this chapter outlines the pilot studies conducted before the SAR operator interviews which were used to inform this down-selection process.

2.2.1 Down-selection of SWARM prompts

The centrality of the ground search response warranted the use of two interviews to fully capture the processes involved during both traditional ground search (i.e., work as done) and UAV-equipped responses (i.e., work-as-imagined). In order to construct the initial SWARM protocols, prompts were down selected from the full SWARM repository, as recommended by Plant and Stanton (2016b). When selecting the SWARM prompts, the primary researcher evaluated each SWARM subtype for its relevancy and provided reasoning for its inclusion. A separate HF researcher subsequently reviewed this down-selected protocols. The inclusion of a UAV in the work-as-imagined interview implicated the requirement to use prompts relating to the Aircraft Status, as the health and status of a UAV is a critical consideration during the launch, deployment, and landing phases of the UAV mission (Drury et al., 2006). In turn, the initial protocol for the work-as-done interview (n = 40) contained fewer SWARM prompts than the work-as-imagined interview (n = 43).

2.3 Method

2.3.1 Participants

Two participants (2 males) were internally recruited to take part in the pilot study. Both participants had previous experience of using UAVs for SAR operations within military contexts and held the relevant qualifications for UAV Piloting. Neither participant were operationally active members of a SAR unit in the UK. The study received ethical approval from the University of Bristol Ethics Committee (Reference 10785).

2.3.2 Procedure

At the beginning of the study, the participants were informed of the research aim and provided consent to being verbally recorded. The participants were then presented with a hypothetical SAR scenario relating to a MISPER search. For the SAR operator interviews, the hypothetical scenario presented to the participants needed to be representative of a generic SAR scenario. Within the context of SAR, the provision of UAVs is mostly described in relation to MISPER searches (Frederiksen et al., 2020; Weldon & Hupy, 2020). Therefore, the hypothetical scenario used in this study involved a MISPER search to understand the typical response of SAR teams, both with and without a UAV. The scenario was designed to enable interviewees to draw on their knowledge of SAR operations without being constrained by the contextual details of a single event.

Once the SAR scenario was presented, the participants took part in a semi-structured interview using the prompts contained within the SWARM repository (Plant & Stanton, 2016b). This interview was divided into two parts: work-as-done and work-as-imagined. During the work-as-done interview, the participants were asked to respond to the SWARM prompts when conducting a SAR mission without a UAV. For the work-as-imagined interview, the same mission brief was presented again; however, participants were asked to provide responses on a UAV-equipped SAR response. An additional sub-set of questions were asked at the end of the interview to discuss the participant’s perceptions towards an image classification module that automatically detected and classified sightings in the aerial imagery.

These questions stated the following:

"If the UAV could provide a confidence estimate for the image classification

- How would you interpret this information?
- Would it be a useful piece of information?
- Is there any other information that would be useful in assisting with image classification?"

These questions were not taken from the SWARM repository. However, their addition enabled operators to discuss their interpretation of automated decision aids and identify other features that could be incorporated within future UAV system designs.

2.4 Data analysis

Both participant interviews were recorded, and notes were taken throughout by the second interviewee. The researcher subsequently read the transcript and notes taken from both interviews to familiarise themselves with the responses.

2.5 Findings

The responses from each pilot interview were reviewed to understand where adaption to the SWARM prompts and hypothetical SAR scenario was necessary. These iterations were critical for ensuring that the interview structure was suitable for future operator interview studies with SAR responders. The following sections present the modifications made to the SWARM protocol and the hypothetical SAR scenario, respectively.

2.5.1 SWARM

During the Pilot interviews, three themes emerged when using the SWARM prompts. Firstly, several prompts resulted in information being repeated by the participants. Secondly, the participants naturally answered the SWARM prompts before being presented with them, rendering some questions redundant. Finally, some prompts required modification to clarify their meaning within the context of a SAR mission. These observations led to several changes to the original SWARM protocol. For the work-as-done interview, a selection of SWARM prompts belonging to the same subtype were combined to produce four merged questions. To define which subset of prompts to merge, the responses of each SWARM subtype were reviewed to determine where the participants repeated similar information. Further, three prompts that needed clarification during the interview received minor modifications to contextualise the question with the SAR scenario. The protocol was further reduced by removing six prompts that the interviewee did not ask due to participants naturally answering the SWARM prompts throughout the interview. As a result of these modifications, the final SWARM protocol contained 30 prompts (see Figure 5). The entire set of SWARM prompts for the work-as-done interview is shown in Appendix B.

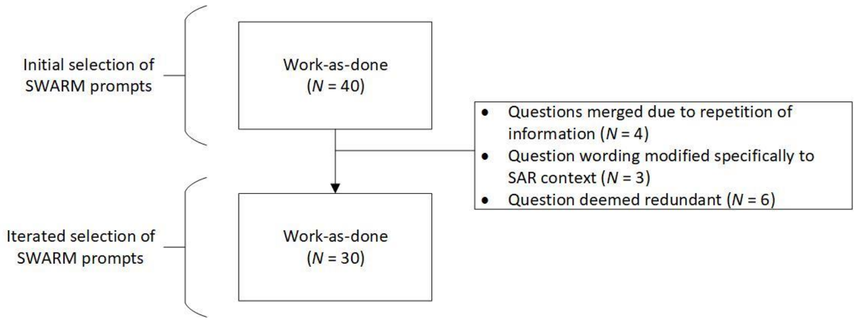

Figure 5. *Modifications to work-as-done SWARM prompts*

During the work-as-imagined pilot interview, the same themes emerged when answering the SWARM prompts. Therefore, the same set of modifications were used to reduce the initial work-as-imagined protocol from 44 SWARM prompts to 33 (see Figure 6). See Appendix C for the complete set of interview prompts employed within the work-as-imagined protocol.

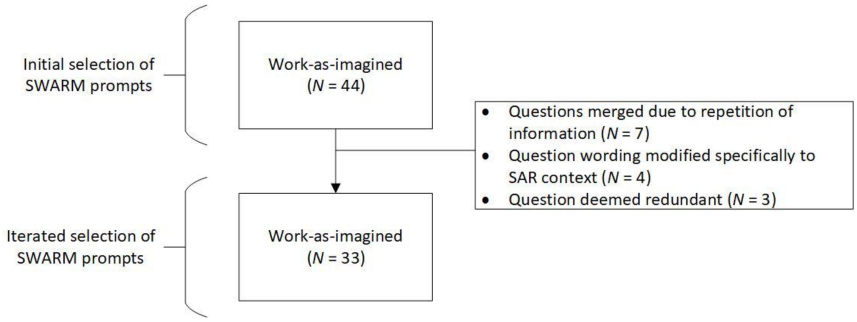

Figure 6. *Modifications to work-as-imagined SWARM prompts*

2.5.2 Scenario Iteration

The development of the SAR mission from its initial conception to the iterated version shown in the interviews with SAR personnel is shown in Figure 7. Following the pilot interview, it became clear that the scenario needed more information to probe the participants' responses. Therefore, the second pilot interview presented a hypothetical scenario that included details on the MISPER's last known location, their experience of hiking, and the temporal information relating to the incident.

In addition, images of SAR equipment were also presented to the participants to probe the discussion of any interactions made with the generic artefacts during SAR responses. This equipment included a map, communication device, signal detection tool, GPS device and an image of the MISPER. The work-as-imagined scenario also provided images of the UAV and its HMI.

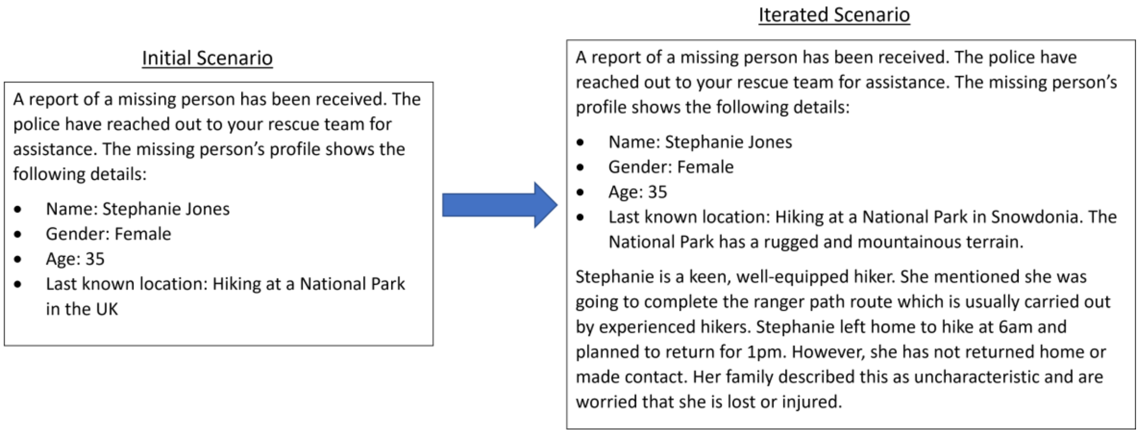

Figure 7. *Iterated SAR scenario*

Note. The hypothetical SAR scenario developed for the current work is entirely fictional.

2.6 Discussion

The preliminary study showed the value of using SWARM to provide insight into the decision-making processes undertaken during UAV operations. This demonstrated that SWARM could be applied within domains other than aeronautical decision-making (i.e., its originating research application). In addition, the qualitative data from the pilot studies offered invaluable insight on the type of participant needed to achieve the overall research aim (i.e., understanding how UAVs are utilised in SAR practice). Hoffman et al. (1998) criticised the reliance on the CDM for requiring personal experience from a domain to capture expert decision-making processes efficiently. This criticism can be extended to SWARM too. Whilst the participants within the pilot study held vast expertise in UAV operations, their verbal reports were heavily centred on procedures utilised during military SAR operations. In turn, the data elicited could not effectively represent the SAR processes of voluntary organisations utilised by the police force in the UK. This was not an outright limitation of the study as, at this point, the aim was not to understand the decision-making processes of SAR responders. Initially, it was thought that the decision models could be generated using interview data collected from generic UAV operators; however, the pilot study highlighted the need to interview currently operational SAR personnel.

2.7 Conclusion

As previously stated, the pilot studies were a precursor to the larger interview study conducted with a more extensive set of SAR operators. The pilot studies enabled the development of the SWARM protocol to meet the objectives of the study, and the identification of a hypothetical SAR scenario. Chapter 3 utilised the modified SWARM protocol and scenario derived within this chapter to continue the investigation of the decision-making processes of UAV operators in a SAR context.

Chapter 3 Operator decision-making during a UAV-equipped SAR mission

3.1 Introduction

In Chapter 2, the utility of SWARM was explored, and, in turn, an interview protocol was developed to elicit insight on the decision-making processes of SAR personnel. As outlined in Chapter 1, the current work aimed to understand how the processes and tasks of the Payload Operator could be supported through the integration of user-centred DSS. Often, support systems are implemented with automated functionality to assist the decision-making processes of an operator (e.g., Sarter & Schroeder, 2011). In turn, the uptake of these decision aids introduces a need for the human and automated agents to work together within a human-automation team.

When designing for effective human-automation teaming, the role of each agent and their associated tasks should be understood holistically relative to their operational environment and the goals encompassed within these settings (O'Neill et al., 2020). Adopting this perspective, the current chapter explored the decision-making processes of UAV-equipped SAR responses. These processes will be conceptualised using the representational medium of the decision models described in Chapter 1, all of which have previously been used to model processes within sociotechnical systems. To recap, these models included the RPDM (Klein, 1989), PCM (Neisser, 1976) and the Decision Ladder (Rasmussen, 1983).

3.1.1 Decision-making and UAV systems

The uptake of UAVs within SAR operations is viewed as having "enormous potential" for supporting responses in the UK (Maritime & Coastguard Agency, 2020, p.1). However, the integration of UAVs within the SAR application is still within its relative infancy. This early stage of integration implicates the need to consider the role and needs of the human operator to design a UAV system that caters for the end-user's requirements (J.A. Adams, 2009; Norman, 1986). In order to achieve this, Bruseberg (2008) cited good HFI processes as an essential mechanism for eliciting these user requirements and embedding them within the design of the UAV system. Of particular importance is the HMI used to monitor and control the UAV. The HMI is a critical system component for presenting clear, relevant information and control inputs that deliver informative feedback when the system's state changes upon interaction with the human operator (Harvey et al., 2011). In that sense, the HMI acts as a bridge between the human operators and the UAV for maintaining awareness of the vehicle's performance and surroundings.

Within the SAR application, research has leveraged the benefits of engaging with SAR responders to identify functional and non-functional requirements for future UAV systems (e.g., Anderson et al., 2021; Steane et al., 2023). In addition, collaborative design partnerships between UAV manufacturers and SAR units have been established, such as between Evolve Dynamics and Buxton Mountain Rescue (MREaW, 2022a). Yet, it appears these design efforts are unique and not widely utilised. The extent of HFI used to support the development of UAV technology, therefore, appears to be limited. Instead, system architecture requirements that determine the design of the HMI are developed based on the assumptions of the system designer rather than through the application of advanced methodologies and human factors tools (Shorrock & Williams, 2016). This is principally known as the 'research-practice gap' (Salmon et al., 2022; Shorrock & Williams, 2016). It is these tools that can abstract the needs of the end-user into novel design interventions through the use of state-of-the art system models that are grounded in theory and data (Salmon, 2016). As a result of the research-practice gap, UAV architecture has been designed with little consideration for who is utilising the system and how they are used to facilitate safe operations within complex sociotechnical systems (Steane et al., 2023). This is despite the need for HMI to be designed in a way that supports decision-making and problem solving within the context of the wider system (Bennett et al., 2008). As such, the limited uptake of system approaches in the UAV domain indicates that the cognitive processes and goals of the human operator has received limited consideration within previous design processes for uncrewed avionic displays. Mohamed et al. (2017) argued that the mental models held by the designers and end-users should be aligned to secure system usability. It is, therefore, concerning that the uptake of HFI methodologies remains limited as current HMI may not fully support the mental models of the UAV operators. In order to reduce the gap between the mental models of the designer and UAV operator, the processes, tasks, and actors involved during SAR missions needs exploration using advanced HF methodologies.

The centrality of traditional ground search responses necessitated the requirement to understand SAR practice both without (i.e., work-as-done) and with a UAV (i.e., work-as-imagined) (Goodrich et al., 2008). This approach provides an understanding on the scope of the system to identify 'where' and 'what' support could be integrated to aid the decision-making processes of SAR personnel (Banks et al., 2020, 2021; Cattermole et al., 2016). The decision models used to capture these processes are outlined in turn, followed by an overview of the SAR environment to contextualise the terminology, roles and equipment referred to throughout the chapter. The qualitative data from these interviews were then applied to each decision model. Following this, the utility of each decision model for understanding the decision-making processes of SAR teams is discussed. To that end, the activities conducted in this chapter cover the decision modelling aspect of the SDF (see Figure 8).

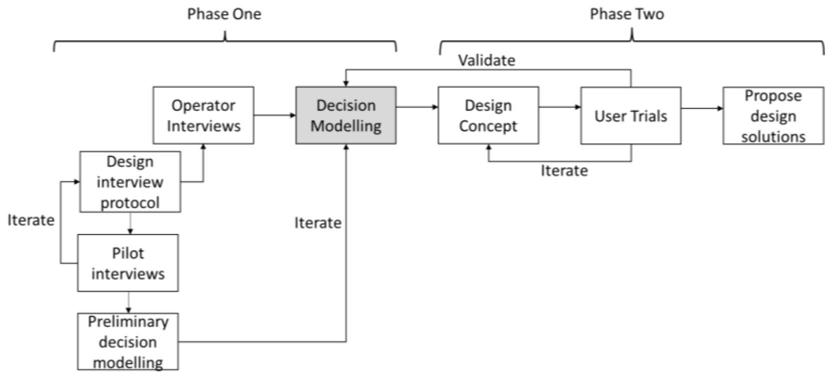

Figure 8. *Aspects of the SDF conducted during Chapter 3, as shown in grey*

3.2 Decision-making models

Chapter 1 provided an argument for applying the Decision Ladder, PCM, and RPDM together to ensure any future systems are designed with the human operator in mind. Each of these models are now described in turn.

3.2.1 RPDM

The RPDM is a seminal NDM model proposed by Klein (1989) to capture how experts make critical decisions when responding to incidents characterised by temporal pressures (see Figure 9).

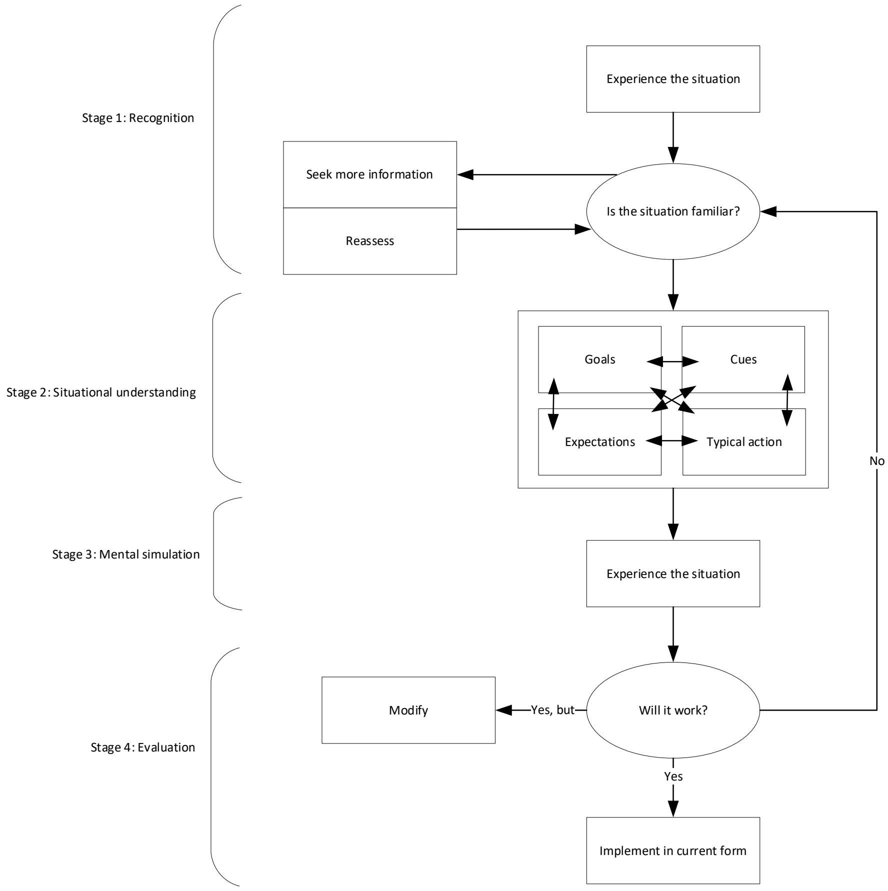

Figure 9. *The RPDM adapted from Klein et al. (2008)*

Klein et al. (2008) argued that decisions are the product of a decision-maker's existing knowledge obtained through experience or training. This body of knowledge is used to guide the decision-maker's interpretation of a situation through pattern matching which, in turn, enables them to draw on similarities from prior experiences to form a response (Wiggins, 2017). The model therefore assumes that extant knowledge is leveraged to help a decision-maker recognise and familarise themselves with the situation at hand (Klein et al., 1989; Klein, 1993). Klein (1989) described this process as recognition-primed decision-making and conceptualised the decision pathway using four stages; Recognition, Situational Assessment, Mental Simulation, and Evaluation (Klein, 1989; Parnell, Wynne, Plant, et al., 2021) (see Figure 9).

Figure 9 shows that in the first stage of the RPDM (Recognition) the decision-maker forms an opinion on a situation's familiarity to assist with their response. If a situation is deemed unfamiliar, the decision-maker will look for further information to reach some degree of understanding. Once a state of recognition is reached, a situational assessment is undertaken to form an understanding of a situation based on four mutually interrelating factors, including: (i) cues in the environment that indicate the type of incident being dealt with, (ii) expectations about the likely outcome of the situation, (iii) the goals of the decision-maker, and (iv) typical actions that can achieve these goals (Parnell, Wynne, Plant, et al., 2021). If the decision-maker's diagnosis of the situation becomes violated by any of these four factors, the initial recognition stage is repeated again by seeking further information within the environment (see Figure 9).

The situational assessment culminates in the identification of a course of action to execute within the situation. This response plan is mentally simulated in the mind of the decision-maker to determine its suitability. Three outcomes can result from this mental simulation; the plan is executed as envisaged, modified to meet the demands of the situation, or abandoned altogether. Should the plan be deemed unsatisfactory, the decision-maker will once again return to the recognition phase to gather more information, thus, beginning the process again. The mental simulation of alternative actions is carried out serially, meaning each possible course of action is not compared for its efficiency (Klein, 1993). This process is thought to give rise to rapid decisions under conditions of extreme pressure and high workload (Klein, 2008). Once a suitable course of action is identified, the consideration of alternative options ends. It is important to note that the chosen action may not represent the optimal option (Parnell, Wynne, Plant, et al., 2021). In other words, the first option to satisfy the demands of a situation may be selected over the best option, a process defined as satisficing (Simon, 1955).

3.2.2 PCM

The PCM (Neisser, 1976) presents a theoretical framework for understanding how the internal knowledge structures (i.e., schema; Bartlett, 1932) of a decision maker interact with their environmental surroundings to inform the execution of a response to an event or incident (Banks et al., 2021). The PCM depicts this dynamic interaction using three components, namely, "Schema", "World", and "Action". An individual's schema is commonly equated to a mental template that guides the allocation of attention in the world and informs the way in which information is understood (Neisser, 1976; Plant & Stanton, 2012). When interacting with stimuli in the world, an individual's schema can become triggered which, in turn, affects the interpretation of information and the subsequent action performed by the human decision-maker (Plant & Stanton, 2013a). As such, each PCM component interacts in a reciprocal, cyclical relationship to inform the execution of a decision (Plant & Stanton, 2012, 2015; Banks et al., 2020) (see Figure 10).

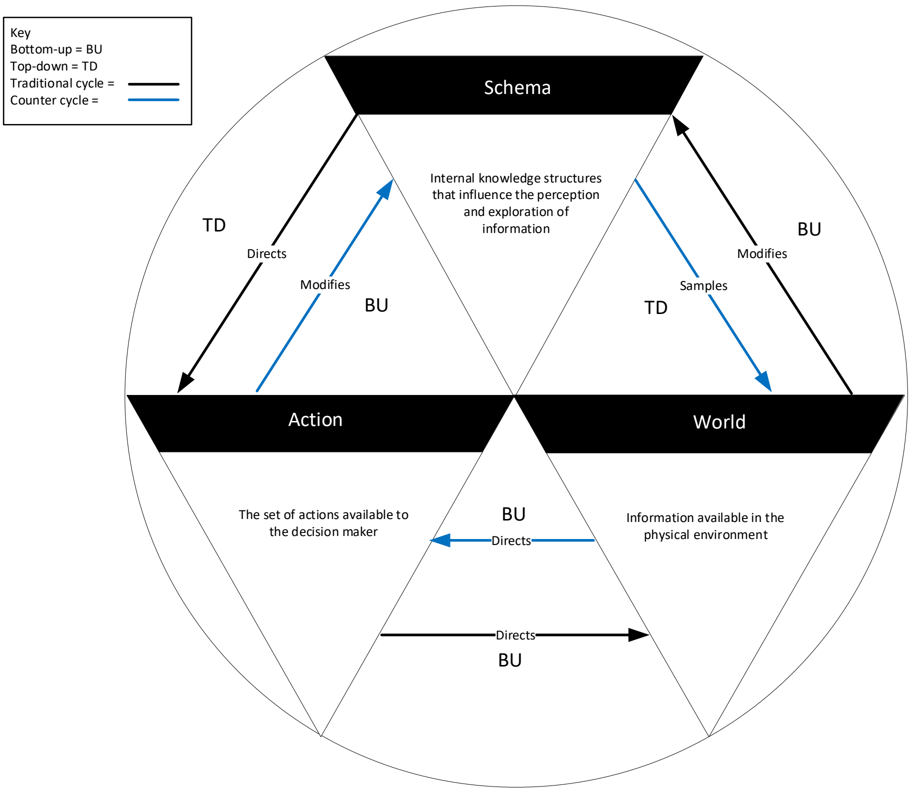

Figure 10. *PCM adapted from Neisser (1976) and Revell et al. (2020)*

The interactional relationship between the PCM components is explained through top-down and bottom-up processes. First, bottom-up (BU) processes occur in response to events that produce further information in the world (Plant & Stanton, 2012). This information is interpreted using the schema as a mental template. For example, a UAV Pilot presented with a warning on their display regarding the presence of other aircraft users would use their schema to identify the meaning of the alert and enact the appropriate behavioural intervention. Secondly, top-down (TD) processes occur when a schema is activated and informs the subsequent perceptual exploration of information and action in the world (Plant & Stanton, 2012). For instance, anticipating large numbers of civilians in a popular tourist location may prompt the UAV to be diverted on a course that avoids this region.

3.2.3 Decision Ladder

The Decision Ladder framework shown in Figure 11 comprises two types of nodes: a rectangle and a circle. The rectangular node represents the information processing activities carried out by the decision maker, and the circular node depicts the resultant state of knowledge (McIlroy & Stanton, 2011, 2015). To describe the decision-making process, the left-hand side of the ladder shows the situational analysis and subsequent diagnosis reached by the decision-maker to understand the severity of a situation. The Decision Ladder conjoins at the top of the diagram to illustrate how the options and goals derived from the situation assessment are sequentially evaluated and used to determine the most appropriate option (Parnell, Wynne, Plant, et al., 2021). The right-hand side of the ladder consequentially shows the planning and execution of the tasks required to perform the selected option.

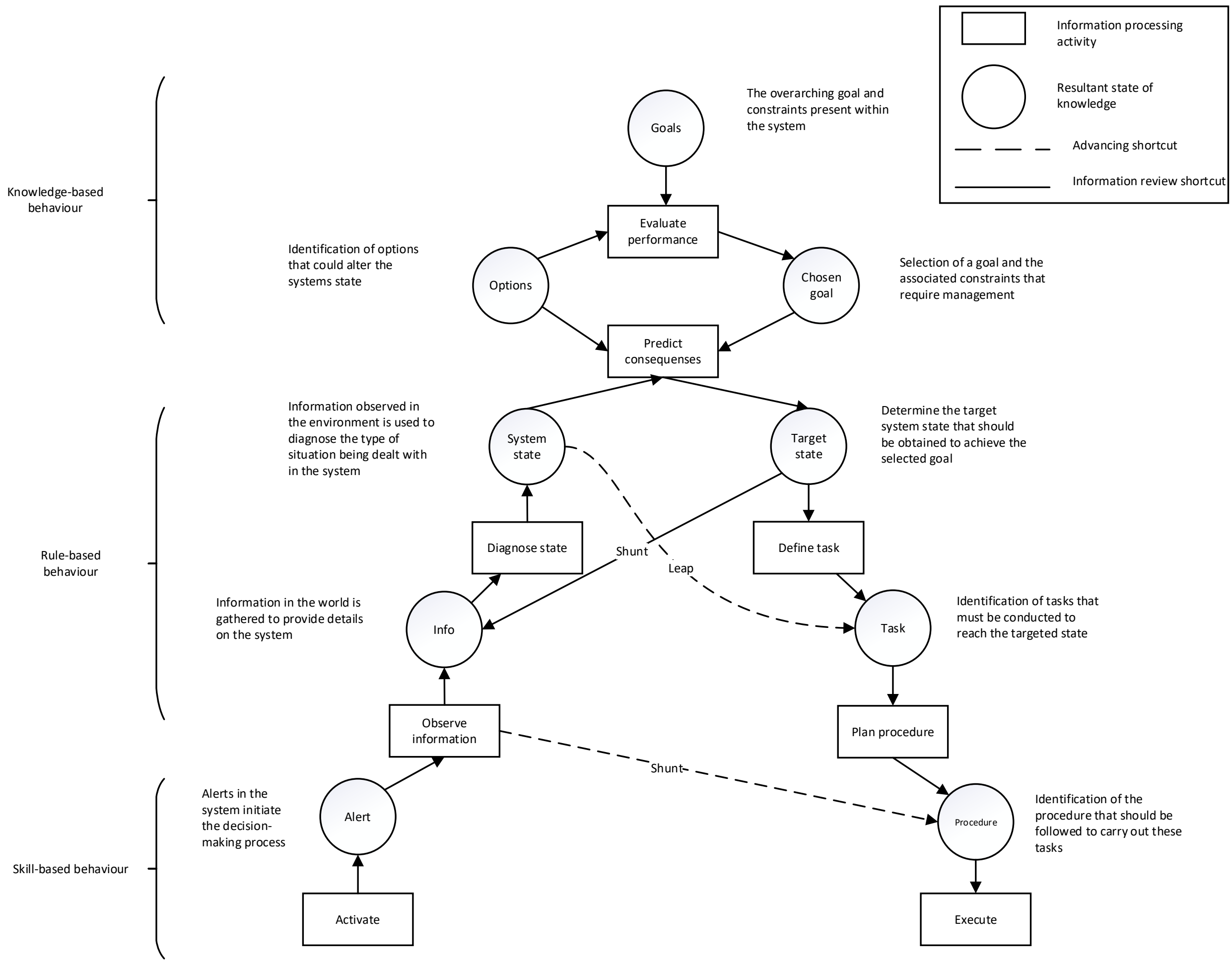

Figure 11. *Decision Ladder template, adapted from Parnell, Wynne, Plant, et al. (2021)*

The Decision Ladder is theoretically underpinned by the Model of Cognitive Control (Rasmussen, 1983) which divides information processing behaviours across three levels of control: skill-, rule-, and knowledge-based behaviour. This is otherwise known as the Skills, Rules, Knowledge (SRK) taxonomy (Rasmussen, 1983). Firstly, skill-based behaviour is an automatic response elicited by interactions between the decision-maker and their environment. Secondly, rule-based behaviour is the product of stored rules that are matched with cues in the environment. It represents a more skillful behaviour as the rules known to the decision-maker are used to synthesise and comprehend information in the environment to diagnose the system's state. Lastly, knowledge-based behaviour requires the application of existing mental models to perform complex problem-solving activities using the information available in the work domain (Rasmussen, 1983). In doing so, the decision-maker can identify the set of options available in the environment and predict their outcome to down-select the most appropriate plan. This level of processing relies heavily on the decision-maker's sensemaking abilities and therefore requires the most cognitive effort. The Decision Ladder in Figure 11 illustrates the information processing activities and their associated level of cognitive control.

Whilst the decision-ladder is shown as a sequential framework, decision-makers with high levels of expertise can bypass aspects of the Decision Ladder (Banks et al., 2020). Figure 11 shows two types of shortcuts that facilitate the differential entry and exit points within the Decision Ladder (McIlroy & Stanton, 2015). Firstly, a 'shunt' connects information processing activities to a state of knowledge (i.e., rectangle to circle) (Banks et al., 2020). Secondly, a 'leap' connects two states of knowledge (i.e., circle to circle) (Banks et al., 2020). A shunt can occur when a task requires more information from the environment before it can be executed, culminating in a shortcut that adjoins an information processing activity on the right side of the ladder to an information node on the left side (Parnell, Wynne, Plant, et al., 2021). Alternatively, a shunt could occur when the activity of diagnosing the system state leads to the intrinsic understanding that a standard procedure is required to respond to the situation (McIlroy & Stanton, 2015). Conversely, a leap occurs when a state of knowledge triggers an association to another state of knowledge residing on the right side of the decision ladder (Banks et al., 2020). For example, knowledge on the systems state may trigger knowledge of the required task that should be executed to recover the system (McIlroy & Stanton 2015). It is important to note that when an expert is exposed to an unfamiliar scenario, the entirety of the Decision Ladder pathway would be undertaken (McIlroy & Stanton, 2015; Mulvihill et al., 2016).

3.3 UAV models and capabilities

An example of the UAV technology used by the Brecon MRT is shown in Figure 12. The type of UAV model owned by each SAR service can vary. Nevertheless, the core technological components installed on the platform mostly remain the same. For instance, each UAV model is installed with onboard payload sensors. The following section summarises these sensors to identify the generic capabilities typically afforded by UAVs utilised within SAR applications.

Figure 12. *UAV model currently utilised by Brecon MRT for SAR responses*

3.3.1 Onboard payload sensors

Each UAV model is equipped with a range of sensor payloads. These onboard sensors enable the UAV to interact and navigate within the environment and collect data that can be transferred back to the human operators on the ground in real-time (Vergouw et al., 2016). The capabilities of each sensor type depend on the size of the UAV but typically include GPS, Inertial Navigation Systems (INS), visual cameras, thermal sensors, and radar sensors (Arfaoui, 2017). A high-level description of these sensor types is provided in Table 2.

Table 2. Description of typical UAV sensor payloads

Sensor type	Description
GPS and INS	GPS and INS measure the position and direction of the UAV during its deployment.
Visual camera	Onboard digital cameras provide real-time videos of a UAV operator's physical environment.
Thermal sensor	Thermal sensors enable the detection of heat signatures in the physical environment.
Radar sensors	Radar sensors can be integrated onboard a UAV platform to conduct target detection and identification.

In order to demonstrate the universality of these sensors, Table 3 shows a set of UAV models and the typical types of payload sensors installed onboard. With this in mind, the decision models presented in this work assume that most SAR teams will have access to UAVs with these payload sensors. The only exception to this was radar sensors (see Table 3). As radar sensors were not always present onboard each UAV model, no reference is made to their usage within the decision models.

Table 3. Generic sensor payloads typically installed onboard UAV platforms

UAV model / Sensor type	DJI Mavic Air 2 (2021)	Parrot ANAFI Thermal (n.d.)	DJI Matrice 300 RTK (2022)	YUNEEC H520 (n.d.)
GPS and INS	X	X	X	X
INS	X	X	X	X
Visual camera	X	X	X	X
Thermal sensors	X	X	X	X
Radar sensors		X	X	

3.4 Overview of SAR operations

In order to assist with the comprehension of the decision models, the following sections provide a generic overview of the responsibilities associated with each SAR personnel role and a description of the typical procedure and tools used to plan and execute a SAR response.

3.4.1 SAR personnel

Table 4 shows the roles and responsibilities of the SAR personnel and their operational location within the SAR space. The structure of a SAR team is akin to the hierarchical organisations found within submarine command teams. Onboard a submarine, data is acquired from a range of sources and assimilated by an Operations Officer (OPSO) with a high level of experience and knowledge of tactical submariner operations (Roberts et al., 2017; Stanton et al., 2021). In the SAR context, the role of the Search Manager is analogous to the OPSO insofar that they must also coordinate with a range of personnel to plan and manage a rescue response (Gotovac et al., 2020).

Table 4. Overview of roles for search teams in the SAR environment (Kent Search and Rescue, 2022)

Search team and location	Role	Description
Control team coordinating the SAR response from the rendezvous point in the control vehicle	Search Manager	Responsible for liaising with the emergency services (i.e., police, ambulance) and coordinating the search plan. The Search Manager identifies any areas that require searching. They also direct the tasks undertaken by the search teams during a response.
	Search Controller	*Manages the set up of the control point and allocates search activities to each team.*
	Search Planner	*Responsible for identifying appropriate rendezvous points and establishing the personnel available (i.e., quantity of resources). They must also process data received via verbal modalities (e.g., radio messages) and operating software systems. This information is then relayed to the Search Manager.*
Ground search team deployed to investigate each region contained in the search plan	Team Leader	Responsible for managing teams of 3 - 5 ground searchers and monitoring their welfare whilst completing the search task assigned by the Search Manager.

	Radio Operator	Responsible for communicating information to the Search Planner (or Search Manager). To manage the number of incoming communications, radios are programmed with two channels for information sharing. One channel broadcasts to personnel in the control vehicle, whilst the second channel is used to communicate with members of their ground search party.
	Medic	Holds the required first aid qualifications to administer medical treatment to the MISPER or injured team members.
	Ground Searcher	The Ground Searchers are qualified members of the SAR party that are responsible for investigating regions allocated by the Search Manager. They must arrive fitted with the correct equipment and be competent across all key aspects of the search, including navigation, radio operation, first aid, crime preservation, and rescue techniques.
UAV team deployed to cover an area of land allocated by the Search Manager	*UAV Pilot*	Responsible for safely navigating the UAV in alignment with CAA regulations.
	Payload Operator	Responsible for monitoring the payload data collected by the UAV.

Note. Italics denote the operator roles that may not be present for all SAR missions

3.4.2 High-level overview of the SAR response

A generic overview of the procedure used by SAR teams to respond to reports of a missing or injured person is given in Figure 13. A SAR response is initiated once the police contact the SAR unit to inform them of an incident and provides demographic details of the MISPER and their last known location (MREaW, 2022b). In response, a hasty search is conducted to investigate the area surrounding the last known location of the MISPER (Phillips et al., 2014). Should the MISPER remain unlocated, the Search Manager expands the search area to cover a greater region of land. This area is divided into sub-regions and assigned a Probability of Detection[2] (PoD) based on information pertaining to the MISPER, such as their mental and physical state (Harrington et al., 2018). These sub-regions are assigned to ground search party groups comprising of 4 -5 ground searchers and a Team Leader who directs and guides their assigned ground team. As part of a coordinated search, the Search Manager may also allocate a region of land to the UAV team.

[2] The PoD is an estimated value that indicates the likelihood of a MISPER being located within a region of land (Goodrich et al., 2008).

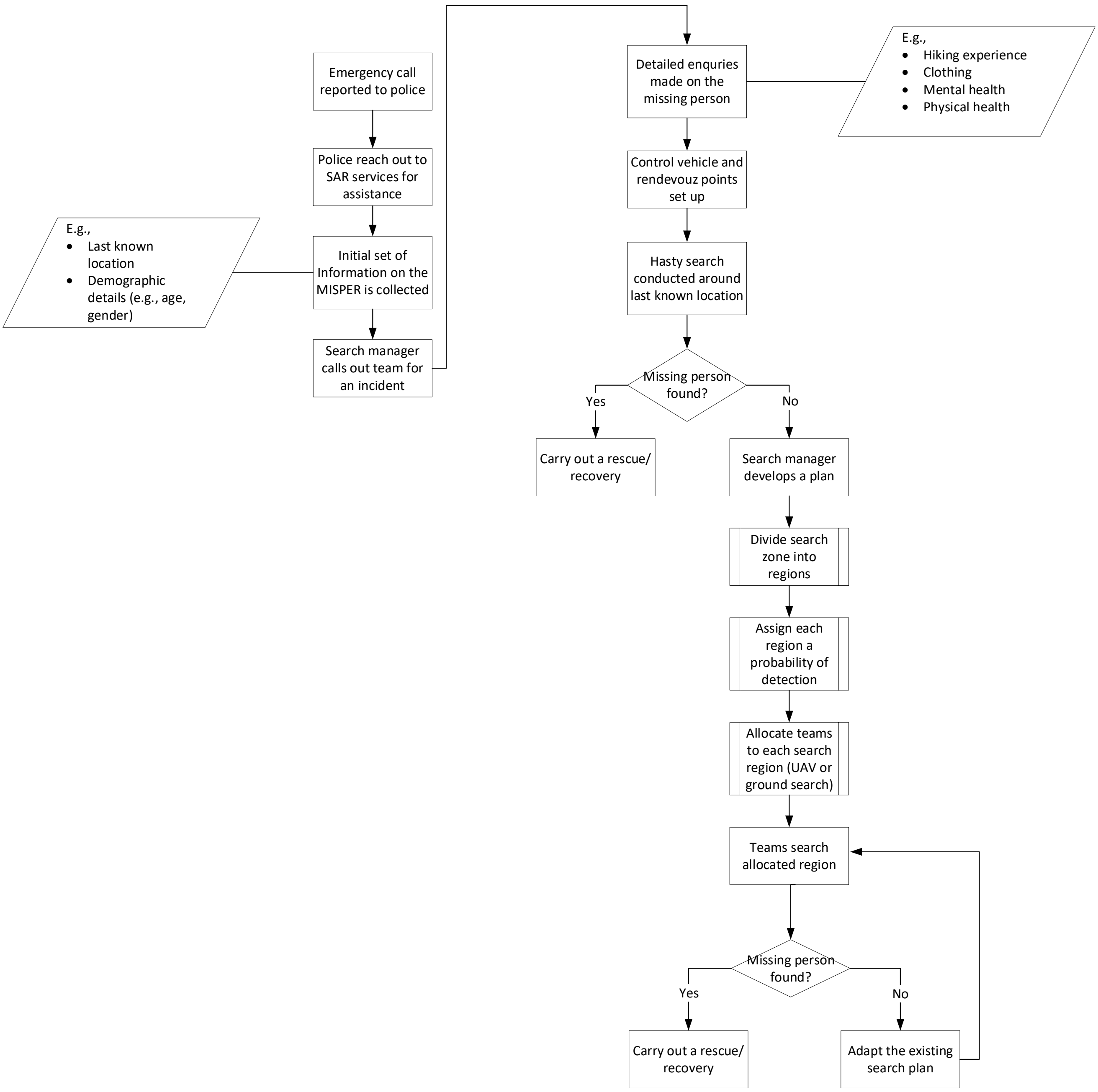

Figure 13. *Overview of a SAR response to a MISPER report (Adapted from Gotovac et al., 2020)*

In order to support these mission planning tasks, the Search Manager uses a mapping software tool that can be used to segment the search region into smaller areas and assign a PoD to each section. The display also provides updates on the locations of each search team which enables the Search manager to monitor progress of each party (see Figure 14). The findings obtained by each ground search party are used to adapt the search plan in a way that constrains the search space to maximise the likelihood of locating the MISPER (Gotovac et al., 2020). This process of iterating the search plan continues in an iterative fashion until the MISPER Is located, or the resources of the search environment are depleted (Harrington et al., 2018).

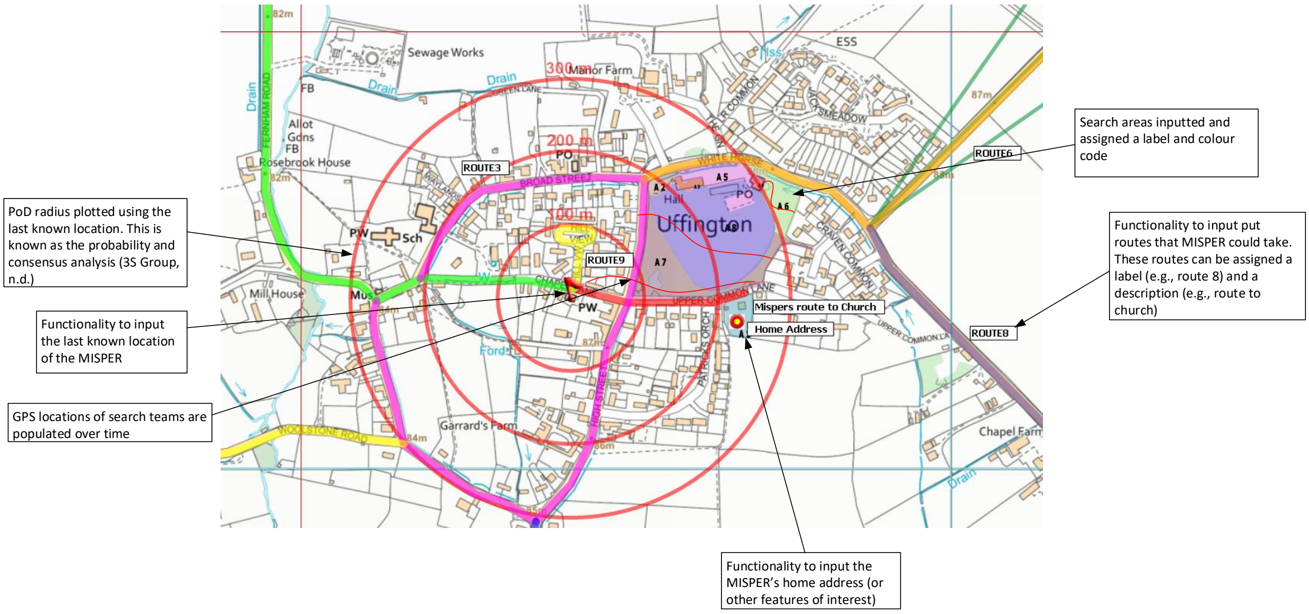

Figure 14. *Mapping software used by the Search Manager (Image taken from 3S Group, n.d.)*

3.5 Method

In order to populate each decision model, interviews were conducted with currently operational SAR responders. The qualitative data yielded from the operator interviews were used to populate each decision model.

3.5.1 Participants

Five participants from Mountain Rescue Teams and the Search and Rescue Scottish Aerial Association were recruited to take part in this study (5 males). All participants were active SAR volunteers with varying levels of experience and knowledge. A range of roles had been assumed by the participants, including the position of ground searcher, UAV Pilot, Payload Operator, and Search Manager (see Table 4). The study received ethical approval from the University of Bristol Ethics Committee (approval code: 10785). Participant recruitment continued until a point of saturation in the dataset was reached whereby statements made by the UAV operators showed trends and similarities (Grady, 1998) and no additional information was being obtained from further participant sampling (Francis et al., 2010).

3.5.2 Equipment

The interviews were conducted using a hybrid format. The majority of the interviews were held in-person, with one being conducted online. A Dictaphone was used to record the in-person interviews (*n* = 4) and the recording tool on Microsoft Teams for the online interview (*n* = 1). During the interviews, participants were shown a PowerPoint slide which presented the SAR scenario brief and a series of images that were intended to serve as prompts for the types of equipment SAR teams use during their operations. Appendix D shows the PowerPoint slides used to support the operator interviews.

3.5.3 Procedure

The data used to populate the decision models was elicited using semi-structured interviews. The interview prompts were taken and adapted from SWARM (Plant & Stanton, 2016a). An in-depth outline of SWARM and the down-selection process used to design the interview protocol for the operator interviews is detailed in Chapter 2. This study used the procedure outlined in Chapter 2 to conduct the operator interviews. However, to recap, the participants completed two interviews. During the first interview, participants answered the SWARM prompts as if they were ground searchers conducting a routine SAR mission without a UAV (i.e., work-as-done). In the second interview, participants answered the prompts as UAV operators and responded to a series of question that probed their perceptions on an automated image classification module (see Chapter 2). The latter part of the interview is referred to as the work-as-imagined interview.

Prior to beginning the operator interview, participants read through the participant information sheet and provided informed consent to confirm they were happy to participate. Each interview was recorded using a Dictaphone to enable transcription of the data. Participants were assured that they were free to end the interview at any time, and that their data would be destroyed upon exiting the study. At the start of the interview, the participants were shown a hypothetical SAR scenario involving the report of a MISPER. The development of the SAR scenario is shown in Chapter 2. The hypothetical scenario remained the same for both the work-as-done and work-as-imagined interviews (see Figure 15).

A report of a missing person has been received. The police have reached out to your rescue team for assistance. The missing person's profile shows the following details:

- Name: Stephanie Jones
- Gender: Female
- Age: 35
- Last known location: Hiking at a National Park in Snowdonia. The National Park has a rugged and mountainous terrain.

Stephanie is a keen, well-equipped hiker. She mentioned she was going to complete the ranger path route which is usually carried out by experienced hikers. Stephanie left home to hike at 6am and planned to return for 1pm. However, she has not returned home or made contact. Her family described this as uncharacteristic and are worried that she is lost or injured.

Figure 15. *Hypothetical scenario involving a MISPER search*

Once the scenario was shown, the interviewer went through the set of semi-structured SWARM prompts (see Appendix B and Appendix C for the complete list of interview prompts). Where necessary, the interviewee asked for further clarification to ensure the tasks, processes, and interactions carried out within the SAR environment were fully understood. There was no time limit placed on the interview to ensure the participant could freely and naturally answer the questions. At the end of the interview, participants were debriefed and thanked for their time. In total, the interviews took an approximate combined time of 7 hours and 30 minutes.

3.5.4 Data analysis

The recordings taken from the operator interviews were manually transcribed for the purposes of data analysis. Each transcribed interview was anonymised to protect the identity of the participant. The primary researcher then read through all the transcripts to familiarise themselves with the dataset. Whilst the participants were from a range of SAR units located across the UK, the response and actions undertaken by each unit were similar. This is likely because each volunteer carries out vast amounts of training to respond to SAR missions in a standardised and effective manner. As a result, the data could be amalgamated to develop the three different types of decision models. Each decision model was developed using guidance available in the literature (RPDM – Klein et al., 1989; PCM – Plant & Stanton, 2016b; Decision Ladders - Jenkins et al., 2010).

3.5.5 Validation assessment

The decision models were continuously reviewed and iterated by two HF experts until a point of agreement was reached wherein both experts deemed the models to accurately depict the decision-making processes of SAR teams. An independent SME subsequently reviewed these models and provided feedback on the processes and tasks captured within the decision models. Overall, the SME determined that the models provided an accurate and thorough representation of decision-making within a SAR application. Minor suggestions were made to emphasise the importance of experience that enables SAR personnel to understand and react appropriately to each MISPER case. In additions, modifications were also made to demonstrate the centrality of checklists that standardise the planning and execution of SAR responses when using a UAV. In addition, the SME recommended adding a calibration phase within the work-as-imagined models as this is a SOP conducted by UAV teams to familiarise the Payload Operator with the display of the operational terrain and identify appropriate flight parameters for the UAV (e.g., height, angle).

3.5.6 Model assumptions

It is important to note that as this work focused on imagery analysis and extracting meaningful data from the UAV, a significant focus was on the processes involved during the execution of a SAR mission. Therefore, the missing planning elements of the traditional ground search response are not exclusively depicted within the models as it was deemed beyond the scope of this work. The models for the work-as-done response were therefore generated under the following assumptions:

- the callout of the SAR team was a valid and necessary response;
- the SAR team had carried out all the necessary pre-mission checks and were carrying the equipment required for the SAR mission;
- the control team had efficiently identified the mission plan through an understanding of statistical profiling data, knowledge about the MISPER, and knowledge of the area itself;
- the search area has been divided into groups of ground search parties comprising several ground searchers and one Team Leader as part of a formal ground search response.

For the work-as-imagined scenario, the following assumptions were also made:

- a set of ground parties are already searching on the ground;
- the UAV team members are readily available;
- it is safe to launch the UAV;
- and the UAV team are working as part of a coordinated search to review areas that have not been covered by the ground search teams.

3.6 Results

The following section will present the amalgamated decision models that were developed using the responses from the operator. Any processes and tasks presented in these models are those that were stated by the majority of participants.

3.6.1 Decision Ladders

Figure 16 and Figure 17 show the completed Decision Ladders for the work-as-done and work-as-imagined scenarios, respectively. The guidance outlined in Jenkins et al. (2010) was used to develop each Decision Ladder (see Appendix E).

3.6.1.1 *Work-as-done*

The amalgamated Decision Ladder for the work-as-done scenario is shown in Figure 16 and depicts the decision pathway triggered when a ground searcher locates potential evidence of a MISPER's whereabouts (e.g., personal belongings of the missing person). It shows how additional information is processed within the SAR system through a series of interactions and tasks carried out by SAR personnel. In the context of a MISPER search, the primary goal of the SAR team is to leverage any new information identified during a mission to assist with the rescue or recovery of the victim, whilst maintaining the safety of the entire search team. The safety of SAR teams is essential to manage as often responders work in environments characterised by hazardous environmental conditions (e.g., poor weather) over an extended period of time.

The type of clue found can vary from a physical belonging (e.g., a backpack, packet of plasters), disturbed undergrowth or a flashing light signalled by the MISPER. As such, physical cues in the environment serve as an alert when new information is discovered. There are, of course, alternative pieces of information that the SAR team can obtain, such as information from members of the public and scent trails identified by search dogs. However, within this Decision Ladder, it was decided to focus on ground objects as the task of searching for information in the physical environment is analogous to feature searching UAV images, thereby enabling better comparison between work-as-done and work-as-imagined. The task of identifying a clue in the environment can be viewed as skill-based behaviour as the process of recognising an object in the world represents an automatic behaviour performed by the ground searcher whilst investigating their allocated tasking (Rasmussen, 1983). This recognition results in the second information processing activity within the Decision Ladder, that is, observing information in the operational environment. The information attended to can include physical cues in the environment surrounding the object, communications between members of the search party, and the information shown on technological devices, such as GPS devices that display the current location of the ground searcher and the MISPER's last known location.

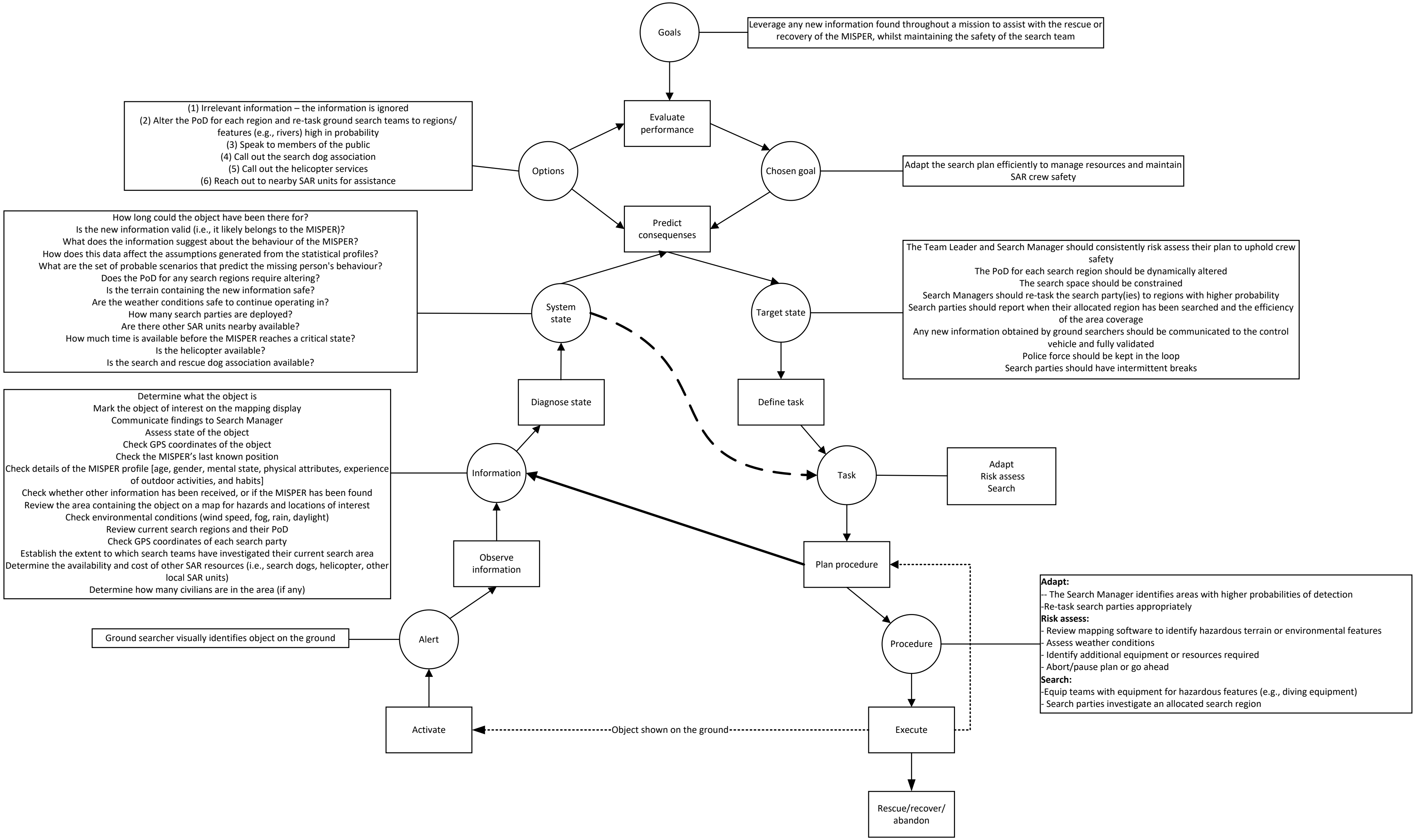

Figure 16. *Decision Ladder for the work-as-done scenario*

The integration of information from these disparate resources provides the impetus for the ground searcher to diagnose the system's state. Parnell, Wynne, Plant, et al. (2021) described the processes of observing information and diagnosing the state of the system as rule-based activities, and the same can be said within the SAR context. This is because stored rules direct the ground searcher to specific information in the environment that indicates whether the object is relevant to the search. In that sense, these initial two processing activities within the ladder can be viewed as the information validation stage, wherein the clue is rejected or confirmed as an object of interest (see Figure 16). For example, a ground searcher who has found a hat on the floor may at first consider this a potential clue; however, on closer inspection, the hat could be covered in mould. If the MISPER case is a recent event, the hat should be rejected as an object of interest as there would not have been time for mould to grow within the timeframe of the MISPER search. This example demonstrates how rules are applied to generate conclusions on the object's status by validating its relevance to the SAR effort.

Further, the diagnostic processing activity is also used to infer information about the MISPER's intention or likely movement by comparing the new information with the data already collected during the search mission, such as their last known location (see Figure 16). This assimilation of knowledge is used to identify where the current search plan requires adapting and the level of resources available within the SAR environment that could facilitate any alterations. For example, the mapping software shown in Figure 14 displays each search region, its corresponding PoD, and the progress of each ground search team. The understanding derived from viewing this technological resource is used to alter the PoD for each search region. These predictions on MISPER behaviour are often heavily informed by statistical profiles that describe the common traits and movement of individuals based on their gender, age and mental state (e.g., Gibb & Woolnough, 2007). However, as no two MISPERs are the same, it is important to reflect on the assumptions generated from these profiles to ensure the search plan takes into account the specific characteristics of each MISPER case. As such, the diagnostic activity could also see the SAR team review the initial set of assumptions generated to ascertain whether the new piece of information contradicts any expectations surrounding the MISPER and whether the plan requires further modification to address this disparity. Additionally, information concerning the environmental conditions would also be considered to determine whether (i) the MISPER may have faced any danger due to extreme conditions and (ii) whether any additional equipment or services are required to mitigate the danger posed to the SAR team (see Figure 16).

Following this diagnosis of the system's state, knowledge-based processing is used to produce a set of options that identify how to respond to the clue. Constraints associated with each option are identified in order to bound the success of each option and enable an accurate prediction of their likely outcome. These options are shown in Figure 16. Each option is mentally simulated concurrently so that the available courses of action are subject to comparative evaluation to identify the most appropriate selection. The high-level system goal directly impacts this evaluation process (Banks et al., 2020). In that sense, the serial evaluation of options is informed by top-down processes (i.e., pre-conceived goals within the SAR environment) and bottom-up processes based on the resources and data available that ultimately set the constraints within the SAR context. For instance, deploying a helicopter is expensive, which is widely known among SAR teams. In some conditions, this constraint may deter the SAR teams from selecting this option as an appropriate response. However, if the helicopter was necessary to manage the safety of the SAR team, then it could be considered a viable option. Even so, the most likely course of action would see the PoD for each search region be altered, and the subsequent re-tasking of the ground teams to investigate any regions with higher probability before calling on more expensive resources.

To illustrate the adaptability of the SAR teams when executing a search plan, a link has been incorporated within the Decision Ladder from the 'execute' node to the 'plan procedure' node (see Figure 16). This link demonstrates that a search plan is continuously altered to account for information stored on the left-hand side of the Decision Ladder. For example, safety may become a point of consideration as the mission is executed due to environmental conditions (e.g., weather). Further, the ground search parties may find new information while conducting the adapted search plan, resulting in the Decision Ladder being processed again. This cyclical process is represented by a link from the 'execute' node to the 'activate' node (see Figure 16). In theory, the mission can be continuously adapted based on intelligence recovered by ground search teams until an outcome is reached as shown by the last information processing activity within the framework (see Figure 16). This outcome could include the rescue or recovery of the MISPER or the abandonment of the mission when the resources available in the SAR team become depleted.

Within the SAR team structure, several members will be present, each equipped with varying levels of expertise and knowledge. The individuals with greater levels of experience tend to work in roles that exert control over the search plan, such as the Search Manager who assimilates information gathered from the described disparate sources of information to build and update a 'picture' of the SAR mission. It is this level of experience that enables decision-makers to progress through the Decision Ladder in a non-sequential manner (Banks et al., 2020; McIlroy & Stanton, 2015). Two shortcuts have been identified within the work-as-done Decision Ladder (see Figure 16).
The first shortcut presents a leap in knowledge from the 'system state' to the 'task' node. This shortcut occurs when the Search Manager coordinating the response recognises that new

information warrants the re-allocation of search party resources to maximise the probability of locating the MISPER.

Secondly, a shunt shortcut is shown which connects 'plan procedure' information processing node to the 'information' knowledge node (see Figure 16). This shortcut demonstrates how decision-makers in a SAR environment maintain awareness of the dynamically changing situation using information from the left-hand side of the Decision Ladder to inform their procedure and allocation of team resources. The information could be data collected from earlier points of the SAR mission (e.g., the MISPER profile) or updated information that is more recently acquired (e.g., the progress of each ground search party) (see Figure 16).

3.6.1.2 *Work-as-imagined*

The final amalgamated Decision Ladder for the work-as-imagined scenario is presented in Figure 17 and outlines the decision-making process of a SAR team when conducting a MISPER search with a UAV. Notably, the work-as-imagined and work-as-done Decision Ladders share the same overarching goal. This is because the data obtained by the UAV is processed as an additional piece of intelligence in the same way that information from ground searchers is incorporated within the SAR environment.

The alert within the work-as-imagined scenario occurs when the Payload Operator identifies a sighting on their HMI. The information subsequently observed in the environment shares the same pieces of information seen within the work-as-done ladder (see Figure 17). However, most UAV operators indicated that any information obtained by the UAV would be subjected to further processing to establish its reliability and relevancy. For instance, one UAV operator (P5) stated that *"ordinarily with the UAV and searching, one thing would back up the other… so we would rely on something else to clarify or confirm that information"*. This means that the information obtained by the UAV must be verified and, therefore, is also subject to an initial validation phase. The validation phase is similar to that described within the work-as-done Decision Ladder, as the object found by the ground searcher would also be assessed for its relevancy. However, on closer inspection, the process of validating UAV data is far more complex as the sighting is only observable on a 2D HMI. From this minimal amount of information, a decision must be made on whether it is worth investigating. Here, information in the environment is reviewed to ascertain whether the UAV data corroborate the details of the MISPER. For example, the last known position of the MISPER may be examined to gain an understanding of the potential distance travelled. If the MISPER had travelled a respectable distance but was an elderly individual, the UAV team may rule out the sighting under the assumption that the MISPER would not have been capable of conducting such activity due to their physical ailments. This demonstrates the rule-based processing applied at this stage of the Decision Ladder.

Further, the Payload Operator analyses the environmental surroundings shown within the aerial imagery to infer whether a sighting matches a MISPER's size, shape, and movement. Concurrently, the status and health of the UAV are also reviewed to determine whether the vehicle can continue to support the SAR mission. For instance, the battery life of the UAV is monitored to estimate the time left before the UAV requires a new battery. As such, the UAV’s technological constraints fundamentally alter the amount and type of information reviewed and the subsequent diagnostic activities. The information and considerations that result from using a UAV are colour coded in red (see Figure 17). This abundance of information processed to verify a sighting could be reduced by integrating the information aspects shown on the left-hand side of the ladder within the DSS using automation and visualisations that minimise the need for rule-based processing.

Once again, the system diagnostic activities lead to expectations and assumptions about what the information could reveal about the intentions of the MISPER. The environmental conditions (e.g., weather, terrain, hazards) would also be considered when identifying an optimal response plan. Unless the UAV data is considered irrelevant, the set of options for the work-as-imagined scenario generally seeks to reallocate the SAR teams or call on additional resources (see Figure 17). The reallocation of extant SAR team resources could involve tasking the UAV team, a nearby ground search team, or both teams to relocate the sighting in an effort to facilitate their rescue. However, if the sighting is deemed irrelevant, the SAR teams would continue their current search, and the UAV may be redeployed to another region of interest. To down-select the best option, knowledge-based behaviour applies constraints to simulate the outcome for each option in a concurrently. An expert decision-maker may automatically recognise the optimal course of action to validate the UAV data once the system state is diagnosed, enabling them to shortcut the decision-making process by understanding which option aligns with the goal of the SAR (see Figure 17). This shortcut is displayed as a leap from the ‘system state’ node to the ‘task’ knowledge node.

As the work-as-imagined ladder focuses on the UAV-equipped SAR operations, the procedure on the right-hand side of the ladder describes the processes involved when re-tasking the UAV (see Figure 17). Typically, a UAV re-tasking procedure would involve landing the UAV and transporting the UAV team to the site of interest. The UAV would subsequently be relaunched, at which point the Pilot and the Payload Operator would work as a team to navigate the UAV safely within the area. Concurrently, the Payload Operator monitors the display for the initial sighting and requests the Pilot to manipulate the UAV parameters in the air and alter the camera’s tilt, pan and zoom. The sensor payload is also alternated between the visual and thermal sensor modes by the Pilot at the request of the Payload Operator. Whilst the UAV is deployed, the UAV team refer back to legacy information, such as the location of the initial sighting. This helps maintain awareness of where to fly the UAV and guides the Payload Operator's attention when searching the aerial imagery. These referrals to the left-hand side of the ladder are depicted in Figure 17 as a shunt between the 'plan procedure' and 'information' nodes.

Whilst manoeuvring the UAV, the human-UAV team must maintain awareness of the system's state to ensure the UAV flight plan adheres to Civil Aviation Authority (CAA) regulations, whilst also monitoring the health and status of the UAV. Currently, the CAA does not permit the UAV to fly more than 120 metres from the earths surface or 500 metres beyond visual line of sight (CAA, 2023). Figure 17 depicts the referral to check these physical parameters as a shunt between the 'plan procedure' and 'system state' nodes. The additional shunt contained within the work-as-imagined ladder demonstrates the increased amount of work introduced by integrating a UAV within the SAR environment. As such, the DSS could utilise these information aspects to reduce the amount of information continuously monitored by the Payload Operator. Upon re-locating the finding and confirming its relevancy, the Search Manager would reallocate the team's resources to reach and attend to the MISPER. Alternatively, if the sighting was concluded to be irrelevant, the area's PoD can be lowered, enabling for more efficient allocation of resources (Anderson et al., 2021). As a result, the order of tasks carried out by the UAV not only increases but also changes in terms of the sequence in which the tasks are completed. This is because the UAV data must be validated before it is integrated within the wider SAR plan, thereby moving the task of adapting the search plan to the final aspect of the procedural strategy. Conversely, for the work-as-done decision ladder, the search plan can be adapted with more ease as the validation process for determining the relevancy of an object is easier when working within the natural 3D environment, meaning the adaption of the search plan takes place first.

One similarity observed between the work-as-done and work-as-imagined response was the links embedded between the information processing activities. The first link between 'plan procedure' and' 'execution' demonstrates that the UAV mission plan may be altered in response to new information or changing circumstances within the environment. This is particularly important because if the environmental conditions are no longer safe, the UAV must be landed to prevent critical incidents such as crashes or a loss of control. Further, the link between 'execution' and 'activation' also exemplifies that the SAR effort continues until an outcome is reached.

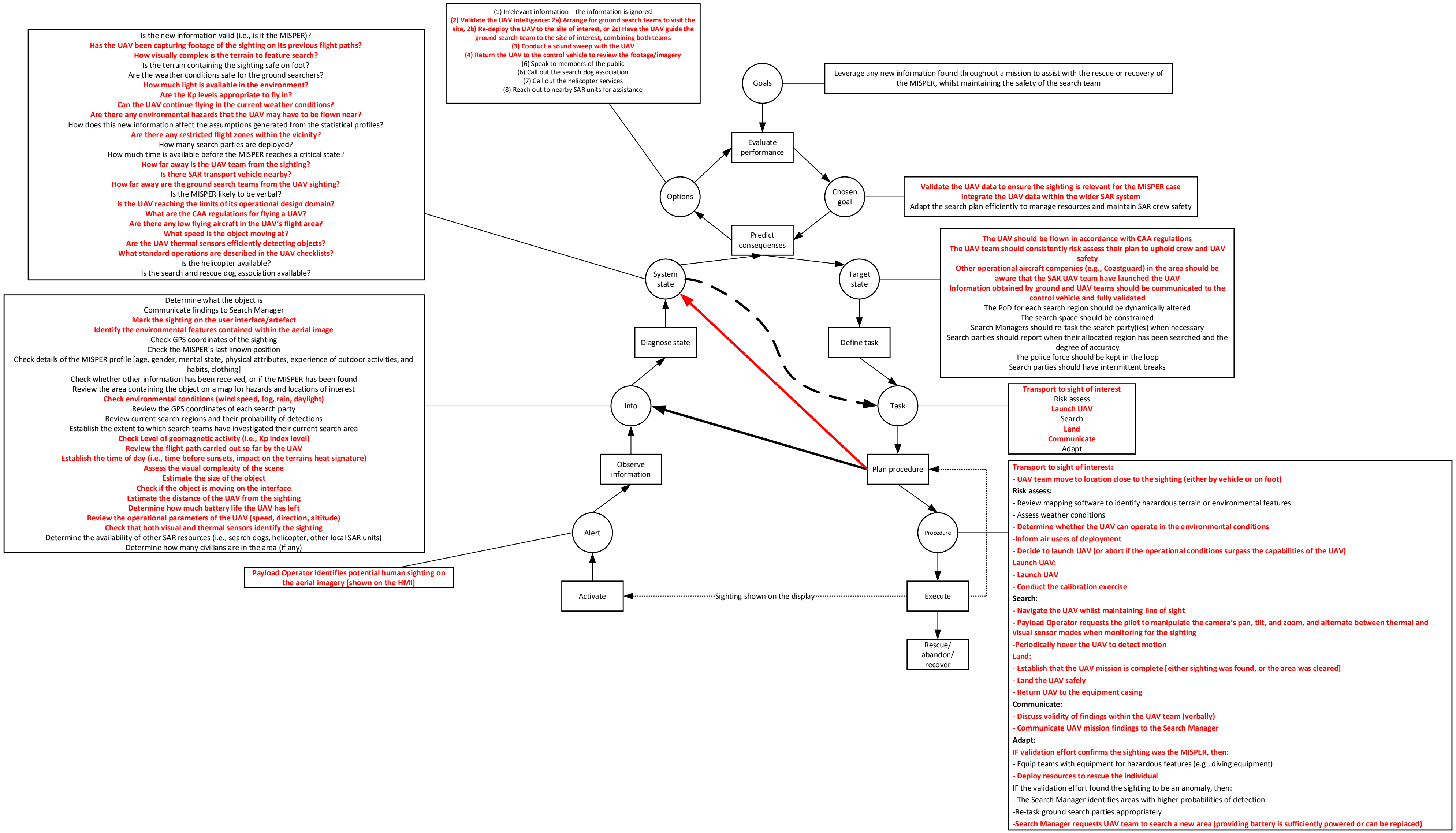

Figure 17. *Decision Ladder for the work-as-imagined scenario*

Note. Aspects colour coded red indicate any new information and tasks that are introduced when using a UAV to support the SAR effort

3.6.2 PCM

In order to apply the participant responses to the PCM models, the interview transcripts were coded into the relevant PCM category (Plant & Stanton, 2016b) and placed in chronological order to show how the SAR response transpires once a tasking has been allocated by the Search Manager. The PCM models therefore outline the perceptual cycle processes of SAR responders when conducting a MISPER search using a traditional ground search response (see Figure 18) and UAV-equipped SAR response (see Figure 20). The PCM primarily flowed in an iterative cycle from the "world" to "schema" to "action" components, and can be followed according to the numbering assigned to each process in the models.

3.6.2.1 *Work-as-done*

The final amalgamated PCM for the work-as-done scenario is presented in Figure 18. The model begins with the Search Manager allocating a region of land to each ground search party. To respond to this information, search parties would intrinsically navigate to their allocated tasking using mapping tools that display their current GPS location in relation to their search region.

Upon arriving at the search region, "schema" regarding the principles and methodologies used to effectively search the terrain would be activated. This knowledge is gathered through training courses that responders must partake in when obtaining their qualification to join the SAR unit, as well as training exercises that are regularly conducted to maintain and build the skill of the SAR team. Often, when searching a region of land, ground searchers will use a parallel line search pattern to ensure the area is rigorously investigated. Figure 19 shows the formation used when carrying out a parallel line search which sees the responders line up along the topographical barrier of their search region (e.g., a hedge line) and walk the length of the area in a linear line whilst maintaining a set distance from their neighbouring search team member (see Figure 19). The Team Leader would position behind the line of ground searchers to monitor the spacing between each team member and assess the ground coverage of the party. These movements can be observed on the mapping display in the control vehicle as the GPS locations of the ground searchers form track lines over time.

Participants reported that when navigating through the region, knowledge acquired from the regular training exercises would be used to monitor the environment to identify objects deemed out of place. This shows how schematic structures can guide the allocation of attention in the "world".

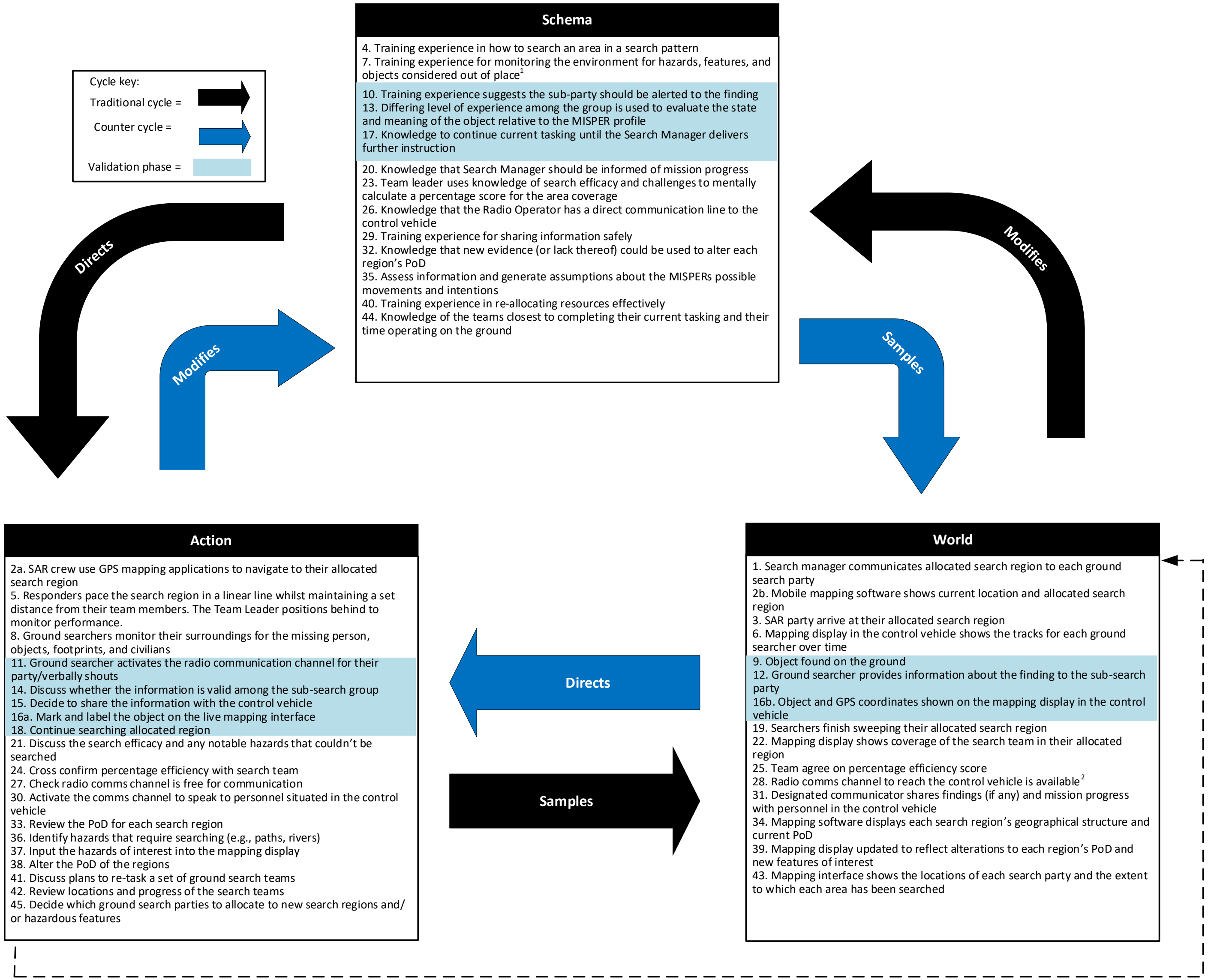

Figure 18. *PCM for the work-as-done scenario*

Note. Processes of the PCM shaded in blue indicate where additional steps are taken to process any objects identified by the ground searchers when sweeping their allocated region. In the event that no objects or clues are identified, these steps would not be followed within the PCM. Further, to denote where tasks are processed differently due to experience or contextual circumstance, numerical indices were used. The descriptions associated with each numerical symbol are detailed as follows:

[1] The task of feature searching could be guided using knowledge obtained from a responder's direct experience of past search operations.

[2] If the channel was not free, the responder responsible for communicating may attempt to use a different comms modality. For the sake of conciseness, this model assumes that a radio device is being used. Other modalities can include Airwave and mobile phones.

The direct experience held by each responder can also assist with this monitoring task by guiding their attention towards specific environmental features and known hazards within the terrain. For example, a responder may be cognisant of investigating shakeholes (i.e., a large depression in the ground) having dealt with a MISPER case where the victim had fallen down a shakehole. However, previous experience cannot always be drawn on. This could be because the responder holds limited experience in MISPER searches or has limited knowledge of the search region and its features due to being called out to an unfamiliar site to assist a local SAR unit. As such, the impact of previous direct experience on this monitoring task has been added as a footnote to recognise that some team members may activate this schema, whilst others will be developing it through experience.

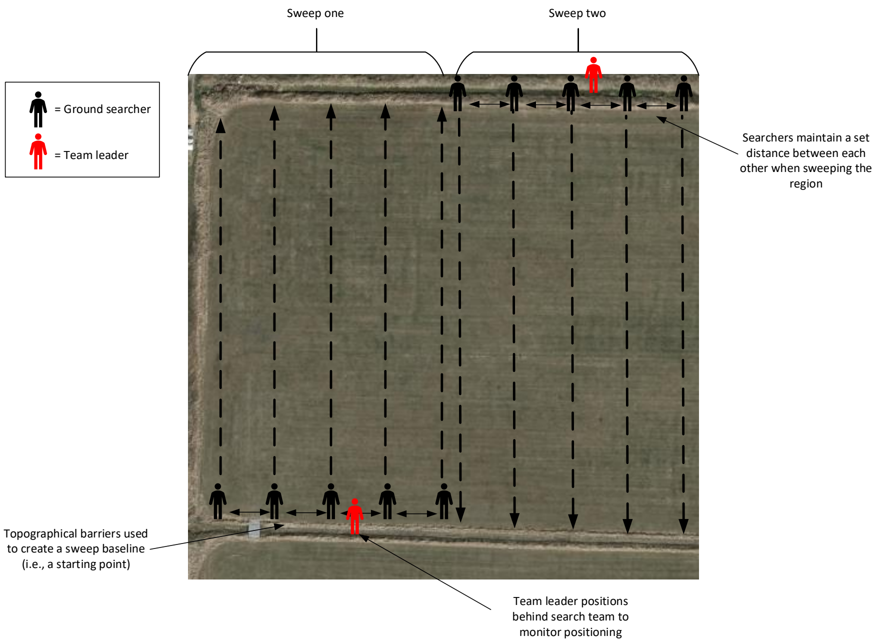

Figure 19. *Visual depiction of the parallel line search method that is often used by responders when investigating a vast region of land*

Whilst searching a region, a ground searcher could locate some form of information in the “world” that serves as a clue (e.g., an object). This finding is reported by the ground searcher to their team by shouting or utilising a radio communication device. Typically, only two members of the search party will have a direct line of communication with the control vehicle; those being, the Team Leader and the Radio Operator. This configuration means that any new information identified in the environment must flow within the ground search party before it is passed on to the Search Manager in the control vehicle. Once this information is shared within the search party, the assumptions and expectations of each team member are pooled together to assess the validity of the object and decide whether to report it to the Search Manager. These information-sharing procedures strategically prevent the communication of potentially irrelevant findings, which could cause an information bottleneck in the SAR environment. An object identified as interesting would be reported using SAR software tools that enable responders to mark the object on a map and include a description of the finding. This information is then accessible to search personnel in the control vehicle. These processes are denoted within the PCM as 16a and 16b as they occur concurrently. This format henceforth represents any processes that take place in close succession. Whilst clues are invaluable for constraining the size of the search space, they may not always be located by search teams. Therefore, steps 9 – 18 have been shaded in blue to demonstrate that these processes may not always occur during a ground search, but the steps that proceed would still be followed regardless of whether a clue has been located to ensure the region can be ruled out of the search plan with some degree of confidence.

Once the ground search team have investigated their region, a report would need to be sent to Search Manager informing them of their progress. To compile this report, the search party will discuss the perceived efficiency of the search and any hazards that could not be searched without additional specialist equipment. When assessing the efficiency of the search, the mapping display can also be used as an additional source of information to assess the coverage of the search party based on their GPS tracks recorded across the search region. By assimilating this information, the Team Leader calculates a percentage score to numerically represent the likelihood that the MISPER is not in the search area following the search team’s investigative efforts. For example, a percentage score of 75% would suggest there is a 25% chance that the MISPER is still in that region. The search party would cross-confirm this score, placing the team in a position to contact the Search Manager and triggering the knowledge that the Radio Operator is responsible for conducting this communicative task.

To initiate this task, the Radio Operator would check the radio communication channel that directly interlinks with the control vehicle is available for transmission. Upon confirmation, the operator’s schema on the communications protocol used to share information safely would be activated. Often, SAR teams will have a communication protocol that must be exercised to keep verbal messages concise so that the channel does not experience a bottleneck. Further, ground searchers must share information safely to prevent sensitive information from being transmitted over a channel that the public or media could access. The radio operator would interact with their radio device to activate the radio device and verbalise the report of the ground party's search effort and percentage efficiency score. This transfer of information is depicted within the "world" component.

Following the reception of the search party's progress, the Search Manager would use their progress update to identify how the PoD for each search region could be altered to maximise the probability of locating the MISPER. This would be completed by reviewing the geographical composition of each search region and its corresponding PoD on the mission planning display (see Figure 14). The Search Manager then combines the knowledge obtained from the ground search party with their understanding of the search region's structure to predict the movement of the MISPER within the terrain. These predictions are used to identify any hazards that the MISPER could have encountered which can be inputted into the search planning system alongside any updates to each search region's PoD. By updating the PoD and hazards of interest, it ensures any aspects deemed high in probability are searched imminently through the re-allocation of team resources. In order to reallocate teams according to any search plan alterations, the Search Manager will use their trained experience to appropriately select which set of ground parties should be re-tasked to investigate the identified feature(s) or area(s) of interest. The Search Manager will discuss with other personnel in the control vehicle which ground teams should be re-tasked whilst also using information on the real-time locations and progress of each party to support their decision. This information is checked to ensure that any parties being re-tasked have access to the new region and are able to undertake a tasking without draining the physical resources of the team.

Once the search teams have been identified the Search Manager would communicate the new search tasking to each ground search party, thus returning to step 1 of the PCM. In theory, this pattern of investigating a search region and using the findings to update the search plan can occur numerous times until an outcome is reached (i.e., rescue, recovery or abandonment). To illustrate the cyclical pattern of this search exercise, a link has been incorporated within the work-as-done PCM between step 45 and step 1.

3.6.2.2 *Work-as-imagined*

Figure 20 shows the final amalgamated version of the PCM for the work-as-imagined scenario. Within the SAR context, the UAV mission begins when the Search Manager requests the support of the UAV team to investigate a region of interest. As a result, the PCM captured the mission planning tasks undertaken by the UAV team to ensure the UAV is safe to deploy and, if so, is flown according to a search plan that manages the limited battery life of the vehicle. In order to devise an efficient search plan, both bottom-up and top-down processing is used. This is because information on the MISPER incident is processed using knowledge obtained from previous SAR missions to generate assumptions about their movement within the search space (i.e., bottom-up processing). As a result, the UAV team would identify a search plan for the UAV that efficiently investigates the region of interest (i.e., top-down processing).

Once this plan has been approved by the Search Manager, the UAV team would know to identify a suitable location to facilitate the set up of the UAV and any pre-mission checks. The launch point would be decided using a map of the search region which is applied with knowledge on the starting point of the UAV mission plan. Once a location has been identified, the UAV team would notify the control vehicle of this location and be transported to the designated launch site. When preparing the UAV for launch, "schema" obtained through training experience is used to ensure all the relevant safety checks are carried out. Here, pre-flight checklists are also used to risk assess the UAV mission and set up the vehicle. Firstly, the checklist would guide the UAV team's attention to weather applications that determine whether the environmental conditions are conducive for UAV flight. Several participants referenced the use of UAV forecast which provides a detailed overview of the weather conditions and recommends whether the UAV can be launched based on several aspects of the environment (e.g., windspeed, Kp-index levels). Even with these applications, UAV operators indicated that they would apply their expectations on the acceptability of the environmental conditions to determine whether they are within the boundaries of the UAV's capabilities.

Subsequently, the UAV team would be triggered to determine whether the UAV is physically capable of a mission by assessing the health and status of the vehicle. Once the vehicle has been deemed airworthy for deployment, the UAV team would notify local aircraft users of the vehicle's deployment and obtain permission to launch the UAV. Upon obtaining permission, the UAV Pilot would refer to their knowledge obtained through training exercises to launch the UAV safely. The UAV team would consequentially observe that the vehicle has launched, thus it has been noted as a piece of information that manifests in the "world" which prompts the team to conduct the calibration exercise. This calibration task requires the Pilot to hover the UAV above themselves and the Pilot until they are visible on the display. Through this exercise, the Payload Operator familiarises themselves with the display and what the MISPER could look like within the terrain, whilst the Pilot ascertains an appropriate height and angle to pilot the UAV on for the duration of the mission.

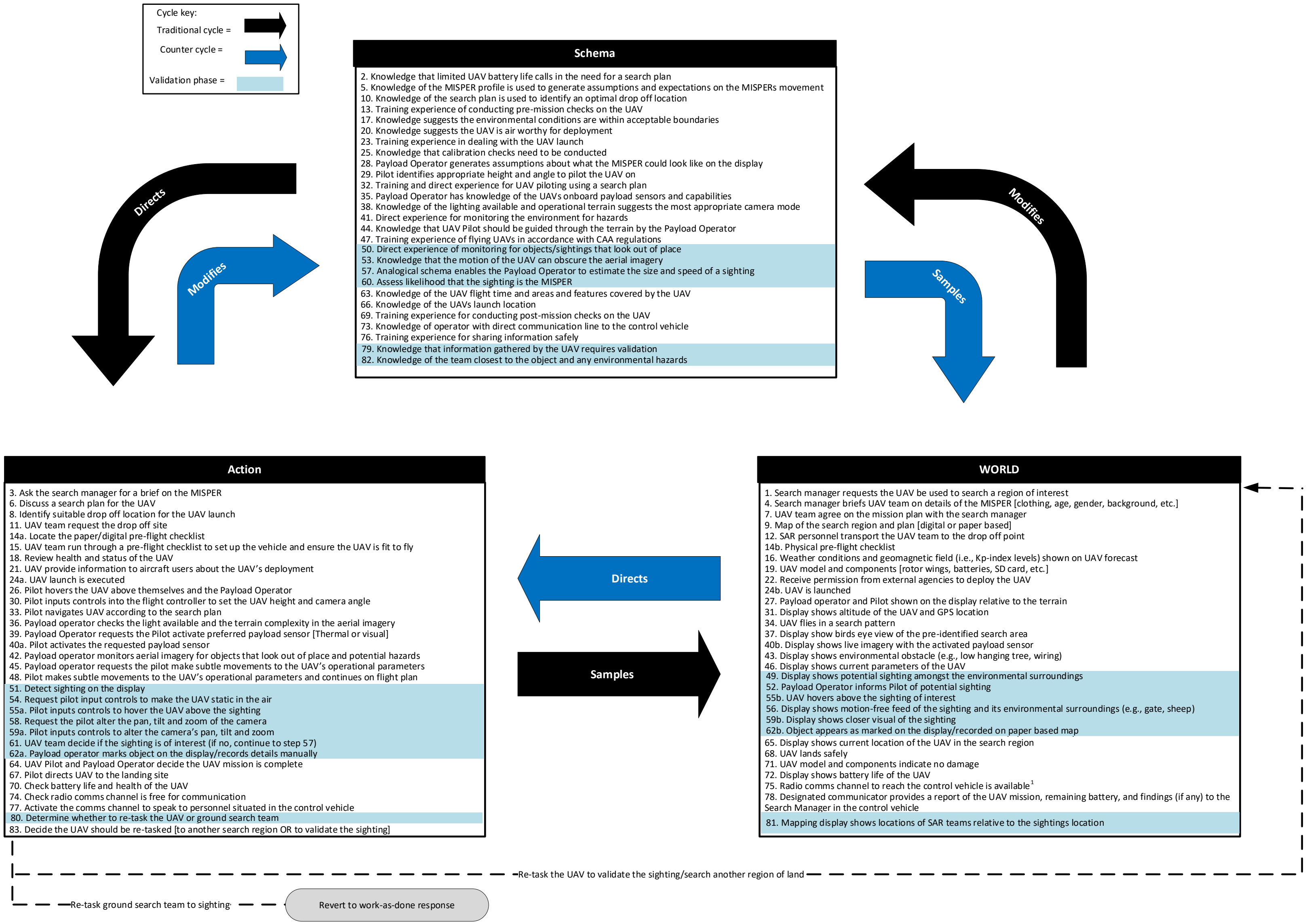

Figure 20. *PCM for the work-as-imagined scenario*

Note. Processes of the PCM shaded in blue indicate where additional steps are taken to process any potential sightings identified by the Payload Operator. In the event that the UAV imagery does not contain any sightings, these steps would not be followed within the PCM.
To denote where tasks are processed differently due contextual circumstance, numerical indices were used. The definition associated with the numerical symbology is detailed as follows:
[1] If the channel was not free, the responder responsible for communicating may attempt to use a different comms modality. For the sake of conciseness, this model assumes that a radio device is being used. Other modalities can include Airwave and mobile phones.

When navigating the UAV, the Pilot uses their extensive body of knowledge on UAV flight that is acquired through training and/or direct experience to input the appropriate control functions that follow the search plan. Both training and direct experience are referred to here as Pilots partake in regular training exercises and must also upkeep their deployment hours by regularly piloting the UAV outside of the SAR context. Much like the word-as-done scenario, the UAV is piloted in a pattern to ensure the maximum amount of the search region is covered. As a result, the UAV can be observed to fly in a uniform pattern in the sky, such as the parallel line search shown in Figure 21.

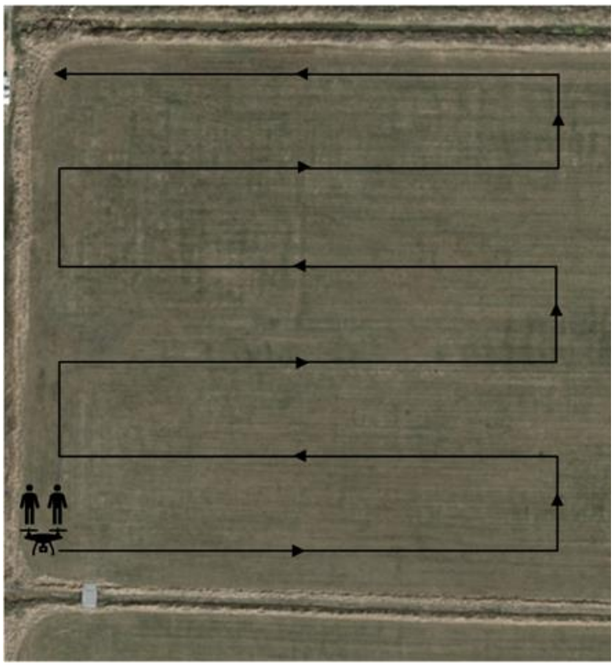

Figure 21. *Visual depiction of the parallel line search that is inputted by the UAV Pilot to navigate the UAV within a search region*

Whilst the UAV is in-flight, the aerial imagery would be visible on the Pilot and Payload Operator's display. In order to support the analysis of the aerial imagery being transmitted in real-time, the sensor payload can be alternated between a visual mode that displays a standard image and a thermal mode that colour codes the heat signature of the terrain to support the detection of heat contrasts. The Payload Operator would hold knowledge of the capabilities of each sensor type and the constraints that limit their effectiveness, such as the environmental conditions. In turn, these schematic structures would direct the Payload Operator's attention to check the level of light available and the complexity of the terrain shown within the aerial imagery using their display. The knowledge obtained through this action is used to determine the most appropriate sensor mode to activate. Subsequently, the Payload Operator requests the Pilot to enact the chosen sensor mode. In turn, the Pilot inputs the controls to activate the camera mode which alters the presentation of the live imagery shown on the UAV team's display. This display is subsequently monitored for objects that appear out of place in the terrain, much like the ground searcher completing the parallel line search. The key difference is that Payload Operators are limited to observing a 2D display which is absent of the 3D cues available on the ground. The Payload Operator must also monitor for any hazards that could potentially damage the UAV. In the event that a hazard is identified, the Payload Operator would provide instructions to guide the UAV Pilot within the terrain to avoid any collisions. Whilst executing these instructions, the UAV Pilot would input the control functions to manoeuvre the UAV whilst also using their trained experience of UAV Piloting to ensure the vehicle's parameters maintain the legal flight requirements set by the CAA.

As the UAV progresses through the search region, a potential sighting could be captured within the aerial imagery. Upon detecting this sighting, the Payload Operator would request the Pilot to hover the UAV in a static position. This enables the aerial imagery shown on the display to be free of any movement caused by the UAV's flight, thus providing a clearer depiction of the sighting amongst the terrain and the environmental features contained within it (e.g., gates, trees). These environmental features provide a reference point that enables the Payload Operator to estimate the size and sighting of the speed by employing an analogical schema. Further, to verify that the sighting is of interest, the Payload Operator could request the Pilot to alter the pan, tilt, and zoom of the UAV camera. Currently, the Pilot must enact these changes as the Payload Operator does not have access to any control inputs when using the mirrored display. Through these analyses, the UAV team assess the likelihood that the sighting is the MISPER. When an object is deemed of interest, the Payload Operator will interact with their display to mark the sighting which records its GPS coordinates and maps its existence on the display. However, not all SAR teams held the functionality to mark objects on their display. In this case, the Payload Operator could manually record the details of the sighting by transferring information shown on the display to another physical artefact (e.g., paper, SAR system software).

It is also important to note that if the Payload Operator did not identify any sighting, it would still be deemed a finding in itself that could enable a region to be ruled out of the search plan or its corresponding PoD to be lowered. In that sense, steps 49 – 62b and 79 – 82 (shaded in blue, see Figure 20) may not take place during a UAV mission, but the majority of the proceeding steps described thereafter would likely still occur. As such, regardless of whether a sighting has been identified, the UAV team would use their knowledge of the distance travelled, the surface area covered, and the UAV flight time to determine whether the mission has been completed. Subsequently, the UAV Pilot would refer to their knowledge of the UAV's original launch point to input the controls that navigate the UAV back to this position for the landing phase. Once landed, the UAV team would refer to their training schematic to guide the execution of the post-mission checks that assess the UAV for any damage and determines the remaining battery life.

As with the work-as-done scenario, a report of the UAV mission should be provided to the Search Manager to inform them of the search findings (if any), the UAV's area coverage, and the remaining battery of the UAV that could be used for further taskings. When transmitting this report, the same communication protocol described in the work-as-done scenario would be used. This verbal report is depicted in Figure 20 as information in the "world" to demonstrate how the UAV data is to update the SA of personnel in the control vehicle. However, rather than automatically integrate the data within the existing plan, an extensive validation stage must be carried out to ensure the findings of the UAV are accurate. This is because UAV operators lacked trust in the findings gathered by the UAV and indicated that some form of validation is required to confirm the report's accuracy. The processes used to support this validation is once again shown in blue to demonstrate how a sighting is treated by the UAV team (see steps 79 – 82 in Figure 20).

The validation phase involves re-tasking the UAV to search a more localised region where the sighting was initially observed or instructing the ground searchers to investigate the search region on foot. Here, the Search Manager uses their knowledge of the locations of each ground search party and knowledge of the remaining UAV battery life to conduct a trade-off analysis that determines whether to allocate the validation task to the UAV or ground search team (see Figure 20). The re-tasking of the UAV team would see the PCM cycle repeat again, with the Search Manager issuing further instructions. However, if the ground search team were re-tasked, the SAR response would revert to that observed within the work-as-done PCM (see Figure 18). As with the work-as-done scenario, this re-tasking process would continue until some form of outcome is reached. Although the work-as-done scenario also contained a validation stage, the required procedures were more straightforward in that the finding was only discussed with other team members to confirm whether it warranted sharing. This demonstrates the complexities of teleoperating a UAV and trusting that the UAV team have covered the search area efficiently enough to identify any critical information. Multiple UAV operators reported that even if a UAV had searched a region, they would not be confident that the area could be ruled out of the plan with great certainty. This implicates the need to provide decision support to help the UAV team better understand the performance of the UAV mission.

In the event that no sighting was identified, the UAV could still be re-tasked to investigate another search region, thus also resulting in another work-as-imagined PCM cycle. Alternatively, the UAV batteries may become drained, meaning the UAV can no longer support the SAR mission.

3.6.3 RPDM

The following section presents the RPDM for the work-as-done and work-as-imagined scenarios. In order to develop the RPDM, the Situational Assessment Record (Klein et al., 1989) was used as an analytical tool. The method has previously been used to capture the expert decision-making of aircraft personnel (Parnell, Wynne, Plant, et al., 2021), train drivers (Tichon, 2007), and most famously fire fighters (Klein et al., 1989). The Situational Assessment Record identifies critical cues in the environment that inform any emergent goals and key decision points during an event (see Appendix F for a full outline of the Situational Assessment Record). In order to populate the Situational Assessment Record for the work-as-done and work-as-imagined, each interview transcript was examined to determine the situational assessments carried out by ground searchers and UAV teams. These situational assessments were then applied to the RPDM for the work-as-done (see Figure 22) and work-as-imagined scenario (see Figure 23).

3.6.3.1 *Work-as-done*

The Situational Assessment Record for the work-as-done scenario is shown in Table 5, and the application of the traditional ground search response to the RPDM is shown in Figure 22. The RPDM begins when the decision-maker experiences an event (Parnell, Wynne, Plant, et al., 2021). Therefore, for a traditional ground search response, the starting point for the RPDM occurs when the ground searcher identifies a clue within their search region. Upon locating an object in the environment, the initial response of the ground searchers would be to contact their ground search party to request further insight (Decision Point 1 in the Situational Assessment Record shown in Table 5 and Figure 22). The distributed nature of SAR environments means that the communications carried out across a network are critical for building and maintaining the SA of SAR personnel situated in the control vehicle overseeing the search mission (e.g., the Search Manager). To preserve the quality of information being passed within the network, the ground searcher would recognise the need to seek further guidance and insight from responders within their search party. In turn, the team members must collectively determine the validity of the information and whether it is relevant to the current search mission. To that end, Decision point 2 in the Situational Assessment Record shown in Table 5 argues that the assumptions of each search member surrounding the MISPER are used to evaluate whether the information obtained is likely valid and relevant. For instance, if the ground searcher located a red hat, and the MISPER were last seen wearing a red hat, the search party would likely regard the information as valuable. Decision Point 3 states that following this validation stage, the finding would be communicated to personnel in the control vehicle and marked on the live mapping interface that is mirrored within the control vehicle (see Table 5 and Figure 22).

Table 5. Situational Assessment Record for the work-as-done scenario

SA-1: Initial assessment of the situation	
Cues/knowledge	Information identified by ground searcher [personal belonging, footprint, fire, flare, whistle or shouting heard, members of public reporting information, flashing light]
Expectations	Information may be useful for constraining the search space by altering the PoD for each search area
Goals	Alert the sub search party group to the finding
Decision Point 1	Report [either verbally or via radio comms] the finding located on the ground to the ground search party
SA-2 (Elaboration): Update of SA based on new information and cues	
Cues/knowledge	Responders within the ground search party discuss the new information, mission reporting software
Expectations	The evidence needs assessing for reliability and validity to ensure information does not flood the communication network
Goals	Determine if the information should be shared with the wider team
Decision Point 2	Evaluate whether the information on the MISPER (held in the mind) corroborates the details known about the MISPER
Decision Point 3	Communicate the information over the radio
Decision Point 4	Mark object on the GPS mapping interface
SA-3 (Shift): Possible shift in the situational assessment based on additional information/events	
Cues/knowledge	Object of interest is shown on the mapping interface, or its location is communicated verbally, Search Managers in the control vehicle can see all search areas and their current PoD
Expectations	Search parties may need to be re-tasked to different search regions with higher PoD in light of new evidence; the location of the MISPER is more likely to be in a search region with a high PoD
Goals	Re-task search parties that are close to finishing the search of their current allocated area; re-task parties to regions within close proximity of their current search space; maintain crew safety
Decision Point 5	Utilise the maps [paper or electronic based] to identify possible hazards
Decision Point 6	Re-task a proportion of search parties to search regions with high PoD
Decision Point 7	Deliver any additional equipment needed to maintain safety

This influx of information into the SAR environment prompts a shift in the initial situational assessment, which indicates imminent changes to the current search plan may be necessary. This is shown in Phase 3 of the Situational Assessment Record in Table 5 whereby the Search Managers and coordinators must predict the impact of the new information on the PoD for each search region contained within the search plan to increase the likelihood of finding the MISPER (see Figure 22). This reliance on probabilities is a continuous theme described during the interviews, with one interviewee claiming that SAR is *"just a game of probabilities"* (P4) and another labelling it *"a glorified hide and seek"* (P1).

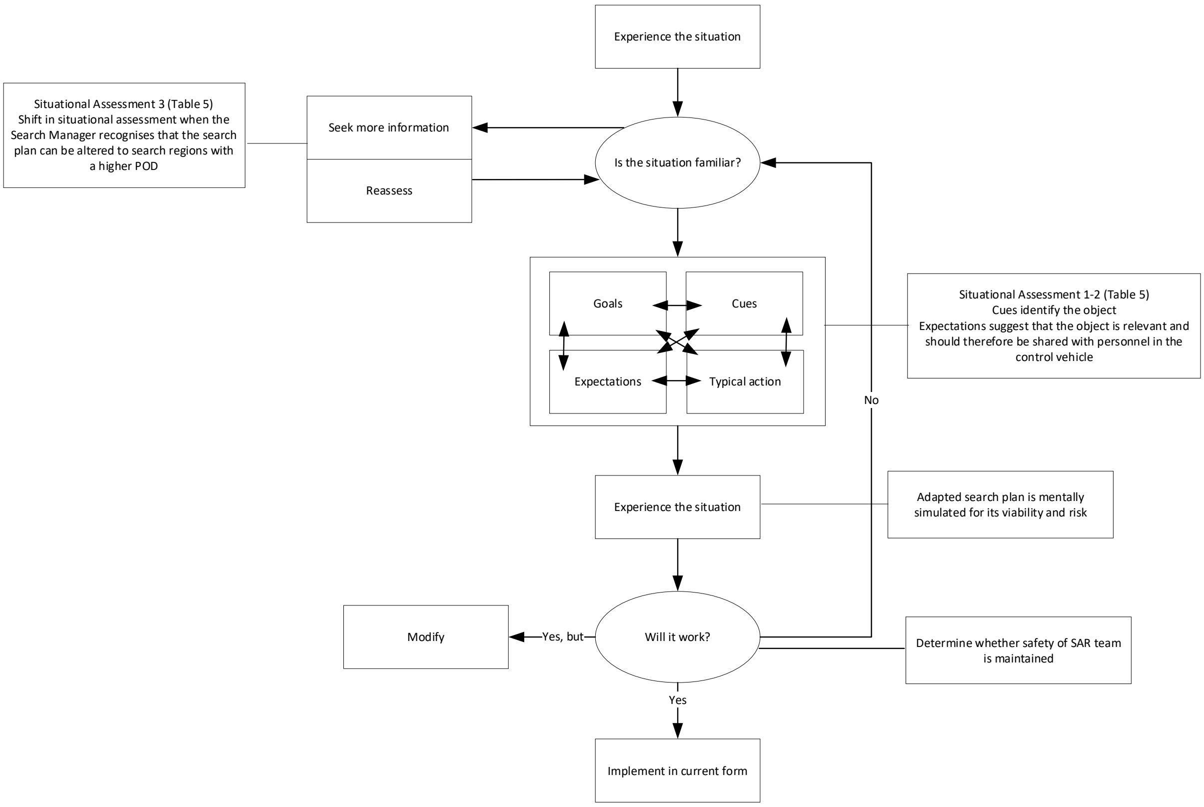

Figure 22. *RPDM for the work-as-done scenario*

The shift in Phase 3 of the Situational Assessment Record shown in Table 5 culminates in the development of an adapted search plan constructed using environmental cues. Here, the Search Managers would use digital or paper-based maps to identify potential hazards within each search region. Within the context of a SAR mission, such knowledge serves a dual purpose. First, it identifies locations where the MISPER may have injured themselves and should be investigated by the ground searchers. It also highlights areas where ground searchers should be aware of their safety. If the safety of the ground searchers is at risk of becoming compromised, equipment would be supplied to enable the searchers to navigate a region safely. For example, if ground searchers anticipated a need to climb steep ledges, they could be equipped with harnesses.

In order to respond to the new information, the Search Manager must decide which ground search teams to re-task using the GPS locations of each ground search party. The mapping interface shows this information to personnel in the control vehicle. The search plan outputted from Phase 3 of the

Situational Assessment Record would be mentally simulated in the head of the Search Manager to assess the viability and risk factor of the plan. If the adapted plan fails to upkeep the safety of the SAR team, the RPDM indicates that a situation assessment would be conducted again in a serial manner until an appropriate plan can be identified (see Figure 22).

3.6.3.2 *Work-as-imagined*

The Situational Assessment Record for the work-as-imagined scenario is shown in Table 6, and the SAR response applied to the RPDM is displayed in Figure 23. The Payload Operator's decision-making process begins once a human sighting that resembles details from the MISPER profile is identified on the display. Phase 1 of the Situational Assessment Record states that once a sighting is perceived, the UAV team must decide whether the mission of the UAV is complete. Once established, the UAV is landed and the UAV team communicates the mission findings, if any, to the Search Manager. This report divulges details about the sighting, such as the perceived likelihood of the finding being the MISPER.

Table 6. Situational Assessment Record for the work-as-imagined scenario

SA-1: Initial assessment of the situation	
Cues/knowledge	UAV Payload Operator monitoring aerial imagery identifies potential sighting of a person; MISPER profile; Interface shows GPS coordinates of the UAV and information on health and status
Expectations	Sighting could be the MISPER but requires validation to reduce uncertainty
Goals	Determine the location of the object using the GPS coordinates
Decision Point 1	Mark the object on the UAV interface to record the GPS coordinates or record details manually
Decision Point 2	Decide that the UAV mission is complete
Decision Point 3	Land the UAV in a safe location
Decision Point 4	Report progress of the UAV mission to the Search Manager and certainty that the sighting observed was the MISPER
SA-2 (Shift): Potential shift in the situational assessment based on additional information/events	
Cues/knowledge	Search Manager receives report about the progress of the UAV mission and the sighting; mapping display shows locations of each search party; certainty that the sighting is the MISPER
Expectations	Either the UAV team or ground search party must inspect the sighting to determine its validity
Goals	Ascertain which team is best to investigate the sighting whilst maintaining safety
Decision Point 5	Identify that the UAV team is closest to the sighting and has enough battery life
Decision Point 6	Search Manager requests UAV is re-launched to investigate the sighting
SA-3 (elaboration): Update of SA based on new information and cues	

Cues/knowledge	Pre-flight checklist; UAV is launched; Calibration stage conducted; Payload Operator scans imagery for the sighting; Pilot navigates the UAV through the search area
Expectations	There is a lag between when the time the sighting was originally identified, the Payload Operator needs to scan the surrounding region whilst the UAV is kept within line of sight, hazardous regions and areas with low visibility should be checked
Goals	Scan imagery until sighting is identified
Decision Point 7	Manipulate the gimbal camera's pan, tilt and zoom and payload mode
SA-4 (elaboration): Update of situational awareness based on new information and cues	
Cues/knowledge	Payload Operator's display shows a close up look of the sighting shown on the Payload Operator's display; Post-flight checklist
Expectations	The original sighting resembles the appearance of the MISPER
Goals	Land the UAV safely and communicate information with the wider search team
Decision Point 8	Land the UAV
Decision Point 9	Communicate where the sighting was seen to the Search Manager
SA-5 (shift): Possible shift in the situational assessment based on additional information/events	
Cues/knowledge	GPS information on the sighting received, knowledge of location of each ground search party
Expectations	Ground search party need to be re-tasked immediately to reach the sighting
Goals	Re-task a ground search party to the sightings location recorded by the UAV team; the search party closest to the location should be re-tasked; maintain crew safety
Decision Point 10	Utilise the maps (paper or electronic based) to identify possible hazards
Decision Point 11	Re-task a proportion of search parties to search regions with high PoD
Decision Point 12	Deliver any additional equipment needed to maintain safety

Phase 2 of the Situational Assessment Record shown in Table 6 asserts that the Search Manager responds to this report by determining which resource should be re-tasked to validate the information obtained by the UAV, representing the first shift in situational assessment (see Figure 23). This re-task procedure could involve allocating the resources of a UAV team or a ground search party to an area near the sighting location. As with the work-as-done scenario, mapping displays show the location of each team and enable the identification of hazards in the environment. However, the Search Manager and UAV team must also consider the battery life of the UAV within the work-as-imagined scenario. This is because the UAV requires enough battery to sustain another mission. If the situational assessment implicates the re-task of the UAV, operators will complete the pre-flight checklist before the UAV's launch. As a result, the re-tasking procedure used to validate the UAV information introduces additional stages to the work-as-imagined RPDM (see Table 6 and Figure 23).

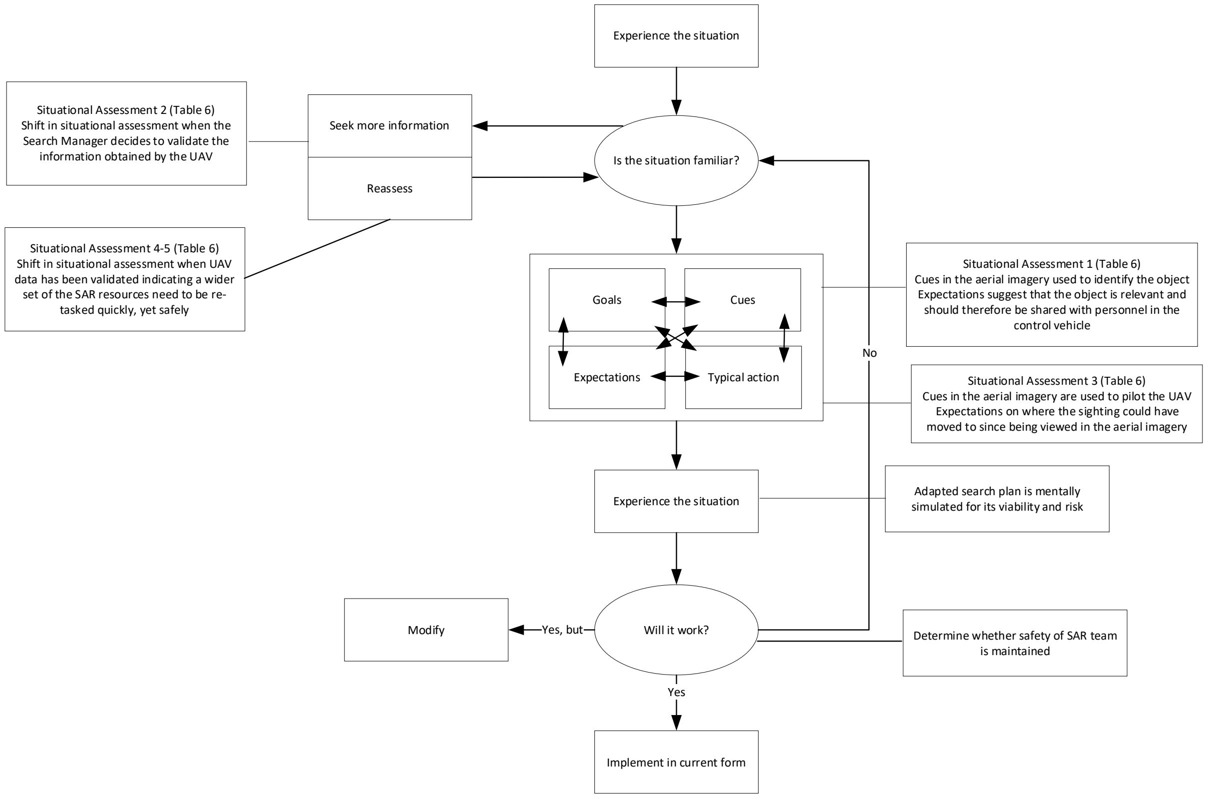

Figure 23. *RPDM for the work-as-imagined scenario*

Once the UAV is re-launched, whilst inspecting the imagery, the UAV team must account for the time lag between the point at which the sighting was identified and the time taken to re-launch or manoeuvre the UAV. This understanding is used to predict the possible movement of the sighting across time. In turn, the generated expectations inform how the UAV is navigated, and which aspects of the aerial imagery received attention from the Payload Operator. Here, regions with low visibility are checked to ensure that the MISPER is not obscured by features within the environment. In addition, any hazardous spaces known to the UAV team would be checked to ensure the MISPER has not injured themselves. To reduce the reliance on the operators experience of UAV operations in the terrain, one aspect of the DSS could assist with the identification of low visibility areas and terrain features that require searching.

Once the sighting is re-identified, the location's GPS coordinates are recorded on the HMI or using a physical artefact within the SAR environment. In turn, the Pilot lands the UAV, and the likelihood of the sighting being the MISPER is communicated to the Search Manager. Evidently, there is a reliance on the UAV team to effectively communicate and justify the perceived certainty of the sighting being the MISPER. To that end, the DSS could assist with this judgement to improve this transfer of knowledge and, in turn, the allocation of resources in response to a UAV team sighting. In addition, the task of estimating the time window between the point last seen and the UAV's movement could also be supported through technological aids that prime the calculation.

In the final phase of the Situational Assessment Record, the Search Manager determines how the UAV data can alter the PoD of each search region. This procedure is undertaken to improve the strategy of the search plan, much like the work-as-done scenario (see Figure 23). The Search Manager simulates any adapted search plan and its likely outcome in the head to identify whether the new strategy is efficient and achievable without exposing the SAR teams to extreme levels of risk (see Figure 23).

3.7 Discussion

The current work applied insights gathered from SAR personnel to the RPDM, PCM and Decision Ladder. Each of these models is derived from differing theoretical underpinnings which resulted in both unique and converging perspectives on the decision-making processes of SAR teams (Parnell, Wynne, Plant et al., 2021). A summary of the differences is given in Table 7. The contribution that each model made for understanding the decision-making processes of SAR teams during UAV-equipped and traditional ground search responses is now discussed.

A defining characteristic of the RPDM is its serial comparison of options (Parnell, Wynne, Plant, et al., 2021). Klein and Calderwood (1996) argued that decision-makers will select the first satisfactory option available. In part, the satisfaction process aligns with the decision-making activities within a SAR environment. This is because the temporal limitations faced by responders mean that fast and decisive action is critical, with the trade-off being that an optimal course of action may not be selected with the benefit of hindsight. Even so, the Search Manager would utilise comparative evaluation to determine which resource is most efficient to re-task, thus limiting the applicability of the RPDM within this research context. Further, the consideration of safety is considered within the RPDM at a team level insofar that the locations of search teams and hazards within the environment would be accounted for within the decision-making process. However, what is less represented are other factors used to determine which resource to re-task, such as the number of resources available in the SAR team, changes in the environmental conditions, and updates on the status of the MISPER received from different sub-systems in the SAR environment. In that sense, the RPDM is limited at capturing complex interactions within a sociotechnical system (Lintern, 2010). It also highlights the inability of the RPDM to capture decision-making processes within dynamic environments across large temporal windows, such as SAR responses where the situation is subject to consistent change (Parnell, Wynne, Plant, et al., 2021). The limitations of the RPDM are arguably something that Decision Ladders and the PCM were more effective at capturing within the SAR environment.

Table 7. Overview of key decision-making themes captured by the decision models

SAR decision-making theme	RPDM	PCM	Decision Ladder
Mission planning is used to determine how resources are utilised optimally	No *model does not incorporate mission planning aspects*	Yes	No *model does not incorporate mission planning aspects*
Evidence in the SAR environment is applied with knowledge acquired from past experiences	Yes	Yes	No *Focus on information gathering rather than processing*
Communication between the Payload Operator and the Pilot is crucial for managing constraints associated with the UAV	No *interactions between the UAV team are not focused on*	Yes	No *interactions between the UAV team are not focused on*
Information used within the SAR is distributed across the sociotechnical system	No *range of information nodes used across the system are not explicitly depicted*	Yes	Yes
The down-selection of options for re-tasking would be compared in parallel	No *options for re-tasking are assessed individually*	Yes	Yes
The overarching goal of safety is maintained to protect SAR personnel and account for dynamically changing conditions	No *Safety is only considered at the level of the team*	Yes	Yes
Interaction with the environment adapts the SAR personnels expectations for the MISPERs movements and UAVs behaviour	No *interaction between cognition and the environment is not represented*	Yes	Yes
The integration of UAVs increases the complexity of decision-making processes	Yes	Yes	Yes

Decision Ladders model decision-making by identifying the various aspects of information used within a work domain for assessing and responding to a situation (Jenkins et al., 2010). This information is listed in a normative manner across the ladder to demonstrate the expansion of knowledge as the scenario evolves. When comparing the work-as-done and work-as-imagined Decision Ladders, it became clear that the introduction of a UAV within a SAR space could result in the processing of more information aspects. This is because the technological and legal constraints associated with UAV operations implicate the need to monitor the parameters of the UAV and its status, as indicated by the referral back to information on the left-hand side of the decision ladder whilst executing a response. The information aspects identified by the Decision Ladder also demonstrated the highly distributed nature of resources across the SAR environment, with or without a UAV. Evidently, a wide number of resources are used to support the execution of SAR responses, including technological equipment (e.g., communication devices, mapping software) and human teammates (e.g., members of the police, ground searchers). The information produced by these resources must be assimilated in a way that maximises the probability of locating the MISPER (Adams et al., 2007). However, the formative nature of the Decision Ladder meant that the interaction between the human operator and their environment is not well encapsulated within the model. It is therefore unclear how personnel within the SAR space would intrinsically seek and interpret these information pieces. Although the model of cognitive control identifies where information processing advances in complexity and effort, it provides little insight into how previous experience and knowledge are used to understand and form judgements based on information in the environment (Plant & Stanton, 2012, 2013b).

Conversely, the PCM considers the human operator within their operational context to capture the modifying, interactional relationship between an individual's schemata and their surrounding environment, thus combining both humanistic and work domain processes (Parnell, Wynne, Plant et al., 2021; Plant & Stanton, 2015). For this reason, the PCM is considered a context-specific model. The RPDM also falls within this category; however, the models share distinctly different approaches to modelling human decision-making processes. Although the RPDM 'understands' decision-making based on the operator's experience and knowledge, it does not consider how this knowledge can help interpret a situation and be modified by it (Plant & Stanton, 2014). Conversely, the inclusion of schemata within the PCM provides an explanatory mechanism for how SAR personnel use their internal knowledge structures to interpret information and update their understanding of the dynamically changing situation.

The starting point of the decision-making process shown within PCM also differentiates the model from the Decision Ladder and RPDM. Parnell, Wynne, Plant, et al. (2021) argued that the PCM and Decision Ladder capture decision-making from the beginning of an initial event, whilst the RPDM begins with the individual's experience. However, the alert stage of the Decision Ladder requires the perception of an event by a human or non-human actor and, therefore, could be considered to begin with an individual's experience. As the PCM starts at the beginning of an incident, the mission planning tasks carried out by UAV teams to manage the operational constraints imposed by UAVs were captured. That is not to say the Decision Ladder would have been unable to conceptualise the mission planning aspect of a SAR response. Rather, it would require a separate ladder to efficiently represent each information aspect used during the initial planning stage of a UAV mission; something which was ultimately beyond the scope of this work. The descriptive nature of the PCM, therefore, meant the model was more flexible for representing decision-making processes over an extended period of time.

The PCM also identified further evidence of counter-cycle processing during UAV-equipped SAR missions (Plant & Stanton, 2015). This counter cycle does not follow the traditional world-schema-action decision flow (Revell et al., 2020). In the current work, both the work-as-done and work-as-imagined PCMs contained World-Action relationships. For example, during the work-as-imagined scenario, once the UAV team had agreed on a search strategy for the UAV, they intrinsically knew to identify a drop-off point for launching the UAV. Similarly, once ground searchers received their tasking, the typical response would see the responders navigate to their region as quickly and safely as possible. This element of automaticity can be explained using the SRK taxonomy (Rasmussen, 1983). The instinctive execution of an action in response to information in the world indicates the use of skill-based behaviour (Lynch et al., 2022; Plant & Stanton, 2015). Within the context of UAV-equipped SAR responses, the actions of the UAV team are heavily guided by a series of checklists and SOPs. In turn, the regularly trained UAV team would already be cognisant of following these set procedures (Cracknell, 2017). As a result, the UAV team would not need to consult their schematic representations of these SOPs as the required processes are heavily practised, culminating in the automatic responses to information in the world (Lynch et al., 2022; Plant & Stanton, 2015; Revell et al., 2020). Similarly, ground search teams receive regular training that enables responders to be reactive in response instructions received from the Search Manager, thus the World-Action relationship is unsurprising given the level of skill and experience present within the SAR environment.

A further benefit of applying the PCM was its ability to compare the complexity of traditional ground search and UAV-equipped responses. The Decision Ladder demonstrated the greater and different types of information required in the SAR environment and the RPDM highlighted the additional stages required within the Situational Assessment Record. However, the PCM provides a user story of the decision-making process and graphically presents these as numerical steps which offers a more explicit depiction of how a non-human agent can introduce complexity within a system. For the traditional ground search missions, approximately 45 steps comprised the response of ground teams to a MISPER search. Conversely, for UAV-equipped SAR missions, this number dramatically increased to 83 steps. These steps identified the set of tasks, processes, and interactions necessitated by integrating UAVs within the SAR environment. The PCM also captured the interdependent relationship between the UAV Pilot and the Payload Operator to ensure the UAV mission is conducted safely and efficiently. This partnership was also highlighted by the Decision Ladder. Where the Decision Ladder identified the types of information used within this partnership, the PCM showed how and where this information would be utilised. Therefore, the PCM and Decision Ladder provided complimentary insights that extend the capabilities of the RPDM.

3.8 Conclusion

The RPDM, PCM and Decision Ladder have been applied across a multitude of domains to conceptualise expert decision-making processes. However, the benefit of applying these models together has not been fully recognised, with most research applying each model in isolation. The work presented here demonstrated that the application of each model offered a holistic understanding of the processes involved during SAR missions. Nevertheless, the RPDM was less applicable within this context due to the dynamic nature of SAR environments that are subject to change across large temporal windows.

To summarise, the work discussed the utility of each decision model for understanding the decision-making processes of SAR teams during UAV-equipped SAR missions and traditional ground search responses. Chapter 4 uses this insight to identify a set of design recommendations for a future DSS intended to support the Payload Operator, and by way of extension, the wider SAR team.

Chapter 4 Summary of research findings

4.1 Introduction

The work presented in this thesis investigated the utility of decision modelling for studying the processes of SAR personnel so that design recommendations for a DSS could be identified to assist the Payload Operator (see Chapter 1). Chapter 4 summarises the methodological approach and design recommendations derived from the models described in Chapter 3. As such, the following chapter begins to cover phase two of the SDF by proposing suggestions for future DSS design concepts (see Figure 24). Further potential avenues of investigation are also provided to address any emergent limitations of the work and to enable for continuity of the user-centred design approach in a way that fulfils the aspects of the SDF not completed within this thesis.

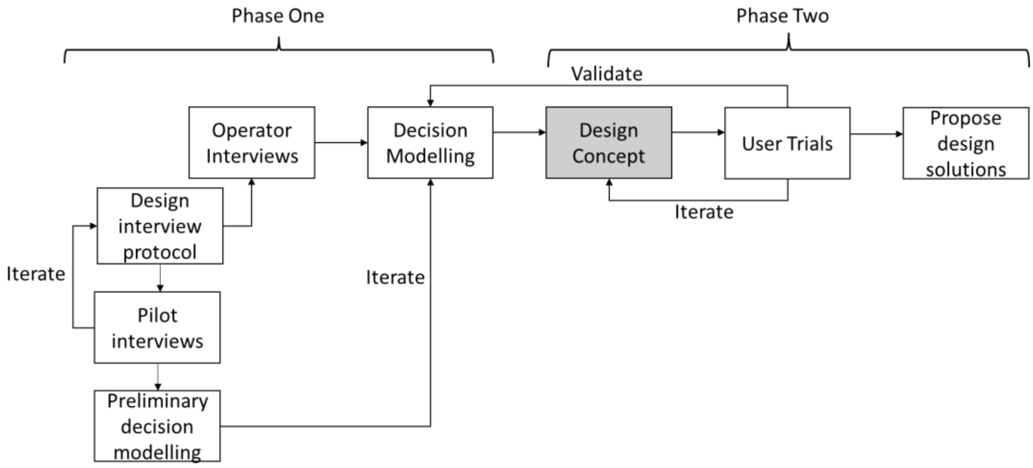

Figure 24. *Aspects of the SDF conducted during Chapter 4, as shown in grey*

4.2 Methodological approach

In order to support the generation of decision models, operator interviews were selected as the primary method of data collection. The interview prompts were taken from SWARM to elicit insight on the tasks and processes involved during SAR operations. Plant and Stanton (2016b) did not explicitly discuss mechanisms to support the down-selection of SWARM prompts beyond identifying those that were relevant to the research objective. In the current work, pilot studies were crucial for informing this process by identifying where modifications to the SWARM prompts were required for clarity and conciseness. As such, it is recommended that future work should use pilot studies with SMEs when designing interview protocols using SWARM. In doing so, appropriate iterations can be made to ensure the finalised protocol elicits the data required for the research objectives in a way that yields the maximum benefit of SWARM.

An outline of the procedure used to inform and design the protocol using SWARM was presented in Chapter 2. This protocol was subsequently utilised to conduct operator interviews with active SAR personnel, and informed the development of the PCM, RPDM, and Decision Ladders presented in Chapter 3. Plant and Stanton (2016b) designed SWARM to elicit the perceptual processes of aeronautical pilots specifically for supporting the generation of the PCM. However, Banks et al. (2020) and Parnell, Wynne, Plant, et al. (2021) demonstrated that the data outputted from SWARM can be applied to the RPDM and Decision Ladders. The current work therefore lends support to the growing body of work demonstrating the utility of SWARM for examining human-system interaction with alternative models to the PCM.

4.2.1 Methodological limitations and future work

Whilst SWARM was invaluable for informing the structure of the operator interviews, a prominent limitation of the method is the dependency on verbal reports (Klein et al., 1989). Although SWARM does not rely on constructing a timeline of a past event (i.e., CDM; Klein et al., 1989) participants must recall and detail their experiences from previous SAR exercises. This means that the issues relating to memory degradation and alteration continue to influence the validity of the dataset (Banks et al., 2021; Plant & Stanton, 2016b). As a result, the assumptions generated within the models regarding the actions and processes of SAR responders may not accurately depict real-life decision-making (Klein & Armstrong, 2005). In order to verify the accuracy of the assumptions generated by systems models, Banks and Stanton (2017) suggest that user trials should be conducted as a validation measure to ensure the processes and tasks captured in any theoretical models replicate that seen in real-world operations (Banks & Stanton, 2017). In doing so, the models can be iterated to reduce any emergent disparity between the processes captured in the models and those observed in the user trials. These trials could be conducted using multiple formats, including, but not limited to user trials in a simulator with adequate fidelity, observations conducted within the end-users' naturalistic environment, and user walkthroughs. Nevertheless, the initial validation of each model by an independent SME suggests that, on some level, they can be considered representative (Banks et al., 2021). In an effort to validate the assumptions generated within the decision models, a user walkthrough of a SAR mission was conducted with an active SAR volunteer to establish the equipment, processes and tasks used during a rescue response. This activity provided further evidence to confirm the accuracy of the decision models. However, empirical validation should also be sought from experimental trials and observations to enable further iteration of the decision models by identifying different approaches and actions that may not have been outlined in the operator interviews or user walkthrough.

A further notable limitation of the methodology relates to the demographics contained within the participant pool, all of whom were males. It is unclear whether this was due to a lack of female UAV operators or if the availability of female personnel was limited. It is anticipated that the former is the more probable reason, given the lack of female UAV operators in the domain (Joyce et al., 2021). To address this, future work should target the engagement of female personnel to either participate in further interviews or, at a minimum, validate the decision models. It is crucial that females be involved during the design process of any future concepts to avoid producing a system designed for the default male, thus further contributing to the gender data gap (Parnell, Pope, et al., 2022). It is also important to note that the tasks and processes encapsulated in this work focussed primarily on wilderness SAR. As such, the generalisability of this work to urban SAR and water SAR may be limited.

4.3 User-centred design of a DSS

Decision models have been leveraged across several research domains to generate novel training protocols (Ross et al., 2014), interface designs (Debernard et al., 2016; Jenkins, 2012; Macbeth et al., 2012), and decision aids (Banks et al., 2020; Parnell, Wynne, Griffin, et al., 2021; Parnell, Wynne, Plant, et al., 2021). Each of these interventions aimed to improve the decision-making processes of the intended end-user.

The design recommendations generated from the decision models described in Chapter 3 are now outlined, followed by a discussion on the relative contributions for each decision model when designing a DSS for a UAV system in a SAR application.

4.3.1 Design recommendations

In total, the application of all three decision models outputted 56 design recommendations for the DSS. Broadly speaking, these recommendations can be divided into four categories based on the area targeted by the design intervention. These include algorithmic development, interface design, communications technology, and regulatory change. Table 8 provides a description of each recommendation category. An arbitrary colour has been attributed to each recommendation category to code the design recommendations summarised in Table 9. Each design recommendation is detailed relative to the processes identified within each decision models that could be integrated with support mechanisms to improve the detection and localisation of a MISPER. When design recommendations could be ascribed to more than one category type, multiple colours were used from the key shown in Table 8 to define which aspect of the recommendation fell under each category.

Table 8. Description of each recommendation category

Recommendation category	Description	Colour key
Algorithmic development	Recommendations regarding the integration of automated functionality that will require algorithmic development for its realisation.	
Interface design	Recommendations regarding the design of the user interface used by the Payload Operator	
Communications technology	Recommendations regarding the integration of functionality that improves the communication within the UAV team, and between the UAV team and the SAR personnel.	
Regulatory change	Recommendations regarding alterations to regulations that are currently adhered to by the SAR team.	

Table 9. Summary of the design recommendations for each decision model

Current practice	Decision model			Design recommendations for future UAV systems could…
	RPDM	Decision Ladder	PCM	
The Payload Operator must detect a sighting in the aerial imagery to trigger the decision-making process.	X (SA – 1)	X (Alert)	X (49 – 51)	Equip the UAV with sensor technology that automatically detect objects in the terrain (e.g., humans, buildings)
				Automatically classify objects and output confidence intervals for the systems perceived degree of accuracy.
The Payload Operator would seek to validate the findings of the automated object detection system using information in the world. This understanding is used to build a schematic structure of the automated system and its performance.			X (49 – 51)	Offer insight into the logic of the automatic classification algorithm by providing images of the outputted classification category to validate the performance of the system (e.g., if a sighting is classified as a human, show imagery of humans) and provide a reasoning for why the classification was selected (e.g., "green colouring was indicative of a tree").
The UAV Payload Operator marks a sighting on their user interface or another physical artefact to record its GPS coordinates.	X (SA – 1)	X (Information)	X (62a – 62b)	Integrate functionality to mark any sightings identified in the aerial imagery. The placement of this sighting could be overlayed on a map of the search region alongside the GPS coordinates.
				With automatic object detection systems in place, requests could be sent to mark an object of interest on the user interface. Such notifications should appear as confirm/disconfirm options.
Information in the environment is matched with factual knowledge known about the MISPER to verify whether a sighting is of interest.		X (Information		Display the GPS coordinates of the sighting and the GPS coordinates for the last known location of the MISPER. Provide an estimate of the distance between the two spatial points. This could be used to gain further insight into the movements of the MISPER or used to determine whether the captured movements could be carried out by the MISPER (e.g., an elderly person may not be physically capable of walking long distances, which could help rule out a sighting from an early point of the UAV mission).
The location of the sighting is contextualised with information in the world to enable the UAV team or ground		X (Information)		Provide estimates of the distance between the GPS location of the sighting and a selected location (e.g., control vehicle, building, hill).

search team to re-locate it. For example, geographical hazards such as trees and buildings are used to describe the location of a sighting.				
				Alongside this, provides a compass that shows the direction between the two coordinates and an estimate of the time that would be taken to reach the sightings location on foot and by vehicle. These estimates could be shown on the UAV display or mapping software to provide ground searchers and the UAV Pilot with a reference point when they are re-tasked to investigate the UAV sighting.
				Automatically sends pictures of the surrounding environment nearby the sighting that were captured by the UAV to ground search teams. This could help the ground search teams navigate the area when an environmental feature is not nearby. The flight path of the UAV could be overlayed on these images to direct ground searchers to a sighting's location.
Each SAR party must maintain awareness of any new information that could dynamically update the search plan (e.g., public sighting).		X (Information and the shunt between 'Plan procedure' and the information node)		Integrate a chat function within the UAV display that enables search personnel to send any critical updates to the UAV team. Such updates could help either quickly re-task the UAV or save the battery life of the UAV for other mission tasks when the current task is no longer the best use of the UAV's time.
The UAV team must determine the efficiency of the search plan based on their understanding of where the UAV has flown and the time of deployment.			X (63 – 64)	Provide functionality for UAV operators to input a search region and monitor the coverage of the footage captured in the region. Record and output a numerical efficiency score that measures the UAV's coverage of the region in real time. This score should be accessible to the UAV team to help them decide when the UAV mission has been completed (this can and should be disabled if the mission intent is not to search a wide breadth of land).
The UAV must be piloted as part of a coordinated effort with the ground teams		X (Information)	X (6 – 7)	Within the UAV display, provide a graphical representation showing areas of land that have been searched by the ground search teams, and the PoD for each sub-region.

by searching aspects of the region that have not been investigated.				Using the graphic, automatically detect areas that require searching and colour code each region according to its PoD. Here, a heat map style display could be leveraged, with bolder colours representing those with higher PoD. This could be used to identify regions that the UAV could search.
Information about the environment (e.g., lighting) and the terrain (e.g., woodlands, river) is used to identify when to activate the thermal or visual sensor technology.			X (35 – 40b)	Provides automatic recommendations for the optimal sensor type to activate based on the environmental conditions and operational terrain. Provides graphical representations that depicts the degree of light available over time. Provides a graphical representation of the heat signature differences detected over time by the thermal sensors. Any peaks may be reviewed on the UAVs footage, and it may also provide another indicator of how well the thermal sensor is picking up any differences in heat signatures.
The performance of the thermal sensor is used to determine whether to activate it during the UAV's flight.		X (Shunt between 'Plan procedure 'information'		Provides graphical representations of the thermal sensors sensitivity rate over time.
The Payload Operator monitors a 2D display for critical information across a range of terrains. The type of terrain being monitored can vary in complexity and disfigure the visibility of information on the display.		X (Procedure and System State)		Automatically classify and display the type of terrain being investigated by the UAV. Information on the terrain should be used to adapt the colour of any metrics/visual aids shown on the display to ensure they are visible to the human eye.
The UAV team must continuously monitor the operational parameters of the UAV to ensure CAA regulations are being adhered to.		X (Shunt between Plan procedure and System State)		Using the GPS location of the UAV team, measure the distance of the UAV from the human operator. Represent this distance using colour coded metrics to indicate when the legal boundaries of the UAVs flight operations are being reached. The colour coding could indicate when the UAV is safely within the boundaries (e.g., green), verging on breaching these boundaries (e.g., amber), and when the UAV is being piloted illegally (e.g., red). Measure the distance of the UAV from the ground using data provided by topographical maps. Represent the altitude of the UAV using colour coded metrics to indicate when the legal boundaries of the UAVs flight operations are being reached.

				The colour coding could indicate when the UAV is safely within the boundaries (e.g., green), verging on breaching these boundaries (e.g., amber), and when the UAV is being Piloted illegally (e.g., red).
Throughout the UAVs deployment, the environmental conditions and Kp index levels must be monitored to ensure the UAV is safe to fly. This is particularly important as weather conditions can rapidly change.		X (Shunt between Plan procedure and System State)	X (15 – 18)	Provide automatic notifications when the environmental conditions (e.g., Kp index levels, wind speed, fog levels) begin to breach the boundaries for safe flight. These notifications should be offset within sufficient time so that the Pilot can safely land the UAV with enough time. Provide a quick overview tab showing information on the weather in real-time weather.
The UAV team would validate any weather alerts using information in the world. This understanding is used to build a schematic structure of the automated system and its performance.			X (15 – 18)	Provide graphical representations of the Kp index levels, wind speed, temperature and fog levels over time. A line showing the maximum boundary for each weather condition could be embedded within these diagrams. This could enable the UAV operators to detect any changes in the environmental conditions whilst also enabling them to quickly identify the relative safety of flying the UAV under these conditions.
Whilst the UAV is moving, the ability to detect motion on the 2D interface is diminished.		X (System state and procedure)	X (53)	Automatically detect motion in the environment. Alert the presence of motion to the Payload Operator by encircling the moving object clearly on their display.
The search plan generated for the UAV mission must take into account the limited battery life which currently constrains the deployment time of the UAV to 30 - 40 minutes.		X (Shunt between Plan procedure and information)		Provide a graphical representation of the UAV battery life over time and projection of how much flight time is left before the UAV battery becomes low; at which point, the UAV mission should be concluded. Provide functionality to input the mission plan. In doing so, the progress of the mission can be monitored throughout and represented to the Pilot and Payload Operator in the format of a mission progress bar.
Prior to launching the UAV, pre-mission checks must be conducted to verify whether the UAV is air worthy and ensure that other air users are informed of the deployment.	X (SA – 3)		X (13 - 21)	When launching the UAV, embed a checklist into the interface that ensures the relevant health and status checks have been conducted, and the flight plan has been accepted by nearby aircraft users. The UAV team should input controls to confirm when these checks have been completed.

Once the UAV has landed, post-mission checks must be conducted to ensure no damage has been incurred to the UAV during deployment.	X (SA – 4)		X (69 – 72)	Once the UAV has landed, embed the post-flight checklist into the interface. The UAV team should input controls to confirm when these checks have been completed.
During a deployment, the UAV team must maintain awareness of any low-flying aircraft deployed within the vicinity.		X (System state)		Automatically detect and notify the operators when nearby vehicles are detected operating in the airspace.
				Provide recommendations on how to avoid the detected vehicle (e.g., immediately land, pilot at a certain height).
				Provide automatic alerts when the UAV is operating closely to a restricted flight zone
Details from the MISPER profile are used by the Payload Operator to determine whether the sighting is of interest.	X (SA – 1)	X (Information)		Provide access to a MISPER profile within the UAV display. Provide an image of the MISPER within the display.
The Payload Operator must ascertain the likelihood that a sighting is the MISPER.	X (SA – 4)		X (53 - 61)	Assist with identification of the MISPER by integrating functionality on-board UAVs to detect electronic signals. These can be compared with details of the MISPER to determine whether they are located in a region, and also confirm that a sighting is human given that they own an electronic device. The provision of electronic signatures may require some form of regulatory change regarding the detective capabilities of the UAV.
The Payload Operator and the Pilot must apply their expectations on the MISPERs movement to help navigate the UAV and direct the gimbal camera.	X (SA – 3)			On the UAV display, clearly show the last known location of the MISPER and generate recommendations of their placement in the world based on assumptions from statistical resources, such as Grampian profiles (Gibb & Woolnough, 2007). This would mean that areas of land that could contain the MISPER may be more easily navigated to by the Pilot, and visually searched by the Payload Operator.
				Clearly display the last known location of the MISPER on the interface, and the time at which the sighting was observed.
The Payload Operator has to examine their display for objects/sightings that appear out of place within the terrain on a 2D display without a basis for comparison.			X (50 - 51)	Provide a database of UAV imagery captured from legacy missions or training to afford comparison of the operational terrain with past data. This may help the Payload Operator to identify features that are out of place.

The Payload Operator must passively monitor a 2D environment for extended periods of time to search for critical information, yet has no access to control functions to note areas that have been searched.			X (41 – 42)	Provide the functionality for Payload Operators to mark off regions of land that they have visually scanned, enabling more of an active role. In more advanced systems, eye tracking could be leveraged to automatically detect when the eye has fixated on an area of land and confirm that is has been searched.
The Payload Operator must request the pilot to manipulate the cameras pan, tilt, and zoom to capture the terrain.			X (58 – 59b)	Clearly display the parameters of the UAV camera to include metrics that represent the degree of zoom, pan, and tilt of the camera. Provide a graphic on the screen which indicates when 360 degrees of the area surrounding the UAV have been captured by the camera.
The Payload Operator must request the Pilot to make any changes to the positioning of the UAV.			X (45 – 48)	Provide functionality for the Payload Operator to input any quick changes to the operational parameters, which would be passed to the Pilot's interface. In turn, the Payload Operator would not need to verbally request any changes to the positioning of the UAV. The Pilot can accept or reject these findings based on their knowledge of the CAA regulations. Alternatively, the UAV system could predict the new operational parameters once the Pilot has moved the UAV, and automatically determine whether this movement could breach the CAA flight requirements.
Due to difficulties spotting cues in the environment whilst the UAV is in motion, the Payload Operator has to request the Pilot to hover the UAV and make adjustments to its operational parameters.		X (Procedure)	X (39 – 41)	Provide automatic reminders to hover the UAV periodically. Provide a timer showing when the UAV was last hovered to serve as a reminder that this may be required. Provide a control input that automatically hovers the UAV upon request.
When the Payload Operator identifies a potential sighting, as they are located at a remote distance, they must apply mental		X (System State)	X (56 – 57)	Provide automatic calculations of an objects size and speed when a human sighting is detected. Provide a confidence estimate to represent the degree of confidence the system has in its output.

calculations to determine whether its size and speed match that of a human as well as other details contained in the MISPER report.				The confidence in these predictions should be represented, either numerically (i.e., as a confidence interval) or graphically (using colour coding). This will assist with the identification of sightings and their characteristics. For example, if an object was detected but was walking at a pace that a human would not be capable of, then this can be ruled out without having to investigate further by re-tasking the UAV or a ground search party.
				Provide predictions on the size and speed of a human sighting based on a statistical profile. These predicted metrics could be compared with the automated systems calculation of the sighting providing to help rule out whether or not the sighting is of interest with a more empirical basis.
				Automatically classify and calculate the size of an object when selected on the display by the Payload Operator. Selection is important to ensure the display does not become cluttered with unnecessary output from the automated system.
Calibration checks must be conducted at the beginning of the UAVs flight to help familiarise the Payload Operator with the payload sensors, and what the MISPER could look like within the operational terrain.		X (Procedure)	X (23-27)	Provide features within the display that support the calibration stage. When this is being conducted, automated recommendations could be provided on the optimal UAV height and camera angle, and a snapshot of the UAV team could be readily accessible to refresh the Payload Operators memory on what the MISPER could look like during the UAV mission.
The UAV must be navigated and landed by the Pilot safely so that no nearby civilians are harmed, or the UAV itself.			X (66 – 67)	Provides functionality that enables the landing point to be inputted into the UAV system. Using the coordinates of this landing point, a real-time estimate could be provided on the amount of time it would take to Pilot the UAV to the landing point from its current position, and the required speed. This could help the Pilot to estimate how long the UAV can be in the air and the time needed for the landing stage of the mission.
When deciding to re-task the UAV or the ground search team, a complex cost trade-off evaluation is made by integrating disparate pieces of information, such as the UAV's health and status, and the locations of the UAV		X (Options)	X (71 - 75)	Automatic recommendations for re-tasking could be outputted based on the locations of each search party and the battery life of the UAV, along with an estimated time that each re-task option could take.
				Provide recommendations for re-tasking based on the most economic option (Banks et al., 2020).

team, the transport vehicle, and the ground search parties.				
The Payload Operator must use their knowledge of hazardous locations in the region to identify which areas may need to be visually searched with the UAV.	X (SA – 2)			Automatic terrain mapping could be provided to help detect regions with low visibility (e.g., sink holes).
				Provide 3-D mapping of the terrain to enable better identification of locations of interest.
Total of design recommendations	13	38	36	55

4.3.1.1 *Design recommendations derived from the RPDM*

The RPDM focused largely on the recognition of environmental cues to enable quick situational diagnosis and, in turn, rapid decision-making (Klein, 2008; Klein, 1993). A decision-maker cannot progress through the model unless some form of recognition has been reached. The significance of operator recognition indicates that decision aids should be designed to assist this familiarisation process. Table 9 shows the design recommendations identified by the RPDM. The described recommendations aimed to provide a cue that primed the decision-making processes of the UAV team (Parnell, Wynne, Plant, et al., 2021). For example, upon detecting a sighting, the DSS could provide an environmental cue to help validate a sighting's relevancy within the context of the SAR mission. Providing electronic signals would confirm to the Payload Operator that the sighting is a human, given that they possess an electronic device. In turn, this could enable the operator to rule out the possibility of a sighting being a contextual anomaly, enabling for more rapid information validation. Further, to prime the calculation of the time lag between the point at which the initial sighting was identified and the re-tasking of a UAV, a DSS could predict the probable movement of the MISPER. Here, statistical profiles could be leveraged and incorporated within algorithms to predict these movements and overlayed onto the aerial imagery or a map of the search region.

The RPDM did, however, produce the least unique set of design recommendations due to the underlying theory that decision-making can only be primed through stimuli in the environment (Klein, 1989). This meant that the recommendations derived from the RPDM only identified support mechanisms that facilitated the recognition of information (e.g., the likelihood that a sighting was the MISPER) or the recall of procedures already known to the SAR responder (e.g., pre-mission checks). Therefore, the design recommendations did not capture the technical aspects of decision-making employed by the UAV team to monitor the performance of the UAV and analogically analyse the aerial imagery.

4.3.1.2 *Design recommendations derived from the Decision Ladder*

The Decision Ladder accounts for the tasks and actions required within a work domain irrespective of the actor (Jenkins et al., 2010; Pacaux-Lemoine et al., 2022). Its framework approach enables system designers to consider 'what' tasks could be transferred to an automated actor (Banks et al., 2020; Parnell, Wynne, Plant, et al., 2021). Several aspects of UAV operations were identified as areas where automated support could be implemented, beginning with the initial alert to a sighting. Currently, the Payload Operator manually identifies a sighting or object of interest by visually scanning aerial imagery. However, this task could be transferred to an automated actor using the requirements such as automatic object detection and classification modules that are becoming more widely available (see Table 9).

A further benefit of the Decision Ladders is their ability to show 'how' design intervention could alter an operator's decision-making process (Banks et al., 2020; Friesen et al., 2022). Figure 25 suggests that the introduction of a DSS could manifest in a cognitive shortcut from the 'alert' to 'task' nodes. The shortcut indicates that the onset of automated alerts, such as automatic object detections and image classifications, could prompt operators to develop an immediate procedural response using the information from the automated actor. However, the UAV operator's responses to the provision of automated functionality indicated that this would be an unlikely response until the capabilities of the automated system were deemed highly reliable. Instead, the UAV operators reported that the information provided by an automated actor would be compared against the information held within the SAR environment to determine whether it corroborates existing information within the SAR environment about the MISPER. In addition, the Decision Ladder demonstrated the distributed nature of information sources within the SAR environment. In order to manage the distributed set of SAR resources and assist with the validation of the automated intelligence, the questions posed within the rule-and knowledge-based processing categories acted as information requirements for the DSS (Parnell, Wynne, Plant, et al., 2021).

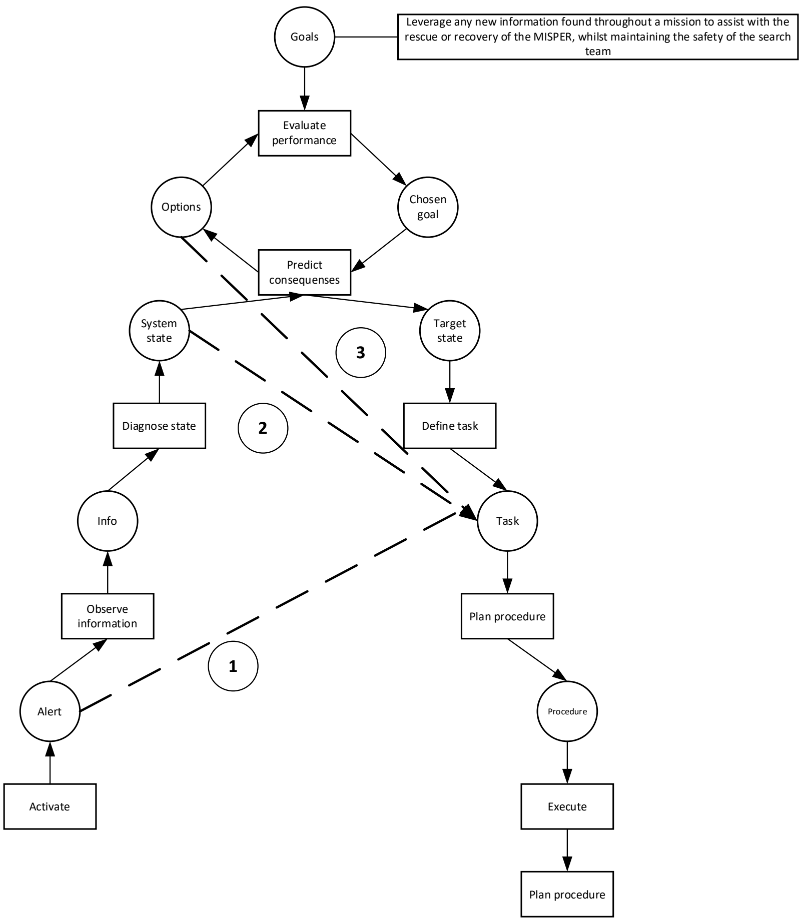

Figure 25. *Decision Ladder indicating where a DSS could assist with UAV operator decision-making during a SAR mission*

The design recommendations shown in Table 9 aim to serve three purposes. The first aim was to leverage the information in the SAR environment to help validate the findings of the automated system. In doing so, less reliance is placed on the human operator's rule- and knowledge-based processing by transforming the cognitive tasks of the Payload Operator into perceptual tasks (McIlroy & Stanton, 2015). For instance, automatic classifications could be outputted with confidence intervals that determine the systems perceived efficiency in its classification algorithm. This provision could help the Payload Operator understand and verify the logic of the automated agent. The second purpose of the design recommendations was to reduce the amount of information referred back to on the left-hand side of the Decision Ladder. This could be achieved by providing automated alerts and graphical representations that help diagnose when the UAV is breaching its ODD and the CAA regulations. With these provisions in place, the human-UAV team may be in a better position to discuss and generate plans to leverage the UAV during a SAR response, culminating in the second shortcut between the 'system state' and 'task' nodes.

Finally, the design recommendations derived from the Decision Ladder aimed to assist with the identification of appropriate action when responding to the intelligence retrieved by the automated actor. A decision aid mirrored between the UAV operators and the personnel in the control vehicle could identify the most appropriate resource to utilise when validating a potential sighting (see Table 9). The preference for the SAR service could also be displayed to show the option with the most economic savings. This mechanism could culminate in a third shortcut between the 'options' and 'task' nodes by explicitly defining the set of options available within a SAR space, enabling for more intrinsic recognition of the most appropriate task to undertake. As such, the design recommendations identified by the Decision Ladder were able to identify interventions that could benefit an individual operator (e.g., the Payload Operator) and the SAR unit as a whole.

4.3.1.3 *Design recommendations derived from PCM*

The dependence on schemata to interpret and respond to a situation suggests that the integration of novel automated technology will also be subject to interpretation through the lens of schema. It is, therefore, crucial that the Payload Operator has an accurate schematic representation of the capabilities of the automated system to ensure inappropriate or faulty schema are not used to perceive and understand the findings presented by the DSS (Banks et al., 2018b). One way of achieving this is by providing a decision aid that details the processes and decisions of the automated system (Seong & Bisantz, 2008). In other words, designing for system transparency as suggested by Maarten Schraagen et al. (2021). The DSS could provide such transparency by assisting with the comprehension of information in the environment, which, in turn, will provide introspective insight into the behaviour of the automated system and 'why' it made certain decisions. For example, providing graphical representations that show the current and projected environmental conditions could be used to perceive the relative safety of the environment both before and during a UAV mission (see Table 9). Combining this aspect of decision support with automated alerts when the weather conditions become unsafe could enable the UAV team to respond quickly to the automated alert as the evidence displayed on the graph acts as a source to validate the findings of the automated system. Providing these visualisations within a system would also adhere to the notion that the human operator should be able to comprehend the automated system's intent, reasoning processes, and future behaviours (Chen et al., 2018).

Further, Parnell, Wynne, Griffin, et al. (2021) argued that decision aids should provide accurate information that contributes to an individual's perceptual processing. For example, to understand the placement of the UAV and the location of a sighting, metrics regarding the cameras positioning should be clearly presented. The manipulation of the camera's pan, tilt, and zoom is critical for locating a sighting in the world, as shown between steps 58 – 59b in Figure 20. Both the Pilot and Payload Operator must have accurate schematic representations of the parameters of the gimbal cameras when Piloting the UAV and scanning the aerial imagery for sightings. As such, the parameters of the UAV camera must be displayed clearly and accurately. Previous incidents suggest that aerial imagery alone cannot be utilised as a reliable source of information for inferring the movement of the UAV and its surroundings (Lynch et al., 2022). To that end, the PCM was able to identify where analogical reasoning could be reduced using the design recommendations specified in Table 9.

4.3.2 DSS design process limitations and future work

While the decision models provided insight that enabled the development of design recommendations, they were ultimately proposed by an HF expert without further involvement from the end users. The inclusion of each design recommendation would likely produce a cluttered system that overwhelms the UAV operator due to the increase of information, thus falling victim to the same critique of the UAV predator system discussed in Chapter 1. Indeed, presenting human operators with unnecessary information can detriment their performance (Salmon et al., 2011). To manage this, an efficient design process will adopt an iterative approach that continues to involve the end-user throughout the design and integration phase of a product (Banks et al., 2018a; Parnell et al., 2021). The current work has provided recommendations for an automated decision aid that could shape the design of future UAV systems, thus beginning the design lifecycle for the DSS. In order to progress the cycle, design concepts should be produced to understand the value, if any, of the recommendations proposed in this chapter. Here, methods such as wireframing can be leveraged as working prototypes are not needed for user input during the initial phases of the DSS design process (Stanton et al., 2014). The wireframes could be used to conduct a heuristic evaluation with UAV operators. Heuristic evaluation is a ‘quick and dirty’ method for assessing the usability of an interface design relative to a set of heuristic criteria (Nielsen & Molich, 1990). In doing so, potential usability issues with the DSS can be identified and mitigated for early on in the design lifecycle.

Following further iteration of the design concepts, empirical evaluation is necessary to determine the impact of the DSS on the performance of the UAV team. Here, user trials can be used to provide further insight into user cognition (Banks & Stanton, 2017) whilst also providing a basis to assess the impact of the DSS on the Payload Operator’s performance. In doing so, potential design weaknesses that were not apparent from the decision modelling and wireframing exercises can be diagnosed and addressed before the integration of the system in a real-world context (Banks & Stanton, 2017; Lockton et al., 2010).

4.3.3 Conclusion

Applying the responses of SAR personnel to three types of decision models provided an understanding of the tasks and processes performed by the Payload Operator that could be aided with a DSS. Although the RPDM identified several unique design recommendations, constraining the processes of SAR responders to a set of primed decisions meant the model offered the least number of design recommendations. By contrast, the Decision Ladder shifted the focus on decision-making away from cognitive processing and instead provided an overview of the complex, distributed range of information and resources utilised within the SAR environment. As a result, a well-defined set of information requirements were identified. However, the Decision Ladder provided less insight into the schematic processes involved during UAV operations. The PCM modelled the interaction between a human decision-maker (i.e., the UAV team) and their environment (i.e., the search region) to provide insight on which aspects of UAV operations require clear, up-to-date information and decision support to reduce the need for analogical reasoning. Therefore, applying the Decision Ladder and PCM in tandem offered a complementary approach to understanding the type of support mechanisms that could be included within a DSS for the Payload Operator. For this reason, it is recommended that the PCM and Decision Ladder be applied together to reap the maximum benefits of decision modelling.

To conclude, the research approach used in the current work highlighted the value of engaging with end-users to support the design of automated technology. The DSS aims to mitigate the human-automation interaction issues identified in Chapter 1 by proposing novel design intervention strategies that keep the Payload Operator in-the-loop. The development and integration of the DSS could enable the operational advantages offered by UAVs to be fully gained by improving the Payload Operators' information acquisition processes. However, empirical validation is needed to determine the benefits of the DSS. Future work seeks to continue engaging with SAR personnel to enable the iteration and evaluation of any future design concepts.

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Appendix A. SWARM Taxonomy (Plant & Stanton, 2016b)

Schema category

Taxonomy subtypes	Description
Vicarious past experience	Prompts regarding knowledge derived from an imagined experience of event based on descriptions from documentation (e.g., reading about an event in the media or an accident/incident report) or another person (e.g., hearing a colleague report describe details of an incident they were involved with)
Direct past experience	Prompts regarding the development of knowledge through direct personal experience of a similar event or situation that has previously happened
Trained past experience	Prompts regarding the development of knowledge through direct experience of a task, event, or situation during a training regime/programme (e.g., simulator training, team training exercises)
Declarative schema	Prompts regarding the activation of schema that results in the descriptive knowledge of facts, and is typically triggered by information available in the world
Analogical schema	Prompts regarding the activation of schema to compare between things to assist with the explanation or clarification of something. These analogies tend to be structural analogies of physical objects or states of affairs in the world (akin to mental maps or mental models)
Insufficient schema	Prompts regarding the activation of schema which is inadequate or lacks knowledge as it has not been developed for the situation at hand

Action category

Taxonomy subtypes	Description
Aviate	Prompts regarding the direct manipulation of flight control that enable the aircraft [UAV] to be flown, whilst maintaining safety
Navigate	Prompts regarding the process of accurately identifying position in the world, and the planning and execution of following a route
Communicate	Prompts regarding the sharing or exchange of communication
System interaction	Prompts regarding the interactive or manipulative processes involved when inputting into the technological system in a way that has an explicit outcome that is observable in the world
System monitoring	Prompts regarding the monitoring actions (observations and visual checks) taken to maintain situation awareness
Environment monitoring	Prompts regarding the observations or checks conducted in the physical or external environment to understand the state of the situation at hand
Concurrent diagnostic action	Prompts regarding the diagnostic actions taken to determine the cause or nature of a problem through analysis of information available at the time of an incident
Decision action	Prompts regarding the conclusion or resolution that is reached after considering all information available in the world
Situation assessment	Prompts regarding actions taken to evaluate and interpret the available information
Non-action	Prompts regarding the actions that were not carried out because the situation did require it, or because the equipment meant the action could not be performed (e.g., sensor failures, breakages)
Standard Operating Procedure	Prompts regarding the procedures that would be carried out in a routine, structured manner during a situation

World category

World subtypes	Description
Natural environmental conditions	Prompts regarding the natural environmental conditions (e.g., weather, light, temperature, noise)
Technological conditions	Prompts regarding the physical and functional sate of technological artefacts
Communicated information	Prompts regarding the information available to the Pilot from other people (e.g., crew members)
Location	Prompts regarding places or positions in the world
Artefacts	Prompts regarding the physical objects used in the world including information, symbols, diagrams and equipment
Display indications	Prompts regarding the information obtained from the physical artefacts (e.g., user interface display)
Operational context	Prompts regarding the routine activities carried out by an organisation (e.g. SAR, military training, etc.). This subtype captures the importance of holding experience for a specific context and how this dictates the decision-making processes of an individual
Aircraft [UAV] status	Prompts regarding the state of the aircraft or its performance (e.g., automated functionality activated by the aircraft, its flight performance)
Severity of problem	Prompts regarding how bad a given situation was
Physical cues	Prompts regarding the external cues in the world that provide information on conditions and the state of affairs (e.g., noises, sounds, vibrations, smells)
Absent information	Prompts regarding any missing information due to technical faults with the equipment, or information that was non-existent

Appendix B. Work-as-done interview prompts

Schema (knowledge) prompts – Questions regarding experience and knowledge

Schema subtypes	Prompts
Vicarious/direct past experience	• Has this situation ever happened to you or is something you have knowledge of through another information source, be it a colleague or report? o Would your previous direct experience or knowledge influence how you approach this situation? If yes, how? o Would the situation presented be comfortably within your experience? o How might your direct experience or knowledge influence your approach and expectations surrounding the SAR mission?
Trained past experience	• What, if any, training would you utilise in this situation? o Would your training experience influence your approach to this situation? If yes, how?
Declarative schema	• Would there be any information that you would expect to be true or certain of in a situation like this? Why? o Would you use any factual knowledge for assistance during assistance like this, if yes what and how would that influence your approach to the scenario? o Would you ever be in doubt of what to do? If yes/no, why?

Action prompts – Questions regarding the actions that would be taken throughout the scenario

Action subtypes	Prompts
Communicated information	• Would you communicate with anyone? If yes, who to/what would be
System interaction	• What physical inputs and actions would you take that would directly impact the technological system? o Has there ever been a particular time when you made more or less system management actions? If yes, why?
System monitoring	• In relation to the technological system, what would you be observing during the event?
Decision action	• What key decisions would you make during this situation? o Would you ever change your decision during the course of the situation? If yes, why? o Would there be other decisions that you could have chosen but wouldn't? If yes, why?
Standard Operating Procedure	• Would your actions be standard and typical for this situation? If yes/no, why/why not? o Would you follow known SOPs or rules? If yes, what? If no, why not? o Would you follow checklist procedures? Would these be memorised or physical checklists?

World (information) prompts – Questions regarding information that is obtained from the environment in which the scenario occurred

World subtypes	**Prompts**

Technological conditions	• What information from the technological system(s) would you utilise?
	  ○ Would the technological information influence you? If yes, how?
	  ○ Has there ever been an instance where additional technological information was required but couldn't be accessed? If yes, what?

Communicated information	• Would you receive information from other members of the search team? If yes, what?
	  ○ How would you receive this information?
	  ○ Has there ever been an instance where additional information was required from the SAR team but not given? If yes, what?
	  ○ Would the communicated information influence you? If yes, how?

Artefacts/display indications	• What artefacts would you have available to you? (e.g., physical objects, equipment, technology, written documents, etc.)
	  ○ What would the display indications and physical artefacts tell you?
	  ○ Would the information provided via the display indications and physical artefacts inform your decision making? If yes, how?
	  ○ Would you ever change your mind about anything based on the information from the displays and artefacts? If yes, how?

Appendix C. Work-as-imagined interview prompts

Schema (knowledge) prompts – Questions regarding experience and knowledge

Schema subtypes	Prompts
Vicarious/past experience	• Could this situation ever happened to you or is something you have knowledge of through another information source, if yes, what knowledge would you draw on for this situation? o Could your previous direct experience or knowledge influence your expectations and approach to the situation? If yes, how?
Trained past experience	• What, if any, training could you utilise in this situation? o Could your training experience influence your expectations and approach to this situation? If yes, how?

Declarative schema	• Could there be any information that you would expect to be true or certain of in a situation like this? Why?
	  o Could you use any factual knowledge for assistance during a situation like this? If yes, what?
	  o How could information that is available or given have an influence on you?
	  o Could you ever be in doubt of what to do? If yes/no, why?

Action prompts – Questions regarding the actions that would be taken throughout the scenario

Action subtypes	Prompts
Communicated information	• Could you communicate with anyone? If yes, who to, and what would be communicated?
System interaction	• What physical inputs could you make into the technological system that would have a direct impact within the situation? o Could there ever be a time when you make more or less system management actions? If yes, why?

System monitoring	• In relation to the technological system, what could you be observing during the event?
	  o Could the information you obtain influence you in any way? If yes, how?
	  o Could there ever be a particular time when you made more or less system monitoring actions? If yes, why?

Decision action	• What key decisions could you make during this situation?
	  o During these situations, could you ever change your initial decision? If yes, why?
	  o Could there be other decisions available that you chose not to take? If yes, why?

Standard Operating Procedure	• Could your actions be standard and typical for this situation? If yes/no, why/why not?
	  o Could you follow known SOPs or rules? If yes, what? If no, why not?
	  o Could you follow checklist procedures? Are these likely memorised or physical checklists?

World (information) prompts – Questions regarding information that is obtained from the environment in which the scenario occurred

World subtypes	Prompts
Technological conditions	• What information from the technological system(s) could you utilise? o How could you get this technological information and what could it tell you? o Could there ever be an instance where additional technological information might be required but can't be accessed? If yes, what? o Could the technological information influence you? If yes, how?
Communicated information	• Could you receive information from other members of the search team? If yes, what? o How might you receive this information? o Could there be an instances where additional information is required from the SAR team but can't be given? If yes, what?
Artefacts/display indications	• What artefacts could you have available to you? (e.g., physical objects, equipment, technology, written documents, etc.) and what information could they tell you? o Could the information provided via the display indications and physical artefacts inform your decision making? If yes, how? o Could you ever change your mind about anything based on the information from the displays and artefacts? If yes, how?
UAV Status	• During the SAR mission, could you be concerned with the status of the UAV, and if yes could it influence you? o Could you ever be uncertain about the reliability or relevance of the information that you have available to you?

Appendix D. Supporting material for the operator interviews

Work-as-done Interview

Search and Rescue Brief

A report of a missing person has been received. The police have reached out to your rescue team for assistance. The missing person's profile shows the following details:

- Name: Stephanie Jones
- Gender: Female
- Age: 35
- Last known location: Hiking at a National Park in Snowdon. The National Park has a rugged and mountainous terrain.

Stephanie is a keen, well-equipped hiker. She mentioned she was going to complete the ranger path route which is usually carried out by experienced hikers. Stephanie left home to hike at 6am and planned to return for 2pm. However, it is now 6pm and she has not returned home or made contact. Her family described this as uncharacteristic and are worried that she is lost or injured.

You have been deployed with the ground search team. Describe the approach that would be taken to locate and rescue Stephanie.

T-B PHASE 3

Ground Search Team Equipment

Map of Snowdonia with planned path shown

Signal Detection Tool

Compass/GPS device

Missing Person Profile

Radio comms device

T-B PHASE

And any other equipment.... 4

Work-as-imagined interview

Search and Rescue Brief

A report of a missing person has been received. The police have reached out to your rescue team for assistance. The missing person's profile shows the following details:

- Name: Stephanie Jones
- Gender: Female
- Age: 35
- Last known location: Hiking at a National Park in Snowdon. The National Park has a rugged and mountainous terrain.

Stephanie is a keen, well-equipped hiker. She mentioned she was going to complete the ranger path route which is usually carried out by experienced hikers. Stephanie left home to hike at 6am and planned to return for 2pm. However, it is now 6pm and she has not returned home or made contact. Her family described this as uncharacteristic and are worried that she is lost or injured.

The Search Manager has decided to use a UAV to collect imagery to support the mission. You are deployed with the UAV team. Describe the approach that would be taken to locate and rescue Stephanie when using the UAV.

T-B PHASE

5

UAV Team Equipment

Map of Snowdonia with planned path shown

Missing Person Profile

Aerial Imagery

Radio comms device

UAV

UAV Human-Machine Interface

T-B PHASE

And any other equipment….

6

Appendix E. Decision Ladder Guidance

Stage	Description
1 – Determine the goal	Ascertain the overarching goal of the system that informs the decision-making activities within the Decision Ladder. Elix and Naikar (2008) advised illustrating the goal in the format "to [insert goal] [insert constraints]
2 – Alert	The chronological descriptions of an event/process is used to identify how participants would initially be alerted to an event. For the work-as-done scenario this was the observation of a clue of the MISPERs whereabouts in the environment, including personal belongings, reports from civilians, smoke, flashing light being emitted, and all of the above which may not be relevant to the search and therefore would be classed as a contextual anomaly
3 – Information	This stage identifies the information used to SAR teams to identify the state of the object and its meaning within the SAR environment. This included the mapping displays and where the marked object appeared on this display in relation to information known about the MISPER case
4 – System State	This stage describes the resultant understanding of the system state based on the information available in stage 3, and the interpretation of this information. It covers the assessment of whether the object is of relevance (and therefore requires further investigation) and the state of the SAR environment that will determine how to adapt the plan, and the way in which to achieve this through optimal re-allocation of the team's resources
5 – Options	The set of options illustrate the different course of action available within the SAR environment to achieve the higher order goal (see stage 1)
6 – Chosen Goal	The chosen goal is identified through the application of constraints with the highest priority (Jenkins et al., 2010). In a SAR environment, the safety of the responders represents the greatest constraint, therefore, the chosen goal will uphold this constraint
7 – Target State	The target state mirrors the options available. When an option has been selected, it becomes the target state. To represent this, Jenkins et al. (2010) recommend using the options to re-phrase the target states
8 – Task	The high-level tasks are what must be completed to reach the target state in a way that maintains the overall goal
9 – Procedure	The procedure outlines the set of sub-tasks that must be completed to achieve the higher level tasks identified in stage 8
10 – Shortcuts	Parnell, Wynne, Plant, et al. (2021) identifies an additional stage involving the identification of shortcuts, which was not included within Jenkins et al (2010) original methodology. Shortcuts represent the sophisticated information processing carried out by experts when facing familiar situations, enabling links to be made across the two streams of the Decision Ladder (i.e., situation assessment to planning and execution and vice-versa)

Appendix F. Situation Assessment Record Guidance

Klein et al. (1989) developed the Situation Assessment Record as a method for documenting the decision-making process of expert decision-makers in a way that lends itself to populating the RPDM. Parnell, Wynne, Plant, et al. (2021) used the description of the Situation Assessment Record to produce tabulated guidance on the Situation Assessment Record, which was used as a template within this work.

Situation assessment stage	Assessment components	Description
SA – 1 Initial assessment of a situation/incident	Cues/knowledge	Information and knowledge used by the decision-maker to conduct an initial situational assessment
	Expectations	The expectations generated about the situation by the decision-makers using the information available (cues) and their knowledge
	Goals	The goal reached to resolve or manage a situation based on the decision-maker's expectations
	Decision Point	Key decision carried out based on the expectations and goals identified within the situation
SA – 2 (Elaboration) Situational awareness is updated in response to new information and cues	Cues/knowledge	New information in the environment that updates the situation awareness
	Expectations	Adapted expectations based on the new information
	Goals	Adapted goals based on any new expectations regarding the situation
	Decision Point	Any updated or new decision made with reference to the new expectations and goals
SA – 3 (Shift) A shift In the situational assessment occurs in response to new information/events	Cues/knowledge	New knowledge and information that alters the original situational assessment
	Expectations	Shifted expectations made based on the new situational assessment
	Goals	New goals based on the shifted expectations about the situation
	Decision Point	A shift in the decision generated based on the shift in the initial assessment and renewed goals