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ABSTRACT

Human Factors play a significant role in the development and integration of avionic systems to ensure that they are trusted and can be used effectively. As Unoccupied Aerial Vehicle (UAV) technology becomes increasingly important to the aviation domain this holds true. This study aims to gain an understanding of UAV operators' trust requirements when piloting UAVs by utilising a popular aviation interview methodology (Schema World Action Research Method), in combination with key questions on trust identified from the literature. Interviews were conducted with six UAV operators, with a range of experience. This identified the importance of past experience to trust and the expectations that operators hold. Recommendations are made that target training to inform experience, in addition to the equipment, procedures and organisational standards that can aid in developing trustworthy systems. The methodology that was developed shows promise for capturing trust within human-automation interactions.

1. Introduction

Trust is a complex and multifaceted construct. Research has long studied the trusting relationships that we have towards other people (e.g., Delhey et al., 2011), the trust we have in our governments (e.g., David & King, 1997) or media channels (e.g., Zimmer, 1979). With developments in technology and our increased reliance on systems that automate typically human performed tasks, trust in automation and automated systems is becoming a central concern (e.g., Hoff & Bashir, 2015; Kaplan et al., 2021; Lee & See, 2004; Parasuraman et al., 2008; Schaefer et al., 2016). Sheridan (2019a, 2019b) present the complexity in defining trust in relation to trust in automation, as well as highlighting the distinction between trust and trustworthiness. Trust relates to the subjective human judgement of trust, while trustworthiness is an objective measure of the automation (Sheridan, 2019b). When seeking to study trust in automation many have sought to review the attributes of trust (Haidt, 2012; Muir & Moray, 1996; Sheridan, 1988, 2019a). Similarities and overlaps have been observed in these attributes, such as the need for predictability, dependability, competence, responsibility and understandability (Sheridan, 2019a).

Unoccupied Aerial Vehicle (UAV) technology is one such area wherein trust is central to its widespread integration and application (Jensen et al., 2018; Mohammed et al., 2016). Trust from the point of view of the public and their use of airspace is a key concern (Nelson & Gorichanaz, 2019). Another is the trust that UAV operators have in the UAV, their confidence in its performance, the information that it relays and the interactions that it may have with other systems. The location of the operator and the aircraft are distributed within the system and therefore the performance of the system is challenged by numerous issues such as limited sensory cues, delays in control and communications (McCarley & Wickens, 2005). The operator must trust that the UAV will operate in line with their expectations. They must be able to trust the communications between themselves and the UAV and trust that the information they receive is accurate and valid. Rogers et al. (2019) identify the role of automation reliability to the trust that people have in UAVs as well as their reliance on them. Others have also highlighted the adverse impact that reduced reliability and a lack of trust can have on workload (Lee & See, 2004; Ruff et al., 2002). Increasing the number of autonomous agents that needs to be monitored, as in the case of multiple UAV operations, brings additional challenges. It is thought that trust is applied broadly across a system, rather than differentially to different components of that system, with one component bringing down operator reliance across the whole system (Keller & Rice, 2009). This has been termed the "pull-down effect" (Keller & Rice, 2009). Walliser et al. (2016) found evidence for this effect in a realistic multiple UAV operations study and highlighted the complex interdependencies within multiple agent autonomous systems that influence trust.

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As UAV technologies develop, opportunity for their collaborative functionality is emerging. "UAV swarm" is the collective term for multiple UAVs working together under a common goal, often to facilitate remote and challenging operations (Schranz et al., 2020). The interaction between the individual UAVs within the swarm, as well as how they communicate with a human operator is critical to their success. UAV swarms can operate at a higher level of autonomy, interacting with each other in a network without human intervention. Yet, human interaction is still important to ensure the swarm is operating as desired and within the objectives of a set mission (Brown et al., 2015; Hussein & Abbass, 2018; Kolling et al., 2013). The design of the interface between the UAVs and the human operator is therefore highly important to facilitate swarm management as well as trust. Within swarm operations the operator must trust that the UAVs are functioning as expected as well as how they are functioning as a team (Hussein & Abbass, 2018). Yet, the complexity of information that can be conveyed from the swarm to the human operator must be considered in relation to individual workload and situational awareness (Hocraffer & Nam, 2017; Hussein et al., 2018; Hussein & Abbass, 2018; Ramchurn et al., 2015). Ramchurn et al. (2015) identified that a user interface with a multi-agent coordination algorithm results in lower operator workloads and better performance in re-planning tasks than one which only involves manual task allocation.

In our earlier work, we conducted a user study with 100 participants to investigate the effect of visualization method on usability of human-swarm interface (Clark et al., 2021) and proposed a control method to enable a single supervisor to operate a large swarm (Divband Soorati et al., 2021). However, the issue of a trustworthy swarm goes beyond a usable interaction interface. This paper aims at creating a broader understanding of a trustworthy human-swarm interaction with expert-driven requirements.

Human Factors research into UAV operator behaviour is in its infancy yet the technology is developing rapidly and becoming increasingly integrated within more domains. This research seeks to understand the key factors that inform the trust that UAV operators have towards the UAV and UAV swarm, from the perspective of the operators themselves [note when referring to UAV operators we include both the Civil Aviation Authority (2021) definition of the drone flyer (the person who flies the drone) as well as their definition of the drone operator (the person responsible for managing the drone)]. Through interviews with UAV operators, a user centred approach is taken to understand how trust is developed, inhibited, and/or maintained through examining their own experiences. These experiences and perceptions will be modelled using the Perceptual Cycle Model (PCM; Neisser, 1976) to understand how the operators' mental models influence the interactions that they have with UAVs and the types of information that they require.

1.1. Perceptual cycle model

The PCM, developed originally by Neisser in 1976, accounts for the interaction between the environment, human cognition and system function (Neisser, 1976; Plant & Stanton, 2012; Stanton et al., 2009). Neisser (1976) developed the model to comprise of three interacting elements within complex systems; schema, action, world. A schema is a knowledge cluster that develops from experience and provides a structure to process new events or environments that are similar or have commonalities to previously experienced environments. Schema Theory (Bartlett, 1932) suggests how schema provide mental templates to inform our future behaviours. These mental templates are adaptable, they are updated and altered with new experiences, as well as modifying the experience for the individual. Within the PCM the interaction between an individual's schema, the information in the world and the action that they carry out dynamically interact in a cyclic way. Thus, the model can account for how the world constrains behaviour, as well as how the way in which we think about the world constrains our view of it (Stanton et al., 2009). Figure 1 presents this cycle whereby schema are triggered from the world, and information available within it. Top-down processing occurs when actions are activated in line with the processing of the schemata, to respond to the event in the world. The utility of applying this approach to study human-machine interaction is the holistic way in which both the cognitive processing of the individual and the environmental factors that influence behaviour can be captured, as well as how each of these can adapt to each other in response to different events (Stanton et al., 2009).

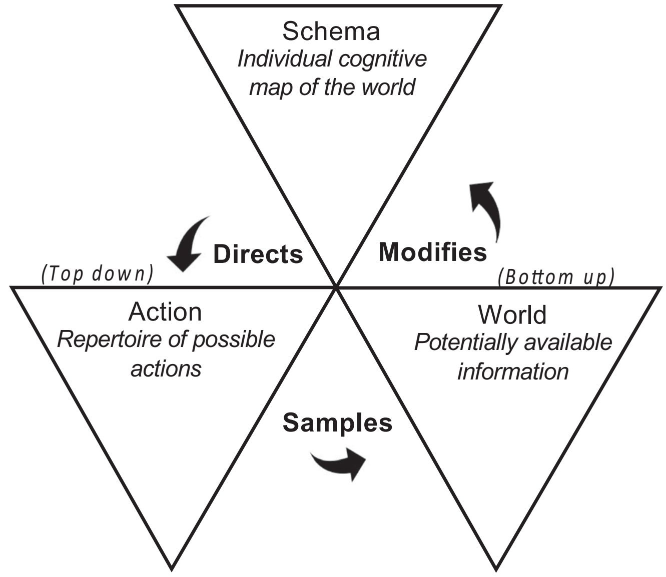

Figure 1. Representation of the PCM adapted from Plant and Stanton (2012).

The PCM has been applied across numerous safety-critical domains to understand human-system interactions (Banks et al., 2018; Plant & Stanton, 2012; Smith & Hancock, 1995; Stanton et al., 2009). Its application within the aviation domain has been particularly useful in understanding pilot decision making (Plant & Stanton, 2015; Parnell et al., 2021), as well as generating design recommendations for future flight deck interfaces (Banks et al., 2021; Parnell et al., 2021). Much of this success is due to the development of a critical aeronautical decision-making method, designed to capture the perceptual cycle of airline pilots during key decision points in real world scenarios (Plant & Stanton, 2016). The Schema World Action Research Method (SWARM; Plant & Stanton, 2016) is an interview method that provides prompts and cues related to the three components of the PCM, to capture how and why decisions are made. Please note that we use the word swarm, in lower case letters, to refer to a fleet of UAVs and the word SWARM, in capital letters, to refer to the interview method. These prompts can also be applied as qualitative coding metrics to analyse decision making and review where some decisions require more support from decision aids and how these decision aids should function relative to the pilot's interaction with the cockpit environment (Banks et al., 2021; Parnell et al., 2021).

Until now the SWARM has only been applied to piloted aircraft but, with the rapid developments in unpiloted aerial vehicles this research seeks to adapt and apply the method to the operators of UAVs to understand the relationship between the UAV operators, the information they receive and the context within which they operate. It is evident that trust will play a large role within this relationship and therefore the SWARM will be adapted to include prompts that question how operators trust UAVs and the information that they receive from it.

The aim of this paper is to capture UAV operator requirements through semi-structured interviews using SWARM in combination with questions on trust. This will seek to determine the practicality of applying the methodology to this domain and the recommendations that can be generated in relation to trust. The method is presented in the following section.

2. Method

2.1. Participants

Participants were sought that had experience with modern UAV technology for both military and civilian service purposes. The criteria were left somewhat open to capture a range of experiences and backgrounds, while also ensuring capable and well experienced operators were recruited. Six male participants were recruited with an average age of 33.83 years (range, 26–52 years). All participants had experience in flying multi rotor and fixed wing UAVs. In addition to this, some pilots also had experience in a single rotor helicopter ($n = 2$), fixed wing hybrid Vertical Take-Off and Landing (VTOL) aircraft ($n = 3$), unoccupied underwater vehicle ($n = 1$) and/or unoccupied surface vehicle ($n = 1$). Some participants had experience in more than one of these additional vehicles. All had undergone training for some form of drone operator/flyer qualification. Participants had academic ($n = 3$), military ($n = 1$) and industrial experience ($n = 2$). They had an average of 90 hours logged flying/operating experience, although this was skewed by one participant who was involved in overseas military trials (range, 6–400hrs). Hours logged reflects the number of hours that they have recorded flying UAVs. Logbooks are used to record UAV flights. Some participants were relatively inexperienced but had more technical knowledge of how the drones operated due to their roles. While others were required to fly the UAVs regularly and had a high number of hours recorded.

2.2. Interview questions

Interview questions were based on SWARM and were adapted to the UAV domain and to incorporate questions of trust, which are not specifically defined within the original SWARM. The following sections present how the questions were developed.

2.2.1. Swarm

Plant and Stanton (2016) utilized transcriptions from pilot discussions on critical aviation events to identify the SAW taxonomy which comprises of 6 Schema themes, 12 Action themes, and 11 World themes relevant to the management of critical aviation events. These comprise the SAW taxonomy (see Table 1 and Appendix A for the full descriptors). Each theme has several interview prompts that allow interviews to be conducted with pilots to extract information for the development of a PCM. There is a total of 95 prompts, however, they are comprehensive and not all prompts are relevant to every event. Therefore, Plant and Stanton (2016) advise down-selection to tailor to specific research aims. The prompts shown in grey in Table 1 were the ones selected by the research team for use in the interviews. Down selection was achieved through several review processes within the research team to limit duplication in question meaning and to focus on what was relevant to the research aims. See Appendix B for the full list of interview prompts.

Table 1. Schema Action World (SAW) taxonomy.

Schema themes	Action themes	World themes
Analogical Schema	Aviate	Absent information
Declarative schema	Communicate	UAV status
Direct past experience	Concurrent diagnosis	Artefacts
Insufficient Schema	Decision action	Communicated information
Trained Past Experience	Environmental monitoring	Display indications
Vicarious past experience	Navigate	Location
	Non-action	Natural environment conditions
	Physical actions	Operational context
	Situation Assessment	Physical cues
	Standard operating procedure	Severity of problem
	System Interaction	Technological conditions
	System monitoring	

Table 2. Questions on trust.

SAW theme	Trust questions
Schema	*Past experience* 1. Can you recall a point in this situation when you did not trust the UAV? • Please expand on this situation and why you did not trust it *Current experience* 2. Would you generally tend to trust the UAV? • Please expand on why this is 3. Do you have any distrust in the UAV? • What is the cause of this distrust? How could it be repaired? 4. Would you be wary or suspicious of the UAV at all? • At which points in an operation would this be? *Future expectations* 5. Would you have any reason not to trust to UAV in the future? 6. How reliable/dependable do you view the UAV to be?
Action	1. What actions would you be relying on the UAV for? 2. What actions would you **not** be relying on a UAV for? 3. How easy would it be to trust the UAV to do their job? 4. How could your trust in the UAV change over the course of the operation? 5. Could there be any negative outcomes? • And how would this effect your trust in the UAV for the future?
World	1. Would you ever be uncertain about the reliability or relevance of the information that you had available to you? 2. What information/knowledge would you need to trust the UAV? 3. Could there be any deceptive information? 4. What information would you need to repair any lost trust in the UAV?

2.2.2. Trust

Questions regarding trust were adapted from relevant and popular trust scales including Merritt's (2019) "Trust and Liking scale," and Jian et al.'s (2000) "Trust between People and Automation scale." These were applied to the schema action world themes, shown in Table 2.

2.3. Equipment

The interviews were conducted via video call on Microsoft Teams, they were recorded and transcribed. Microsoft Teams autogenerated transcripts were used as the starting point for the transcription and the researcher read through these while listening to the audio recording and amending the output to get an accurate transcript. The video files were deleted and the transcripts were anonymised. The data analysis software Nvivo 12 was used to qualitatively analyse the data.

2.4. Procedure

Participants were recruited using contacts from the Trustworthy Autonomous Systems (https://www.tas.ac.uk/) project (although not directly involved in the project itself) under the criteria that they had experience in operating UAVs. The interviews were organised for a time that best suited the participants. The interviewer started the interview by giving an overview of the area of interest; operator-UAV interactions and trust in this interaction. They then asked the participant to describe a scenario in which they had experience in piloting/operating a UAV. The three main areas of focus within the interview (Schema, Action, World) were then presented on a shared screen with prompts relating to each area. The interviewer asked the questions relating to the Schema, Action and World in turn, as well as the additional trust questions. The interviews were semi-structured and the interviewer probed further into areas of interest where they arose. In the final part of the interview participants were asked to give their thoughts on swarming UAVs and how trust may play a role in the interaction with the swarm, given what they had previously discussed based on their own experiences. At the end of the interview participants were debriefed and thanked for their time.

The research received ethical approval from the University of Southampton ethics board (Ethics ID: 64283)

2.5. Data analysis

Using Nvivo 12, the researcher coded the interview transcripts to the SWARM themes. The SWARM descriptions denoted in Plant and Stanton (2016) were used but the term aircraft was replaced with UAV. A primary researcher initially coded the transcripts, with an additional two researchers performing a reliability analysis on this coding (see below).

To target the aspects of trust that UAV operators discussed, aspects of the transcript where trust was discussed (i.e., responses to the questions posed in the Table 2) were identified and coded to a "trust node" in Nvivo 12. Parts of the interview where single UAV operations were discussed and where swarms of UAVs were discussed were also coded to different nodes to allow these segments of the transcripts to be reviewed independently. This allowed for the discussion on trust in operating individual and swarms of UAVs to be reviewed and compared.

2.5.1. Reliability assessment

Two experienced Human Factors professionals provided a reliability assessment on the coding. This followed the guidance of O'Connor and Joffe (2020). Rater 1 had 10 years of HF experience and Rater 2 had 6 years of HF experience. Both were familiar with the PCM and have been involved in UAV operator research. They were provided with excerpts that equated to approximately 10% of the full set of transcripts. They were also provided with the SWARM code book and were asked to use it to code the excerpts. Both raters initially coded the excerpts independently before meeting together with the researcher to discuss their codes. Initial percentage agreement with the primary researchers coding was 42.1% for Rater 1 and 39.9% for Rater 2. These agreement scores are stated to be fair to moderate (Landis & Koch, 1977). Hruschka et al. (2004) notes that a large number of codes, such as in the SWARM code book, are more likely to lead to lower levels of agreement. Therefore, the raters met with the primary researcher to discuss the rationale for their coding. Following the discussion, the percentage agreement was 71.8% for Rater 1 and 64.8% for Rater 2 which is "substantial" agreement (Landis & Koch, 1977). The Cohen's kappa scores were 0.96 and 0.94 for Rater 1 and Rater 2 respectively. This is deemed to be a better metric when considering the probability of selecting the codes by chance (McHugh, 2012) and due to the high number of codes used, this metric is high for this study as there is very low chance that the same codes were selected by chance. Nonetheless, within the discussions with the raters, it was evident that there was some possibility for overlap within the SWARM codes when applied to this dataset. Clear distinctions between some themes were determined (see Table 3). The primary researcher applied these clarifications in a secondary phase of the analysis wherein they reviewed the data coded to each node to check for relevance and make any alterations following the discussion with the inter-raters.

2.5.2. Identifying key trust factors

Due to the limited research into this area and the large number of SWARM codes that are evident, the topmost important factors discussed in relation to trust were sought. A scree plot was used to identify the codes with the most importance within the discussions. Scree plots are a useful tool when undertaking an initial review of an area of high complexity, in order to focus on the most significant factors (Parnell et al., 2016; Rafferty et al., 2010). The scree plot presents the importance of each of the themes to trust and then a point of inflection is taken by reviewing the intersection of two lines from the most and least important factors (Cattell, 1966). The intersection, or point of inflection, identifies where the importance of the variables under analysis become less significant and their contribution to meaning does not warrant any further review at this early stage. This is not to say that they are not important but that, in the early stages of understanding the complexity in this area, the top most referenced codes should be reviewed first.

3. Results

Each of the interview participants discussed a scenario where they had experience in piloting a UAV. Two participants (P2 and P3) described the same scenario as they worked within the same organisation, however they performed different roles within the scenario so were able to give different perspectives. Three of the scenarios discussed by participants (P4-6) involved the UAV performing a search role, although the reason and circumstances for the search varied. The other three participant scenarios (P1, P2 and P3) related to the collection of data and/or samples from locations that were largely remote and inaccessible (e.g., rainforests and volcanoes) and therefore UAVs provided an opportunity to obtain previously unattainable data. None of these scenarios included a swarm of UAVs. One scenario did involve multiple UAVs performing a surveillance task, but the UAVs were operated independently and did not communicate with each other and therefore it is not classified as a UAV swarm.

3.1. Swarm coding

The full interview transcripts were coded to the SWARM prompts in Nvivo 12, including their current scenario discussion, questions on trust and questions on UAV swarms. All of the original SWARM codes presented by Plant and Stanton (2016) were evidenced within the UAV operator

Table 3. Clarifications made for SWARM codes that provided confusion within the inter-rater process.

Location Relates to comments on the place or geographical location in space with respect to the UAV and/or the operator	**Navigation** Relates to actions to determine or alter the direction of travel of the UAV or operator. Usually includes reference to way points and navigation systems.
System monitoring Relates to the monitoring of the whole system including the UAV, displays, environment and how they are functioning together.	**Display indicators** Relates to information that specifically comes from displays and indicators within the system
Concurrent diagnosis The process of trying to diagnose a fault or possible problem within the system. If there is not fault it is not diagnosis but a situation assessment.	**Situation assessment** Process of assessing what is occurring with the scenario of specific event, drawing conclusions. This is usually detailed when informing decisions of making interpretations of system functioning.
Severity of problem References to the criticality of a problem or incident, how bad it is or could become.	**UAV status** References to the current status of the UAV itself with regard to its integrity and performance. This can include its ability to fly, its automated functionality etc. It may not necessarily be negative but relates to status updates.

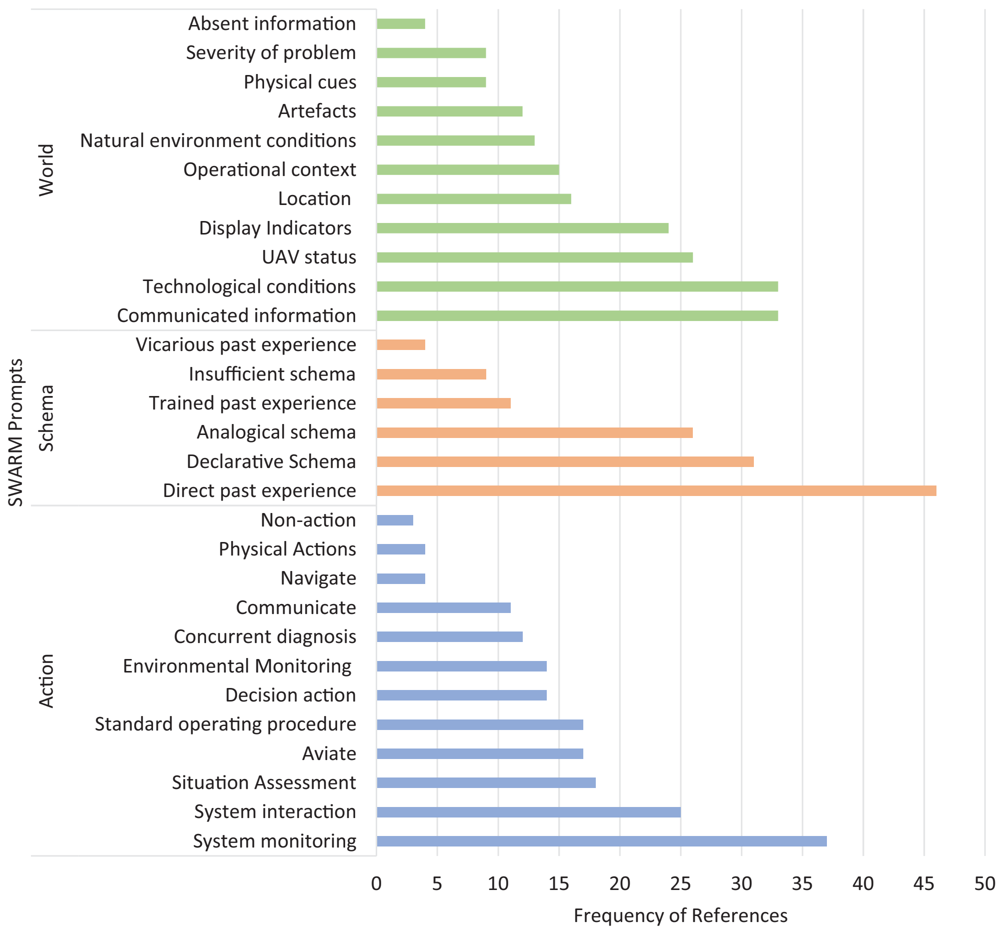

Figure 2. Graph showing the Frequency of references to the SWARM prompts within the UAV operator transcripts.

transcripts. The total frequency of references to each SWARM code across the whole transcripts are shown in Figure 2, organised by frequency within the Action, Schema, World themes. Actions and information in the world had a very similar number of references (Actions $n = 154$, World $n = 153$). While Schema codes received less references in total ($n = 130$), "Direct Past Experience" was the most referenced sub-code ($n = 46$). This is somewhat unsurprising due to the nature of the interviews probing into the participants' experience with UAV operations. The most referenced Action code was "System monitoring" ($n = 37$). The two World codes with the equal, most number of references was "Communicated information" ($n = 33$) and "Technological Conditions" ($n = 33$). These frequently referenced codes suggest the importance that operators place on monitoring the functionality of the UAV system and the information that the UAV can communicate to them within the operation.

3.2. Trust

The number of references to the SWARM codes in the responses to the trust questions were of interest to review how the SWARM prompts intersect with trust. Due to the rare availability and use of UAV swarm technology, none of the participants interviewed had direct experience in operating a swarm of UAVs in the real world. Yet, they were able to talk hypothetically about how their own experiences may influence and direct their ability to trust a UAV swarm. Table 4 presents the frequency of the SWARM taxonomy codes that were referenced in discussions about trust during single UAV operations, with quotes to provide examples. Table 5 presents the same with regard to discussions that were coded to UAV swarms.

The varying frequency of the codes that were referenced gives an idea of the key things that operators consider when developing trust in UAV technology, and those which are less important. The most referenced SWARM code was "Direct Past Experience" due to the participants talking about the trust that they have personally gained or lost through their UAV interactions. The majority of operators stressed that more exposure to operating the UAV allowed them to gain an understanding of its behaviours, which was key to gaining trust in the system. "UAV status" was the second most referenced code which suggests the importance of understanding the functioning and integrity of the UAV at any one moment, to the trust that UAV operators hold. The next most referenced code was "Declarative Schema" ($n = 15$) which is a descriptive knowledge of facts that is usually based on the information available within the world. The high number of references to this code relate to the discussions on trust that operators stated to arise from their knowledge of how the UAV operated and what they needed to be aware of to understand how it was functioning. The "Analogical Schema" code was also frequently referenced

Table 4. References to SWARM codes during discussions on trust in single UAV operations.

SAW code	Frequency	Example quote
Direct past experience	23	*I think for me it's time on the platform, time operating the platform along with previous experiences.* (P1)
UAV status	17	*But at any point he can tell the state of it is if there's anything that gets flagged up, he doesn't need to be concerned about the state of the aircraft at any point.* (P5)
Declarative schema	15	*It's got to a point where when the plane is flying around, I don't even look at the plane because I know that it's solid. It's not, it's not failing. We have fuel. We have batteries. We have health monitoring, so that's something which were quite proud of.* (P1)
Analogical schema	11	*would have maybe been a different story if say you know the role rate or the roll angle protection was to a more acute angle and it couldn't make a turn, then we'd probably be left for quite a while, wondering what went wrong.* (P3)
System monitoring	10	*They're generally looking at a combination of a map view that shows the route and feedback that says where the vehicle thinks it's going. So that… are they getting a feedback that says it's following along…* (P6)
Technological conditions	10	*But umm yeah, it's just a case of it doing what's supposed and us being able to deliver an output and the more [reliable] the system is, the better output we can deliver 'cause the less time we spend fighting the system* (P4)
System interaction	7	*Your primary interface with the drone flight control system is always through the telemetry link* (P5)
Standard operating procedure	7	*Also is the altitude it's reporting within the band that you're allowed to operate within.* (P6)
Aviate	7	*But due to that it didn't allow us to make a full bank to turn, so it's like limiting its role angle. So that was a little bit, yeah umm, nerve wracking.* (P3)
Display indications	6	*well it took off and then it was reading 15 meters per second speed, but it should have been much more and it just kept a steady 15 and we didn't know why* (P3)
Physical cues	6	*So how it sounds and how it looks as well as the data you're seeing on your computer screen. Combining all those together is very important to build that trust.* (P2)
Operational context	5	*For takeoff and landing, there had to be more than 5 meters away from the drone, at any other phases of flight, we had to be more than 30 meters away* (P5)
Concurrent diagnosis	4	*we first of all make sure that's what it was. Umm and then once we were pretty confident that that's what it was, we just made physical changes to the system.* (P3)
Situation Assessment	4	*… certainly doing trials, If we weren't sure why it had done something odd, like suddenly turned around and gone in a in a different direction, we'd be much like more likely to bring it down* (P6)
Artefacts	4	*The flight controllers that we use log a lot of information, a lot of data, so often can kind of troll through all that and most of the time you know get a good idea of what went wrong* (P3)
Communicated information	4	*So, you would be hoping that when you got information from it, it told you reliably where it had been, what it was intended to do and the information that it had had gathered.* (P6)
Location	4	*Whenever we develop a fault, regaining trust is a big thing especially for a lot of our drone operations were we actually go beyond line of sight where the very second it clears your line of sight, it's 100% don't trust that it's doing what's supposed to be doing because you have no other way of checking.* (P5)
Natural environment conditions	2	*but if anything happens at that time, you don't really have the height to, to recover.* (P3)
Severity of problem	2	*when we eventually found what the problem was, it was the Autopilot companies fault. We felt a little bit more at ease knowing now what we have done up until now is the right thing.* (P1)
Communicate	1	*Obviously, we do talk to each other and there is a very large overlap.* (P5)
Navigate	1	*and a classic one is that somebody has accidentally uploaded a waypoint with zero altitude and the vehicle suddenly starts going down really fast and you know then you've hopefully got somebody in the loop to pick it up and say no. This is bad.* (P6)
Physical actions	1	*'cause the less time we spend fighting the system, the more we spend actually utilizing the capability.*(P4)
Insufficient schema	1	*If we weren't sure why it had done something odd, like suddenly turned around and gone in a in a different direction, we'd be much like more likely to bring it down, you know, manually bring it down* (P6)
Trained past experience	1	*we're tending to say you probably need to have done training with the system enough times before hand to be able to say, yeah, I I'm recently I've done it before and it's found the things that I'm looking for, so I'm fairly reasonably confident* (P6)
Absent information	1	*As soon as you're beyond that sight, that visual line of sight, that's where you're most wary.* (P2)
Non-action	0	–

($n = 11$) when discussing trust in single UAV operations. The analogical schema references included statements where operators made elaborations as to why they may or may not trust the UAV given variable circumstances or outcomes. These gave detail on the metal model that UAV operators held in relation to trust.

A number of codes only had one or two references in relation to trust but only one code did not have any references to trust in single UAV operations, "Non-action."

Table 5 presents the frequency of references to the SWARM codes within discussions of trust in UAV swarms. The total number of references across all the codes is reduced in comparison to Table 4, due to lack of experience of the participants in UAV swarm operations. This is evident with the reduced number of schema codes that were referenced in comparison to the single pilot operations discussions, where the operators could talk of their own past experiences and their knowledge of the system.

3.3. Identifying key trust factors

A scree plot was used to identify eight codes which held the most importance within the discussions, see Figure 3. The intersection falls on the code "Aviate" leading to the top eight factors to the left of the intersection in Figure 3 to be considered the most valuable to review. These are "Direct Past experience," "UAV status," "Declarative Schema," "Technological Conditions," "Analogical Schema," "System Monitoring," "System interactions," "Standard Operating Procedure" and "Concurrent diagnosis."

4. Discussion

Interviews with six UAV operators have sought to understand their trust in UAVs within operations that they have personally experienced, as well as how they perceive trust may impact within UAV swarm operations. This paper

Table 5. References to SWARM codes during discussions on trust in UAV swarm operations (hypothetical)

SAW code	Frequency	Quote
Technological conditions	8	*So you know at the moment I'll be very concerned, for example, if somebody had said "Oh well, actually I've got an air to air collision avoidance system," because there's you a lot of difficulty in saying, well, can you actually detect things? And will you make a response in an appropriate length of time? Those are all … they're difficult to get working.* (P6)
UAV status	5	*… always when things are going wrong that you start to lose trust, so as soon as something happens, you need to know what's going wrong. So having some means of doing that builds trust and that you can quickly decipher the problem and then trust that either it's going to do the right thing, or that you can take action to fix it.* (P2)
Concurrent diagnosis	4	*You know, if half of them land, UM, is that because you're looking at it and then say "Oh well, actually, yes … .It's only the at the edge of the area that we're operating in, and so that's a precaution for those ones, but the others are far enough away that they don't need to react yet." But you, you need to sort of understand those things.* (P6)
System interaction	4	*It needs to be managed as much by the system as physically possible to the point where the user doesn't, especially when we talk about swarms, where the user doesn't have to do too much input or worry too much about it.* (P4)
Analogical schema	4	*It may be that you know that that once those are all worked through, people become very confident that says, yeah, these systems work fine. They're actually better than people staring at windows 'cause they don't get board* (P6)
Declarative schema	4	*Well the key trust really is, as I said. It's not the technology layer that often fails. The technology layer does what it's supposed to do. It's the human layer that fails, and when you get into the more complexity and more complex environments. It's understanding the intended and unintended consequences of the system.*(P5)
Direct past experience	4	*I think as as you have more confidence with them, you get, you're more likely to kind of trust and use things* (P6)
Standard operating procedure	3	*if, for example, the standard procedure was that, if they thought that an UM a manned aircraft was approaching, they all dropped to the ground and tried to land and you need to understand that that's what's happening, otherwise it would be really disconcerting.* (P6)
System monitoring	3	*how much capacity is that going to take to be able to worry about that and to where it's going in to let the right people, the right people know that that's happening, at the same time as managing your other nine that you've got in one area.* (P4)
Severity of problem	3	*I don't care if it's doing what it's supposed to do, it is when something fails, I would want to know what it's going to do and having more components or elements to the, the whole picture. I want know what everything else is going to do.* (P2)
Non-action	1	*Because yeah, as you can imagine there not controlled by one person at that point. It's an entirely automated script. I hate the word autonomous, but it is entirely automatedly scripted* (P5)
Situation assessment	1	*It's understanding the intended and unintended consequences of the system.* (P5)
Trained past experience	1	*In particular when it comes back to sort of the training, some of the arguments that were trying to make is that you you need to understand what those situations are and then have experienced them either for real or more likely in simulations, where you're able to see what would happen* (P6)
Communicated information	1	*You need to make sure that you're not giving them too much information* (P2)
Display indications	1	*I guess 'cause you see how it has been performing even though it's not a detailed information even it's just a trend line saying … .Kind of it is going down..or is going up is quite important.* (P2)
Physical cues	1	*if you see that happening and you, you can then go and look for the cues that say, Oh yeah, OK, that that's what's happened.* (P6)
Aviate	0	–
Communicate	0	–
Decision action	0	–
Environmental monitoring	0	–
Navigate	0	–
Physical actions	0	–
Insufficient schema	0	–
Vicarious past experience	0	–
Absent information	0	–
Artefacts	0	–
Location	0	–
Natural environment conditions	0	–
Operational context	0	–

Within the discussions on UAV swarms "Technological Conditions" received the most frequent number of references ($n = 8$). There were discussions related to the uncertainty over the technical competency of the UAVs within swarm operations which impacts their trust. The operators highlighted that there are still many uncertainties over how well certain features would work within UAV swarms as well as concerns about their ability to function as a unit and what happens if something were to go wrong. The second most referenced code "UAV Status" ($n = 5$) also highlights the concern over the integrity and understanding of the functionality of UAVs within a swarm. Thirteen codes were not referenced within discussions about trust in UAV swarms.

provides two novel contributions of the Schema World Action Research Method (Plant & Stanton, 2016); its practical application in providing recommendations from UAV operators, as opposed to aviation pilots, and its methodological contribution of mapping trust within the PCM. Together, this novel application of the SWARM to UAV operations has shown the key factors that UAV pilots' reference when discussing their trust in UAVs/swarm operations.

4.1. Practical contribution

Through qualitative coding using the SWARM taxonomy, this research provides an insight into the key factors that influence UAV operators trust in single UAVs and UAV swarms. The scree plot in Figure 3 identified the most valuable SWARM codes for exploration in relation to trust. These codes are mapped onto the PCM in Figure 4.

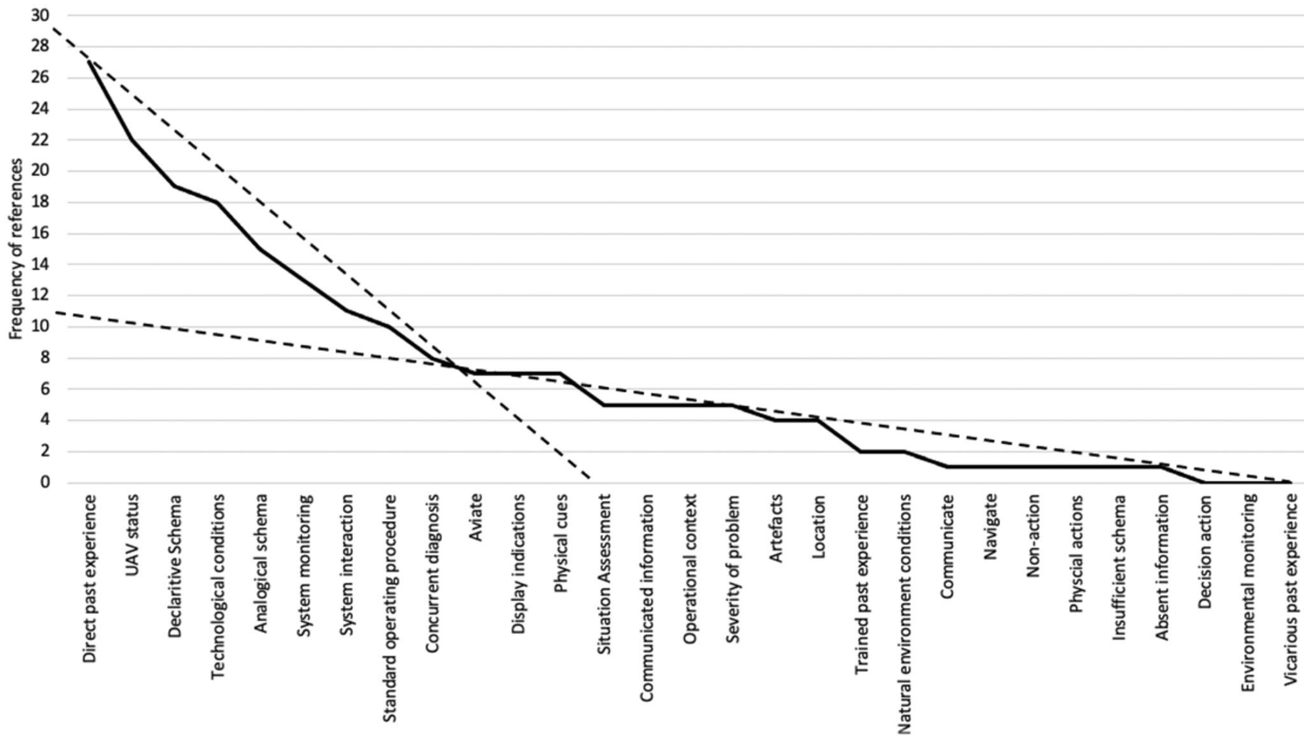

Figure 3. Scree Plot highlighting the most important factors discussed in relation to UAV operators trust in the UAV/swarm.

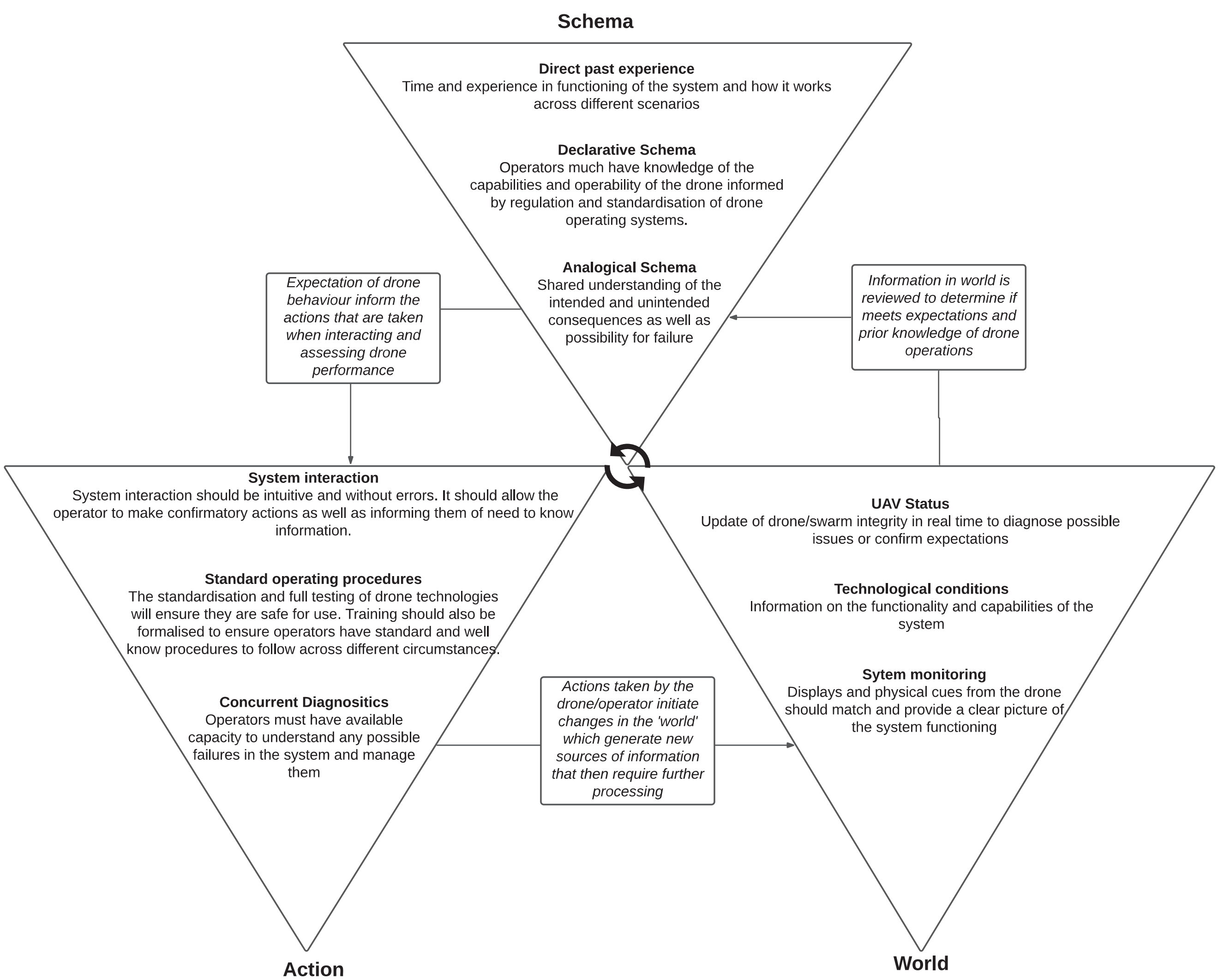

Figure 4. Top trust requirements on the PCM.

The PCM shows how trust can be fostered through each of the key factors identified within the operator interviews. The information that is presented within the world must clearly convey the status of the UAV/swarm as well as their technical capability and enable these key parameters to be monitored across the operation. Within the interviews it was evident that the trust that operators hold towards the UAVs depends on their ability to rely on the system to act as expected. Therefore, the operators need feedback from the system that conveys how it is performing, to either confirm it is operating as expected, or to highlight when there may be an issue or malfunction. When considering UAV swarms, this was particularly important as the operators had little trust in the capability of UAV swarms and their ability to function as a unit, or what would happen in the event of one UAV not co-operating or failing. Much of this may be due to the limited experience that the operators that were interviewed had with UAV swarms, as experience was also very closely linked to feelings of trust. Indeed, the schema for the UAVs' behaviour is informed by the information that they have received and encoded through past experiences.

Direct past experience was the most referenced factor in trust and, while this may largely be due to the nature of the interviewers asking operators to reflect on their experiences, previous experience does play a large role in the expectations and trust that we place on systems (Blomqvist & Stahle, 2004). The importance of building knowledge and mental models of the UAV/swarm and their behaviours are evidenced through the "Declarative schema" and "Analogical schema" codes. Their knowledge for systems capabilities (Declarative schema) and ability to compare possible eventualities based on this knowledge (Analogical schema) allows them to pick out the information of importance to inform their future actions. Therefore, intuitive interfaces will allow for ease of interaction. Progression of UAV swarms needs to ensure that the interactions with the swarm are well thought through and align with the operators' expectations and mental models of the swarm. Possible ways of achieving this include understanding the users' expectations within certain events and providing comparable information and interfaces that can allow them to determine if their expectations have been met or not. This should strive to minimise workload as many participants commented on the need to be only presented with required information rather than overloading them. This was a particular concern within the UAV swarm discussions, with participants apprehensive about how to manage possible divergent UAVs within the swarm and their limited capacity to monitor each UAV individually.

4.1.1. System requirements

The system requirements for the key SWARM factors, as identified within the interviews, are presented in Table 6. The design requirements are categorised into four main areas of system design; training, procedure, organisation and equipment (Stanton, 2004). "Training" relates to the required training needed to operate the UAVs and understand their behaviours. "Procedures" relate to the processes that need to be in place, to govern system performance and design. "Organisation" refers to the wider systemic influences in which UAV operations occur. "Equipment" relates to the technology itself, its functionality and design. Detail on each requirement is provided within Table 6.

4.2. Theoretical contribution

This is the first attempt, to the authors knowledge, to map trust onto the perceptual cycle model. The use of the model within this work had been valuable is both the collection and analysis of data to understand how trust may be gained and/or lost through human interactions with UAV(s). The cognitive experience of trust can be modelled with respect to the actions that users undertake and the way in which they process and attend to certain information in the environment. The benefits of applying this model enable the interactional nature of trust between humans and technologies to be assessed. Furthermore, the methodologies that accompany the PCM can be used to capture, analyse and build trust.

4.3. Methodological contribution

Previously the SWARM had only been applied to airline pilot interactions, this paper presents the first application of the SWARM taxonomy to UAV operator interactions as well as its focus on trust.

4.3.1. Applying SWARM to UAVs operators versus aircraft pilots

Aviation is typically a very closed and heavily regulated domain (Billings, 2018). Yet, the rapid development and application of UAV technology has preceded their full regulation and standardisation. Application of the SWARM to the UAV domain has shown that, while there are some overlaps in the themes and issues that operators and pilots discuss in relation to the SAW taxonomy, there are also many differences that need to be considered when comparing traditional aviation practises to UAV practises.

In traditional, piloted aircraft operations, there is rigorous training, numerous set procedures and checklists that ensure aircraft pilots are knowledgeable and can act in a standardised and justifiable manner. In other words, they have well developed schema for how to act and respond in variety of situations. Due to the complexity and safety risks associated with the domain, this has been of central importance for many decades in both military and commercial aircraft. Previous applications of the PCM and the SWARM interviews to the piloted aviation domain have highlighted the importance of simulator training, which pilots must regularly undertake. Assessments of decision making in relation to emergency events such as engine failure on take-off, have shown that flight simulators can provide a strong schema, similar to directly experiencing the event, that allow them to respond in an effective and standardised way (Parnell et al., 2021). It could be argued that this allows pilots to be

Table 6. Top SWARM codes based on the number of times they were referenced in relation to trust in UAV swarms and single UAV operations.

SAW taxonomy	SAW	Single UAV operation (freq)	UAV Swarm (freq)	Total	Design/system requirement
Direct experience	Schema	23	4	**27**	**Training** Extensive training is required to build confidence in the system so that operators understand how it will react in different environments and circumstances. These experiences can be gained in low pressure environments where trust can be gained incrementally while building up UAV functionality.
UAV status	World	17	5	**22**	**Equipment** Incorporate information on the functionality and status of the UAV within the system on the feedback interface. Trust is gained through gaining an understanding of the capability of the UAV/swarm in real time and what it will do next.
Declarative Schema	Schema	15	4	**19**	**Organisation** The operators need to have significant knowledge on the capabilities of the UAV across a range of operations and contexts. Training, official standards and certification are required at the organisation level to provide a benchmark for reliable systems.
Technological conditions	World	10	8	**18**	**Equipment** Improvements in the functional capacity of UAV technology will foster more trusting relationships with UAVs/swarms. This will require robust testing. There also needs to be clear feedback to the operator when functionality is compromised so that operators can understand why incidents or issues arise. This can help them to develop their mental model.
Analogical Schema	Schema	11	4	**15**	**Training** Extensive training will help to build the operators mental model and therefore their understanding in how the UAV/swarm will operate across a range of scenarios. They will therefore be able to confidently understand UAV behaviour and make informed decisions.
System monitoring	Action	10	3	**13**	**Equipment** The HMI must match and reinforce any visual or other sensory cues that can be physically detected from the UAV itself. This can provide an enhanced awareness of the UAVs functionality and its progress through the operation. There could also be the possibility for external HMI (eHMI) on the UAV/swarm itself when is in line of sight to confirm its actions, status and direction e.g., indicators, coloured lights.
System interaction	Action	7	4	**11**	**Equipment** The inputs and interactions that UAV operators have to the UAV/swarm must be clear and reliable. Where the UAV does not operate as expected trust is easily and quickly lost. UAV system feedback must also allow operators to confirm their expectations on the upcoming actions of the UAV.
Standard operating procedure	Action	7	3	**10**	**Organisation/Training** Official standards and certification is required at the organisation level. This should feed into the requirement for training to ensure only qualified operators are permitted who have undergone extensive training and have a strong mental model of how the UAV functions and its capabilities.
Concurrent diagnosis	Action	4	4	**8**	**Procedure/Equipment** System interaction permits insight into possible errors in a way that can be easily diagnosed and managed. i.e., not introducing unnecessarily high workload.

Including the trust requirements for each code and system design requirements.

confident that they can manage adverse events and therefore their trust in the technology is enhanced.

When the SWARM is conducted with aircraft pilots, the similarity in the pilots' responses leads to few pilots being interviewed before the point of data saturation is reached as they all tend to give very similar answers (Banks et al., 2021; Parnell et al., 2021). Yet, the interviews conducted within this work with UAV operators showed large variances, both in the interaction and application of UAV technology. The operators were knowledgeable about the things they observe and monitor within specific scenarios, but these were far from standardised or comparable across participants. Standardisation, certification and training within the domain is in its infancy and many UAV operators commented that this was a concern and plays a role in the trust they have with the system.

The inter-rater reliability assessment enabled a wider discussion on the application of the SWARM prompts to UAV operator behaviour, in contrast to the standard aircraft pilot user population. For example, the subtleties across themes such as system monitoring versus display indicators, or concurrent diagnosis versus situation assessment (as presented in Table 3) need to be clear on which part of the interaction is being reviewed. In traditional aviation the system and the display indicators both relate to the cockpit and its interface, yet within UAV operation the system is more complex and involves the remote UAV as well as the ground operations. Furthermore, while in traditional aviation "concurrent diagnosis" may be standardised with checklists, in UAV operations this is more complex. The operator is routinely trying to diagnose the status of the UAV to ensure it if acting as expected. Therefore, it was decided that situation assessment relates to the behaviour of reviewing system functioning, while concurrent diagnosis should only be reserved for diagnosing actual problems or errors that have already been identified in the system. This suggests that there may need to be some reframing in the application of traditional aviation methods and practises in relation to the UAV domain.

4.3.2. Including trust in the SWARM

This paper also presents the first application of trust to the PCM, to the authors' knowledge. The schema, action and world components of the PCM (Neisser, 1976) have provided a useful basis from which to assess trust in automated UAV technologies. The PCM is able to capture the dynamic trust process, and how trust within the head of the operator is formed from the information received about the status of the UAV and the context within which it operates. This approach therefore views trust at the system level, arising through the interaction between system elements and not solely within the head of the individual. This is important when UAV swarms are considered, as they will form a highly complex sociotechnical system that will demand high levels of trust in its automated capabilities (Herrmann & Weber, 2020). Within this domain of application, it is important that trust can be captured within the interaction between the UAV technology and the operator. The PCM offers this perspective and demonstrates how trust is constructed through the human-technology interaction. Future work is planned to build on the outputs of this work and develop the Trust-Schema World Action Research Model (T-SWARM).

While the SWARM codes have given an insightful analysis of trust requirements for UAV operators in this research, further research will seek to determine the relative importance of each of the SWARM codes and determine if an adapted version may be developed that specifically captures UAV operators' behaviour. This may also contribute towards being able to review how operators' behaviour and interactions with the UAV system may alter with respect to UAV swarms in comparison to single UAV operations.

4.4. Limitations and future work

Trust is a construct that varies across individuals as well as across different situations (Hancock et al., 2011; Hoff & Bashir, 2015). Therefore, caution must be applied when applying the findings outside of this study and to other drone operators who may have different backgrounds and experiences. Further validation and testing in realistic/simulated environments is required, as well as utilising a larger sample size than was used in this study.

This is the first attempt to combine trust within the PCM framework and therefore further work will need to validate the updated SWARM protocol with its inclusion of trust themes.

When using qualitative methods such as interviews the results must be interpreted with some caution as they may be subject to bias and may not truly represent all information that the participants have, only that which they are willing to convey. Consideration must also be given to the participant sample, which was entirely male due to the lack of female UAV operators. This is a considerable limitation of this work, as well as the domain itself (Joyce et al., 2021).

5. Conclusion

Human Factors methods have historically contributed to the successful development of aviation technologies and pilot performance. As the aviation domain advances with the development of UAVs, and the role of the human operators changes to be one of supervision and remote control, HF work will continue to be integral to successful operations. This paper aimed to understand UAV operators' trust requirements when piloting UAVs by utilising the popular aviation interview methodology SWARM, in combination with key questions on trust. Applying questions on trust, from previous validated trust questionnaires, has shown the value of SWARM in identifying the key factors that influence trustworthy relationships between UAV operators and UAVs/swarms. It has highlighted the importance of past experience to future experiences of trust. Furthermore, it has highlighted that operators trust systems that act as they expect them to act, therefore they require information of the status and functioning capabilities of the UAV to inform trust. The PCM is able to successfully capture how trust is experienced, informed and acted upon. The SWARM has enabled the key aspects of the schema, world, action pillars of the PCM to be identified in UAV operator trust and has informed design recommendations that can help to increase trust. These fall within the human factors categories of training, operation, procedure and equipment. Caution is, however, advised on the application of traditional aviation methodologies to the UAV operator domain due to its infancy and limited standardisation or certification process. Future research should seek to determine how aviation based methods such as the SWARM can be adapted to the UAV/UAV swarm interactions. Furthermore, work to develop the theoretical and methodological contributions of adding trust to the PCM and SWARM is suggested.

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Data availability statement

Due to the nature of this research, participants of this study did not agree for their data to be shared publicly, so supporting data is not available.

References

Banks, V. A., Allison, C. K., Plant, K. L., Parnell, K. J., & Stanton, N. A. (2021). Using the Perceptual Cycle Model and Schema World Action Research Method to generate design requirements for new avionic systems. *Human Factors and Ergonomics in Manufacturing & Service Industries*, *31*(1), 66–75. https://doi.org/10.1002/hfm.20869

Banks, V. A., Plant, K. L., & Stanton, N. A. (2018). Driver error or designer error: Using the Perceptual Cycle Model to explore the circumstances surrounding the fatal Tesla crash on 7th May 2016. *Safety Science*, *108*, 278–285. https://doi.org/10.1016/j.ssci.2017.12.023

Bartlett, F. C. (1932). *Remembering: A study in experimental and social psychology*. Cambridge University Press.

Billings, C. E. (2018). *Aviation automation: The search for a human-centered approach*. CRC Press.

Blomqvist, K., & Stahle, P. (2004). Trust in technology partnerships. In *Trust in knowledge management and systems in organizations* (pp. 173–199). IGI Global.

Brown, D. S., Goodrich, M. A., Jung, S. Y., & Kerman, S. (2015). Two invariants of human-swarm interaction. *Journal of Human-Robot Interaction*, *5*(1), 1–31. https://doi.org/10.5898/JHRI.5.1.Brown

Cattell, R. B. (1966). The scree test for the number of factors. *Multivariate Behavioral Research*, *1*(2), 245–276. https://doi.org/10.1207/s15327906mbr0102_10

Civil Aviation Authority. (2021). Registering to own a drone or model aircraft. Retrieved December 17, 2021, from https://register-drones.caa.co.uk/individual

Clark, J., Divband Soorati, M., & Ramchurn, S. D. (2021). *Usable and interpretable human-swarm visualisations: A user evaluation study*. The Chartered Institute of Ergonomics and Human Factors.

David, J. S. N. P. Z., & King, C. (1997). *Why people don't trust government*. Harvard University Press.

Delhey, J., Newton, K., & Welzel, C. (2011). How general is trust in "most people"? Solving the radius of trust problem. *American Sociological Review*, *76*(5), 786–807. https://doi.org/10.1177/0003122411420817

Divband Soorati, M., Clark, J., Ghofrani, J., Tarapore, D., & Ramchurn, S. (2021). Designing a user-centered interaction interface for human–swarm teaming. *Drones*, *5*(4), 131. https://doi.org/10.3390/drones5040131

Haidt, J. (2012). *The righteous mind*. Random House.

Hancock, P. A., Billings, D. R., Schaefer, K. E., Chen, J. Y., De Visser, E. J., & Parasuraman, R. (2011). A meta-analysis of factors affecting trust in human-robot interaction. *Human factors*, *53*(5), 517–527.

Herrmann, G., & Weber, J. (2020). Game of Swarms. Swarm technologies, control, and autonomy in complex weapons systems. In C. Emmert, J. Bleible, D. Busch, I. Neddermeyer (Eds), *Game of drones: Of unmanned aerial vehicles*. Neofelis, Germany.

Hocraffer, A., & Nam, C. S. (2017). A meta-analysis of human-system interfaces in unmanned aerial vehicle (uav) swarm management. *Applied Ergonomics*, *58*, 66–80. https://doi.org/10.1016/j.apergo.2016.05.011

Hoff, K. A., & Bashir, M. (2015). Trust in automation: Integrating empirical evidence on factors that influence trust. *Human Factors*, *57*(3), 407–434. https://doi.org/10.1177/0018720814547570

Hruschka, D. J., Schwartz, D., St John, D. C., Picone-Decaro, E., Jenkins, R. A., & Carey, J. W. (2004). Reliability in coding open-ended data: Lessons learned from HIV behavioral research. *Field Methods*, *16*(3), 307–331. https://doi.org/10.1177/1525822X04266540

Hussein, A., Abbass, H. (2018, October). Mixed initiative systems for human-swarm interaction: Opportunities and challenges. In *2018 2nd Annual Systems Modelling Conference*, 1–8. IEEE.

Hussein, A., Ghignone, L., Nguyen, T., Salimi, N., Nguyen, H., Wang, M., & Abbass, H. A. (2018). Towards bi-directional communication in human-swarm teaming: A survey. arXiv preprint arXiv:1803.03093.

Jensen, T., Albayram, Y., Khan, M. M. H., Buck, R., Coman, E., & Fahim, M. A. A. (2018). Initial trustworthiness perceptions of a drone system based on performance and process information. In *Proceedings of the 6th International Conference on Human-Agent Interaction* (pp 229–237). https://doi.org/10.1145/3284432.3284435

Jian, J. Y., Bisantz, A. M., & Drury, C. G. (2000). Foundations for an empirically determined scale of trust in automated systems. *International Journal of Cognitive Ergonomics*, *4*(1), 53–71. https://doi.org/10.1207/S15327566IJCE0401_04

Joyce, K. E., Anderson, K., & Bartolo, R. E. (2021). Of course we fly unmanned – We're women!. *Drones*, *5*(1), 21. https://doi.org/10.3390/drones5010021

Kaplan, A. D., Kessler, T. T., Brill, J. C., & Hancock, P. A. (2021). Trust in artificial intelligence: Meta-analytic findings. *Human Factors*, *2021*, 001872082110139. https://doi.org/10.1177/00187208211013988

Keller, D., & Rice, S. (2009). System-wide versus component-specific trust using multiple aids. *The Journal of General Psychology*, *137*(1), 114–128. https://doi.org/10.1080/00221300903266713

Kolling, A., Sycara, K., Nunnally, S., & Lewis, M. (2013). Human swarm interaction: An experimental study of two types of interaction with foraging swarms. *Journal of Human- Robot Interaction*, *2*(2), 103–129. https://doi.org/10.5898/JHRI.2.2.Kolling

Landis, J. R., & Koch, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, *33*(1), 159–174. https://doi.org/10.2307/2529310

Lee, J. D., & See, K. A. (2004). Trust in automation: Designing for appropriate reliance. *Human Factors*, *46*(1), 50–80. https://doi.org/10.1518/hfes.46.1.50_30392

McCarley, J. S., Wickens, C. D. (2005). *Human factors implications of UAVs in the national airspace*. http://www.tc.faa.gov/logistics/Grants/pdf/2004/04-G-032.pdf

McHugh, M. L. (2012) Interrater reliability: the kappa statistic. *Biochemia Medica. 22*(3), 276–282.

Merritt, S. M., Ako-Brew, A., Bryant, W. J., Staley, A., McKenna, M., Leone, A., & Shirase, L. (2019). Automation-induced complacency potential: Development and validation of a new scale. *Frontiers in Psychology*, *10*, 225. https://doi.org/10.3389/fpsyg.2019.00225

Mohammed, F., Jawhar, I., Mohamed, N., & Idries, A. (2016, April). Towards trusted and efficient UAV-based communication. In *2016 IEEE 2nd International Conference on Big Data Security on Cloud (BigDataSecurity)* (pp. 388–393). IEEE.

Muir, B. M., & Moray, N. (1996). Trust in automation 2. Experimental studies of trust and human intervention in a process control simulation. *Ergonomics*, *39*(3), 429–460. https://doi.org/10.1080/00140139608964474

Neisser, U. (1976). *Cognition and reality*. W. H. Freeman and Company.

Nelson, J., & Gorichanaz, T. (2019). Trust as an ethical value in emerging technology governance: The case of drone regulation. *Technology in Society*, *59*, 101131. https://doi.org/10.1016/j.techsoc.2019.04.007

O'Connor, C., & Joffe, H. (2020). Intercoder reliability in qualitative research: Debates and practical guidelines. *International Journal of Qualitative Methods*, *19*, 160940691989922. https://doi.org/10.1177/1609406919899220

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2008). Situation awareness, mental workload, and trust in automation: Viable, empirically supported cognitive engineering constructs. *Journal of Cognitive Engineering and Decision Making*, *2*(2), 140–160. https://doi.org/10.1518/155534308X284417

Parnell, K. J., Stanton, N. A., & Plant, K. L. (2016). Exploring the mechanisms of distraction from in-vehicle technology: The development of the PARRC model. *Safety Science*, *87*, 25–37. https://doi.org/10.1016/j.ssci.2016.03.014

Parnell, K. J., Wynne, R. A., Griffin, T. G., Plant, K. L., & Stanton, N. A. (2021). Generating design requirements for flight deck applications: Applying the perceptual cycle model to engine failures on take-off. *International Journal of Human–Computer Interaction*, *37*(7), 611–629. https://doi.org/10.1080/10447318.2021.1890488

Plant, K. L., & Stanton, N. A. (2012). Why did the pilots shut down the wrong engine? Explaining errors in context using Schema Theory and the Perceptual Cycle Model. *Safety Science*, *50*(2), 300–315. https://doi.org/10.1016/j.ssci.2011.09.005

Plant, K. L., & Stanton, N. A. (2015). The process of processing: Exploring the validity of Neisser's perceptual cycle model with accounts from critical decision-making in the cockpit. *Ergonomics*, *58*(6), 909–923. https://doi.org/10.1002/hfm.20869

Plant, K. L., & Stanton, N. A. (2016). The development of the Schema World Action Research Method (SWARM) for the elicitation of perceptual cycle data. *Theoretical Issues in Ergonomics Science*, *17*(4), 376–401. https://doi.org/10.1080/1463922X.2015.1126867

Rafferty, L. A., Stanton, N. A., & Walker, G. H. (2010). The famous five factors in teamwork: A case study of fratricide. *Ergonomics*, *53*(10), 1187–1204. https://doi.org/10.1080/00140139.2010.513450

Ramchurn, S. D., Fischer, J. E., Ikuno, Y., Wu, F., Flann, J., & Waldock, A. (2015, June). A study of human-agent collaboration for multi-UAV task allocation in dynamic environments. In *Twenty-Fourth International Joint Conference on Artificial Intelligence*.

Rogers, H., Khasawneh, A., Bertrand, J., Chalil, K. (2019, November). Understanding reliance and trust in decision aids for UAV target identification. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *63*(1), 1953–1954. SAGE Publications. https://doi.org/10.1177/1071181319631172

Ruff, H. A., Narayanan, S., & Draper, M. H. (2002). Human interaction with levels of automation and decision-aid fidelity in the supervisory control of multiple simulated unmanned air vehicles. *Presence*, *11*(4), 335–351. https://doi.org/10.1162/105474602760204264

Schaefer, K. E., Chen, J. Y., Szalma, J. L., & Hancock, P. A. (2016). A meta-analysis of factors influencing the development of trust in automation: Implications for understanding autonomy in future systems. *Human Factors*, *58*(3), 377–400.

Schranz, M., Umlauft, M., Sende, M., & Elmenreich, W. (2020). Swarm robotic behaviors and current applications. *Frontiers in Robotics and AI*, *7*, 36. https://doi.org/10.3389/frobt.2020.00036

Sheridan, T. B. (1988). Trustworthiness of command and control systems. In *Proceedings of the IFAC/IFIP/IEA/IFORS Conference on Man-Machine Systems* (pp. 427–431). Pergamon. https://doi.org/10.1016/S1474-6670(17)53945-2

Sheridan, T. B. (2019a). Individual differences in attributes of trust in automation: Measurement and application to system design. *Frontiers in Psychology*, *10*, 1117. https://doi.org/10.3389/fpsyg.2019.01117

Sheridan, T. B. (2019b). Extending three existing models to analysis of trust in automation: Signal detection, statistical parameter estimation, and model-based control. *Human Factors*, *61*(7), 1162–1170. https://doi.org/10.1177/0018720819829951

Smith, K., & Hancock, P. A. (1995). Situation awareness is adaptive, externally directed consciousness. *Human Factors*, *37*(1), 137–148. https://doi.org/10.1518/001872095779049444

Stanton, N. A. (2004). *Human factors and ergonomics methods.* CRC Press.

Stanton, N. A., Salmon, P. M., Walker, G. H., & Jenkins, D. (2009). Genotype and phenotype schemata and their role in distributed situation awareness in collaborative systems. *Theoretical Issues in Ergonomics Science*, *10*(1), 43–68. https://doi.org/10.1080/14639220802045199

Walliser, J. C., de Visser, E. J., Shaw, T. H. (2016). Application of a system-wide trust strategy when supervising multiple autonomous agents. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, *60*(1), 133–137. https://doi.org/10.1177/1541931213601031

Zimmer, T. A. (1979). The impact of Watergate on the public's trust in people and confidence in the mass media. *Social Science Quarterly*, *59*(4), 743–751.

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Appendix A. SWARM taxonomy

SCHEMA

Taxonomy subtype	Description
Vicarious past experience	Statements relating to experiencing something in the imagination through the description by another person (e.g., hearing a colleague recall an incident they were involved with) or documentation (e.g., reading about a certain event in an industry magazine or incident/accident report)
Direct past experience	Statements relating to direct personal experience of similar events or situations in the past. This covers events experienced in live, operational contexts as opposed to those experienced through training.
Trained past experience	Statements relating to knowledge developed by direct personal experience of a specific task, event or situation, experienced within the confines of a training scenario (e.g., ground school training, simulator training or training sorties)
Declarative schema	Statements relating to a schema that manifests as a descriptive knowledge of facts, usually as a product of the world information available
Analogical schema	Statements relating to comparisons between things for the purpose of explanation and clarification. Typically these analogies will be structural analogies of physical objects or states of affairs in the world (akin to mental map or mental model)
Insufficient schema	Statements relating to inadequate or lacking knowledge, i.e., a schema is not developed for a certain situation

ACTION

Taxonomy subtype	Description
Aviate	Statements relating to direct manipulation (handling) of flight controls in order that the UAV can be flown and safety is maintained
Navigate	Statements relating to the process of accurately ascertaining position and planning and following a route or desired course
Communicate	Statements relating to the sharing or exchange of information
System interaction	Statements relating to the processes of making an input into technological systems in order that the interaction or manipulation has an explicit output
System monitoring	Statements relating to looking at (observing, checking) displays to gain an understanding of the situation
Environment monitoring	Statements relating to observing or checking the internal or external physical environment in order to establish the current state-of-affairs
Concurrent diagnostic action	Statements relating to the process of determining, or attempting to determine, the cause or nature of a problem by examining the available information at the time the incident is occurring
Decision action	Statements relating to a conclusion or resolution that is reached after considering the available information
Situation assessment	Statements relating to actions that relate to the evaluation and interpretation of available information
Non-action	Statements relating to actions that were not performed, either because the situation didn't warrant a particular action or because equipment faults did not allow a particular action to be performed or because the pilot made an error or omission.
Standard Operating Procedure	Statements relating to following the prescribed procedure that ought to be routinely followed in a given situation

World – (Information)

Taxonomy subtype	Description
Natural environmental conditions	Statements about natural environmental conditions (e.g., weather, light, temperature, noise)
Technological conditions	Statements relating to the state of technological artefacts (e.g., with regards to appearance and working order)
Communicated information	Statements relating to information available to the pilot from other people (e.g., other crew members, ATC, coastguard etc.)
Location	Statements relating to particular places or positions
Artefacts	Statements discussing physical objects, including written information, symbols, diagrams or equipment
Display indications	Statements relating to the information elicited from the physical artefacts
Operational context	Statements relating to the routine functions or activities of the organisation (e.g., Search and Rescue, Police search, military training etc.). This can include statements about the importance of being serviceable for the operational context or crew familiarity with the aircraft and how this effects decision making.
UAV status	Statements relating to the current status of the aircraft's integrity or performance (e.g., how good or bad it is flying, the current configuration of the aircraft, autopilot activation etc.)
Severity of problem	Statements relating to how bad (or otherwise) the critical incident is
Physical cues	Statements relating to external cues that provide information of conditions
Absent information	Statements relating to information that was missing, not present or lacking.

Appendix B. Interview prompts

Please describe a recent, or typical, scenario in which you operate a UAV, e.g., environment, UAV type, operation aim. This scenario will form the basis of the interview.

EXPERIENCE (Schema) prompts – Questions relating to experience and knowledge.

Schema themes	Prompts
Direct past experience. Trained past experience Trust Experience of trust in UAVs	• Is the situation comfortably within your experience? • What (if any) training would you utilise? PAST EXPERIENCE • Can you recall a point in this situation when you did not trust the UAV? ○ Please expand on this situation and why you did not trust it CURRENT EXPERIENCE • Would you generally tend to trust the UAV? ○ Please expand on why this is • Do you have any distrust in the UAV? ○ What is the cause of this distrust? ○ How do you think this distrust could be repaired? • Would you be wary or suspicious of the UAV at all? ○ At which points in an operation would this be? FUTURE EXPECTATIONS • Would you have any reason not to trust to UAV in the future? • How reliable/dependable do you view the UAV to be?

INFORMATION (World) Prompts – Questions relating to information obtained from the environment surrounding the activity.

World themes	Prompts
Natural environmental conditions	• What information from the natural environment could you utilise? (e.g., weather, time of day) ○ How and where would you get this information? ○ What could this information tell you?
Technological conditions	• What information from the technological system(s) could you utilise? ○ How and where would you get this information? ○ What could the technological information tell you?
Communicated information	• Would you receive information from others? (If yes, what) ○ How could you receive this information? ○ What could the communicated information tell you?
Location	• Where would you be located? • Where is the UAV located? • Is there information about location that you would you use to assist you?
Artefacts	• What artefacts would you have available to you? (e.g., physical objects, equipment, written documents, etc.) ○ Would you use any of these to inform your decision making?
Display indications	• What would possible display indications tell you? ○ And what would that look like?
UAV status	• Would you be concerned about the status of the UAV? • Would you ever be uncertain about the reliability or relevance of the information that you had available to you? • How would you know if the UAV has become unreachable? ○ How would this effect your trust in the UAV? ○ What information would you need to trust the UAV in this situation?
Physical cues	• Would there be any physical cues available to you? (e.g., sounds, smells, sights)
Absent information	• Would there be any other information that you would like available to assist you, that you otherwise would not have? (If yes, what?)
Trust	• What information/knowledge would you need to trust the UAV? • Could there be any deceptive information? • What information would you need to repair any lost trust in the UAV?

ACTION Prompts – Questions relating to actions taken.

Action themes	Prompts
Physical actions	• What physical actions would you take? ◦ What information (mental and/or physical) would you use to assist with your physical actions?
Navigate	• Would you take any navigational actions? ◦ What information (mental and/or physical) would you use to help you navigate?
Communicate	• Would you communicate with anyone? (If yes, who to / what was communicated?)
System interaction	• What inputs would you make into the technological system?
System monitoring	• In relation to the technological system, what would you be looking at (observing or checking) during the event? • Would there be a particular time when you make more or less system monitoring actions? (If yes, why)?
Environment monitoring	• In relation to the physical environment, what would you looking at (observing or checking)? • Would there a particular time when you make more or less environment monitoring actions? (If yes, why)?
Decision action	• What would be the key decisions?
Situation assessment	• How would you assess the situation? • How would you evaluate and interpret the available information to you?
Standard Operating Procedure (SOP)	• Do you follow known standard operating procedures (or conventions or rules)? (if yes, what? If no, why not?)
Trust	• What actions would you be relying on the UAV for? And why? • What actions would you **not** be relying on a UAV for? And why? • How easy would it be to trust the UAV to do their job? • How could your trust in the UAV change over the course of the operation? • Could there be any negative outcomes? ◦ And how would this effect your trust in the UAV for the future?