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Publication date
2023

Document Version
Final published version

Citation (APA)
Zou, Y., & Borst, C. (2023). *Investigating Transparency Needs for Supervising Unmanned Air Traffic Management Systems*. Paper presented at 13th SESAR Innovation Days, Sevilla, Spain.

Investigating Transparency Needs for Supervising Unmanned Air Traffic Management Systems

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***Abstract*—To facilitate a smooth integration of drones into the current Air Traffic Management (ATM) system, Unmanned Air Traffic Management (UTM) systems, services and protocols are currently under development. Unlike current ATM, UTM will rely on high levels of automation. This is potentially problematic, because 100% safe and reliable automation under all circumstances cannot be guaranteed. UTM therefore warrants human supervision and interaction, especially at small airports near urban areas where drone traffic may cross the arrival and departure routes of manned air traffic. Supervision, however, requires some form of transparency for humans to understand the limitations and the behavior of an automated system (e.g., what is it currently doing, what it is planning to do next, and why?). Previous research underlined the importance of UTM transparency, but also indicated that it remains unclear what type of human operator will eventually supervise the UTM system. The background, training and expertise of a human operator may impact the transparency needs and what information needs to be communicated and when. In this paper, the results of a questionnaire-based user study are presented in which information needs were collected from twelve operational Air Traffic Controllers and twelve drone operators and engineers. Results indicate that transparency is deemed imperative for UTM and that information elements categorized as 'operational transparency' are typically preferable over 'engineering transparency' elements, regardless of operator group. Surprisingly, we found no significant difference in transparency needs between controllers and drone operators, suggesting that a 'one-size-fits-all' transparency solution for UTM would be possible.**

***Keywords*—Unmanned air traffic management; Transparency needs; Operational transparency; Engineering transparency; User study; Air traffic controllers; Drone operators**

I. INTRODUCTION

In recent years, drone usage has rapidly increased in various domains, such as agriculture, delivery, surveillance and entertainment. It is expected that a large number of drones will share the airspace with manned aircraft in the (near) future [1], [2]. To safely cope with the increased number of drones, Unmanned Air Traffic Management (UTM) was proposed and is currently under development [3], [4]. Numerous projects have been launched to investigate various scientific and engineering challenges for UTM, such as Metropolis 2 [5] and AURA [6]. Different from the traditional Air Traffic Management (ATM) system, UTM will be built from the ground up to rely on high levels of automation. However, this is potentially problematic since it is impossible to guarantee 100% safe and reliable automation under all circumstances. To maximize safety, UTM still necessitates human supervision and interaction to address situations beyond the capabilities of automation. To facilitate operators in gaining a comprehensive understanding of automation's behaviors and limitations, research suggests that more 'seeing-into' transparency is needed that presents information and/or explanations about the inputs, outputs and internal processes of automated systems [7], [8].

Some research has been committed to developing human-machine interfaces aimed at assisting operators in overseeing UTM operations [6], [9]. Their results indicated that operators preferred to receive more transparency information to understand drone behaviors (e.g., why Path A rather than Path B) and also that UTM supervision may not be appropriate for air traffic controllers (ATCos) to perform besides their regular air traffic control (ATC) task [10]. A dedicated UTM supervisor may be required, and this role does not have to be a trained and licensed ATCo and could be someone more familiar with drone operations, like a drone pilot or a drone engineer. As indicated by the MAHALO project [11] and the explainable AI (XAI) community [12], transparency needs may vary among distinct individuals and user categories. Similarly, the different professional backgrounds of ATCos and drone operators may also impact their transparency needs for the UTM system. Therefore, this research attempted to collect the needs of ATCos and drone operators for supervising the UTM system via a questionnaire-based user study, in which twelve professional ATCos and twelve drone operators participated.

This research primarily centers on UTM in controlled traffic regions (CTR) around (small) airports [6], [9], in particular Rotterdam The Hague Airport[1]. Participants were made aware that the main task of a UTM supervisor is to avoid losses of separation between drones and manned aircraft and that a centralized (time-)optimal conflict-free path-planning algorithm will be responsible for drone rerouting (path-finding-based conflict resolution service), while operators would also have ways to directly interact with the algorithm to influence drone routes. The focus of this investigation was to explore what information operators want to know about the automated

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[1] Demo available at URL: http://dronectr.tudelft.nl/, ID: demo

path-finding conflict resolution service. The findings may not only provide guidance for the UTM community, but may also benefit XAI [13] and explainable path planning [14] in general.

II. TRANSPARENCY TAXONOMY FOR UTM

To investigate the transparency needs of operators, offering a pre-defined template as inspiration may be more effective than directly inquiring their preferences, especially when most ATCos and drone operators are not yet very familiar with UTM. However, a biased template can potentially misguide operators, resulting in the acquisition of incomplete demands. Therefore, in preparation for this investigation, it was deemed imperative to first devise a *transparency taxonomy* that encompasses a wide spectrum of transparency information.

A. *Transparency in ATM*

To promote the applications of AI in ATM, SESAR 3 Joint Undertaking initiated 15 projects [15] that addressed all phases of flight from strategic and pre-tactical planning to tactical operations. The most relevant projects for our use case in tactical operations are ARTIMATION [16], MAHALO [11] and TAPAS [17].

ARTIMATION proposed three levels of transparency: 1) Black Box, 2) Heat Map and 3) Storytelling. The Black Box level showed only the proposed solution along with the instructions for execution. The Heat Map level presented what was explored by the algorithm (explored trajectories) and whether it was good or bad. The Storytelling level provided a step-by-step preview of the proposed solution while also explaining alternative possibilities.

MAHALO devised three transparency conditions: 1) Vector Line, 2) Vector Line and Solution Space Diagram (SSD) and 3) Vector Line, SSD and text-based explanation. The vector line, indicating flight speed and heading, represented the proposed solution for conflict resolution. The text-based explanation clarified the target Closest Point of Approach (CPA) and the agent's purpose. The core of MAHALO is SSD, which could *visually* explain whether the proposed solution is feasible and how robust it is.

TAPAS did not have different transparency levels in their Conflict Detection & Resolution (CD&R) use case. It mainly utilized text-based tables to present detailed information and possible solutions associated with CD&R, such as start time of conflicts, severity score and horizontal/vertical rate of closure.

To summarize, these projects all had different perspectives on addressing the same problem (i.e., CD&R in ATC). Each of them developed its unique transparency elements, covering different visual and textual parameters representing the tactical ATM context. Nonetheless, some similarities were found in that they all center transparency information around *solutions*, revealing information about the proposed solution (e.g., planned actions) and the expected outcomes (e.g., predicted minimum separation). To devise a more generic transparency taxonomy, we will briefly review the perspectives on automation transparency from other fields.

B. *Perspectives on Transparency*

Automation transparency has also emerged across other various fields, giving rise to three main perspectives: *user-centered* [18], [19], *model-centered* [20], [21] and *ecology-centered* [22] perspectives. From a user-centered perspective, transparency information should be presented in accordance with user demands, limitations, preferences and needs. To avoid overwhelming users, transparency is generally divided into different levels, enabling a progressive and incremental disclosure of information [19]. For example, Situation Awareness–based Agent Transparency (SAT) model [18] contains three levels: Basic Information (Level 1), Rationale (Level 2) and Outcomes (Level 3). In practice, these levels are usually combined in visual and/or textual presentations. However, the information revealed by the SAT model might be insufficient in some cases, because the agent's internal process (i.e., *how* the agent make decisions) is not explicitly reflected in the SAT model.

The model-centered approaches are mostly developed in the XAI community, aiming to construct explainable models that are readily comprehensible to humans, such as Shapley Additive Explanations (SHAP) [20] and explainable Reinforcement Learning (RL) via reward decomposition [23]. The main focus is to thoroughly dissect the internal processes of the models and attempt to explain them in human-understandable terms. From this perspective, the internal processes of the automated UTM services (e.g., path-finding algorithms) should probably also be presented to operators, such as cost function/values and computational/search process.

The ecology-centered approach puts emphasis on visualizing the (physical and intentional) constraints governing the work domain, intuitively revealing its deep structure for achieving *domain* transparency [22], [24]. It aims to provide a common ground for user-centered and model-centered approaches since both humans and machines should obey the same domain constraints. By incorporating the ecology-centered approach, operators could gain more insights into *solution spaces*, enabling a clearer understanding of the feasibility and robustness of solutions as well as serving as input/output feature spaces for human intervention.

C. *Proposed Transparency Taxonomy*

In summary, considering the information discussed above, we propose a unified transparency taxonomy as shown in Figure 1. Referring to the EASA AI Roadmap in Aviation [25], we integrated two fundamental concepts related to transparency: *operational* transparency and *engineering* transparency. Operational transparency reveals the information that *directly* supports operators to understand the situation with the appropriate level of detail at the appropriate time: *what* the situation is. In contrast, engineering transparency deals with the algorithmic information that supports operators to understand the inner mechanism of the system: *how* the system works. The taxonomy contains seven categories. From the Solution category towards the Computational Process category, deeper (algorithmic) information is progressively disclosed.

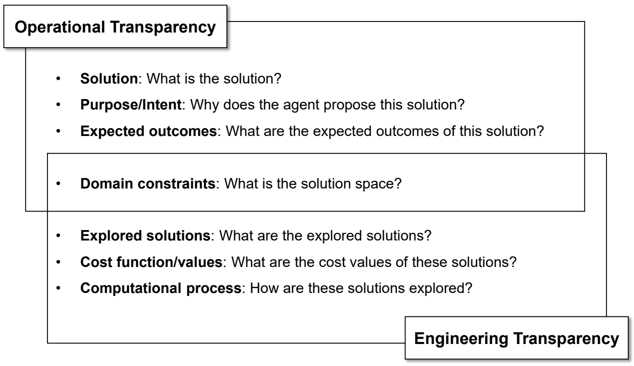


Figure 1. Proposed unified taxonomy for algorithmic transparency.

Transparency Category	MAHALO	TAPAS	ARTIMATION
Solution	●	●	🔴
Purpose/Intent	●	○	○
Expected outcomes	○	🔴	●
Domain constraints	🔴	○	○
Explored solutions		●	●
Cost function/values			
Computational process			

○ Implicit ● Explicit 🔴 Focus

Figure 2. Mapping several SESAR projects onto the transparency taxonomy.

The Domain Constraints category lies at the intersection, forming solution spaces to explain the feasibility and robustness of solutions (operational) and also serving as a basis for system computation (engineering). Please note that the transparency category is not entirely equivalent to the transparency level. A level may contain elements from one or more categories.

Based on the unified taxonomy, the SESAR projects discussed above can also be summarized, as shown in Figure 2. MAHALO mainly focuses on the SSD which reveals the domain constraints, while TAPAS proposes many indicators related to the expected outcomes, such as severity scores and compliance measures. ARTIMATION centers around solutions, which not only provides the instructions (Black Box), but also presents a step-by-step preview by a sequence of images (Storytelling). Some transparency information is not explicitly stated in the projects, but can be inferred from other contextual cues. The Cost Function/Values and Computational Process are not represented by any of the considered projects. This can be attributed to the fact that ATCos do not always have an engineering background and their (extensive) operational experience make ATCos pay more attention to the information directly associated with maintaining their own situation awareness. However, UTM is a completely new system and provides highly automated services to handle drones with diverse types and capabilities. As such, UTM operators may therefore require insights into the internal processes, especially in cases where issues arise (e.g., automation failures).

III. METHODOLOGY

A. *Overview*

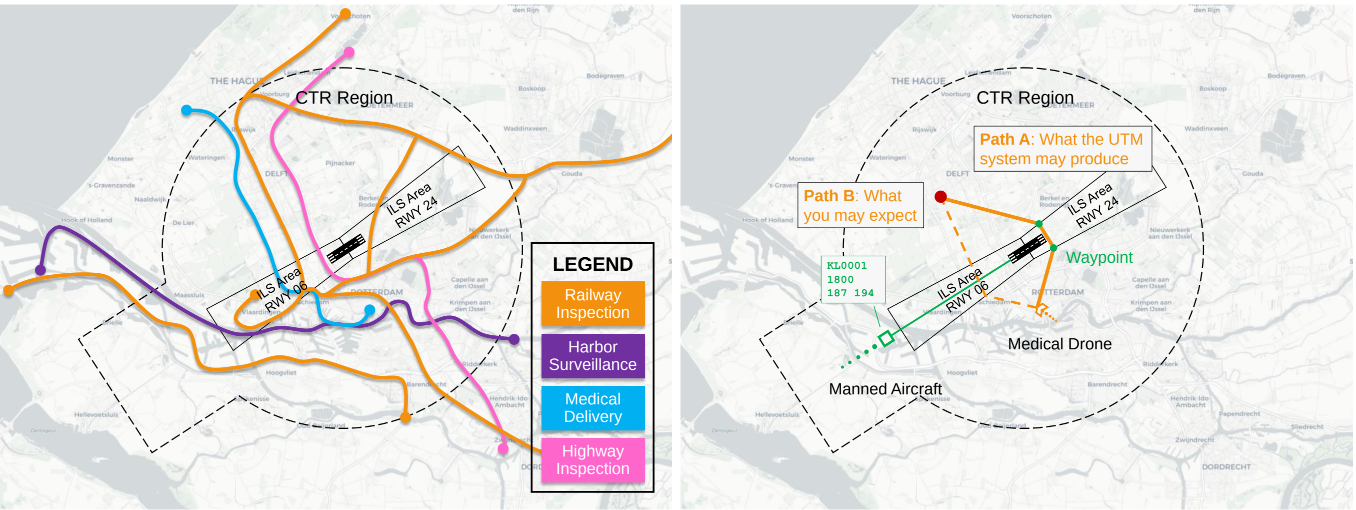
The main goal of this research is to investigate the transparency needs of operators for supervising the UTM system. We have formulated three central research questions:

- **RQ1**: What transparency information do operators prefer and how does that depend on the situation?
- **RQ2**: How do operators group transparency information?
- **RQ3**: What differences exist in transparency needs between ATCos and drone operators?

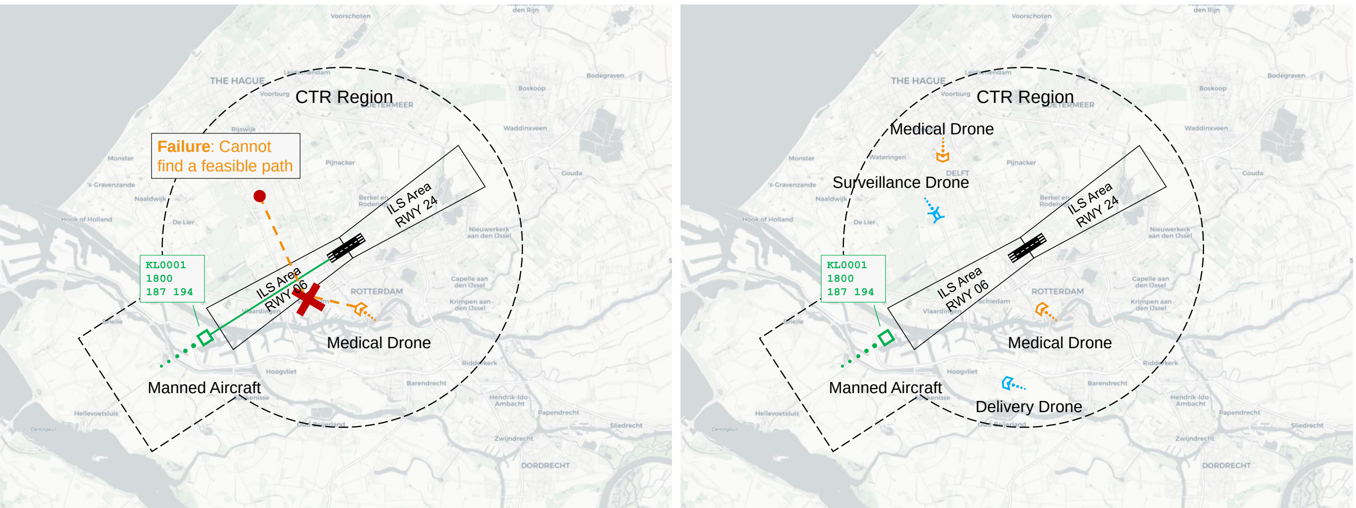
Based on these research questions, an online questionnaire targeted specifically at ATCos and drone operators was designed for the investigation. At the start of the questionnaire, considering ATCos and drone operators may have different visions for future UTM operational concepts, a detailed illustration regarding the background and hypothetical operational concept was provided to participants. Given the primary focus on UTM in the CTR, Rotterdam-The Hague Airport was selected as a use case. The potential drone applications in the airport's vicinity, such as railway and highway inspection and medical delivery, are illustrated in Figure 3a. Three distinct hypothetical scenarios, as depicted in Figure 3b-3d, were presented to stimulate participants' thoughts: a simple scenario encompassing only a single drone, a failure scenario entailing an automation failure case and a complex scenario involving multiple drones. For the simple and failure scenarios, a trajectory-contrastive question and a failure question [26], [27] were provided for further inspiration: 1) why path A rather than path B, and 2) why the system fails. For the complex scenario, time pressure issues will be more salient [16] and the usefulness of transparency information for supervision might be different. Some personal information was collected to help classify participants into two groups for data analysis: ATCos and drone operators (RQ3).

To answer RQ1 and RQ2, two main parts were integrated into the questionnaire. In the first part, 20 candidate transparency elements derived from the unified taxonomy were presented as response options, with their order being randomized. Participants were asked to rate the elements using a 5-point Likert scale according to their perceived usefulness for understanding and supervising the automated UTM conflict resolution service. Participants were told that the conflict resolution service was based on a conflict-free path-planning algorithm. Open-ended questions were also present to inquire the reasoning behind their ratings. The second part of the questionnaire aimed to investigate how participants proposed to group transparency elements that belonged together in their opinion. This could also offer valuable insights into how to establish transparency models: what transparency categories or elements should be connected and/or presented together in practice. The questionnaire ended with some general opinions on a transparent UTM system in terms of importance, additional workload and acceptance concerns.

Considering that each participant may have his or her own groups of transparency elements (RQ2), we employ a



(a) Potential Applications (b) Simple Scenario



(c) Failure Scenario (d) Complex Scenario

Figure 3. Schematic diagrams for operational scenarios.

weighted adjacency matrix to summarize their preferences. The weight here refers to the number of times two elements are divided into the same group. Then, based on this adjacency matrix, a weighted graph can be constructed to visually depict the interconnections among various transparency elements. Finally, to group these elements (i.e., the vertices of the weighted graph), the Walktrap community detection algorithm [28] will be applied, as illustrated in Figure 4.

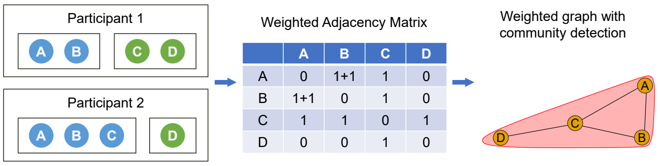


Figure 4. Data processing of the grouped transparency elements

B. *Transparency Elements*

The primary task of the questionnaire was to ask participants to rank, rate or group the proposed transparency elements in different situations. Moreover, participants were encouraged to put forth new elements as well if deemed necessary. Following the transparency taxonomy outlined in Figure 1, a total of 20 transparency elements have been proposed for assisting the supervision of the automated UTM path-finding conflict resolution service, as shown in Table I.

In terms of operational transparency, the Solution category contains two elements: the old path and the proposed (new) path. The old path is the path the drone followed before rerouting, which hints at why the drone needed to reroute in the first place (e.g., due to a conflict). A path is essentially built from a sequence of states and actions. To gain a deeper understanding of the proposed path (solution), the estimated states and planned actions should be clearly revealed (e.g., where certain heading changes will take place). The Purpose/Intent category

TABLE I. PROPOSED TRANSPARENCY ELEMENTS.

Transparency Category	Transparency Element
Solution	The proposed (new) path and old path Estimated state and planned action (e.g., heading change) at each waypoint
Purpose/Intent	The underlying goals and intentions of the system (e.g., minimizing flown track miles)
Expected outcomes	If the drone follows the old path • Predicted location of separation loss • Predicted start time of separation loss • Predicted minimum separation • Predicted probability of separation loss If the drone follows the proposed (new) path • Predicted location of CPA • Predicted time to CPA • Predicted minimum separation • Predicted probability of separation loss
Domain constraints	Safe separation standards between aircraft **Maneuvering space**: the flight range governed by battery power and environmental conditions **Flight mission boundary**: certain drones can only fly within a pre-approved area **Wind field**: wind speed and direction
Explored solutions	**Search graph**: a search graph is how automation discretizes a continuous space, and the generated path can only follow the edges of the graph **Explored nodes**: explored potential waypoints **Search trees**: explored potential paths
Cost function/values	The cost values of the explored potential paths given the system's goals and intentions
Computational process	**Search process**: a dynamic process that indicates how to generate the path

can be presented by text-based explanations. In this case, the path generated by the UTM system aims to be time-optimal and conflict-free. For the Expected Outcomes category, two different situations are considered: following the old path and the proposed (new) path. To observe the outcomes of the paths, four metrics were proposed based on the considered SESAR projects: predicted location of separation loss (and predicted location of CPA), predicted start time of separation loss (and predicted time to CPA), predicted minimum separation and predicted probability of separation loss. Regarding the Domain Constraints, a range of restrictions linked to drone endurance and no-fly zones, such as drone maneuvering space and flight mission boundary, were presented. The wind field was also incorporated since drones are susceptible to wind.

In terms of engineering transparency, the domain constraints, such as the maneuvering space, limit the search space of path planning, explaining why the system only searches within a certain range. At the Explored Solutions category, three elements were proposed: search graphs, explored nodes and search trees. These three elements can also be simultaneously showcased to convey information that is more meaningful and integrated. The cost function/value is somewhat similar to the expected outcomes, with both utilizing specific metrics for computation. However, the cost function represents the goals of the system, while the outcomes are future projections of the solution. The cost function in this study optimizes only a subset of factors, such as flight efficiency (time-optimal), without considering environmental uncertainty (e.g., optimizing for robustness). The Computational Process category reveals the algorithm's dynamic search process (can be achieved through animation), providing more details about the algorithm's expansion of search nodes and search trees.

C. *Participants*

A total of 24 operators from Europe and China volunteered to participate in this survey of which 12 were licensed ATCos (e.g., Rotterdam and Shanghai controllers) and 12 were drone operators (e.g., drone researchers from TU Delft and drone pilots from companies). Their experience in ATC and drone operations is summarized in Figure 5. A participant who serves as both an ATCo and a drone operator was classified as an ATCo in this survey. Drone engineers are also considered as drone operators since they have extensive knowledge of drone operations and often perform flight tests for their drones.

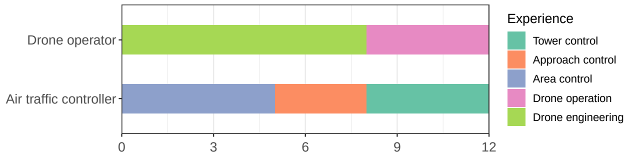


Figure 5. Participants' experience in air traffic control and drone operations.

IV. RESULTS

A. *Preferred Transparency (RQ1 and RQ3)*

The Likert scale ratings for the proposed transparency elements are shown in Figure 6. In general, all proposed elements were considered valuable for supervising the UTM system, although some of them may have limited utility in some scenarios. For a clear comparison, average ratings for operational and engineering transparency in different scenarios have been computed, as shown in Figure 7.

Operational and Engineering Transparency. Wilcoxon Signed-Rank tests found significant differences between operational and engineering transparency in both ATCo ($V = 544, p < 0.001$) and drone operator ($V = 493.5, p = 0.004$) groups. In contrast to operational transparency, engineering transparency is considered less useful, as expressed by an ATCo: "*I need it to tell me why it gives this route and the disadvantage of this route. I don't think how it finds this route is useful*". Drone operators had similar views: "*I would be most interested in knowing when, where and how the conflict might occur from the system's point of view … I need to access objective metrics which I can verify the goodness of the proposals. I do not want to be bothered by the inner workings of the system (e.g. how the search is conducted) since I feel it may be an information overload.*" These arguments are consistent with the SESAR projects reviewed in this paper, which focuses on the goals and intentions of the system and the expected outcomes of the solution. Additionally, a drone operator remarked: "*It has to be simple during actual*

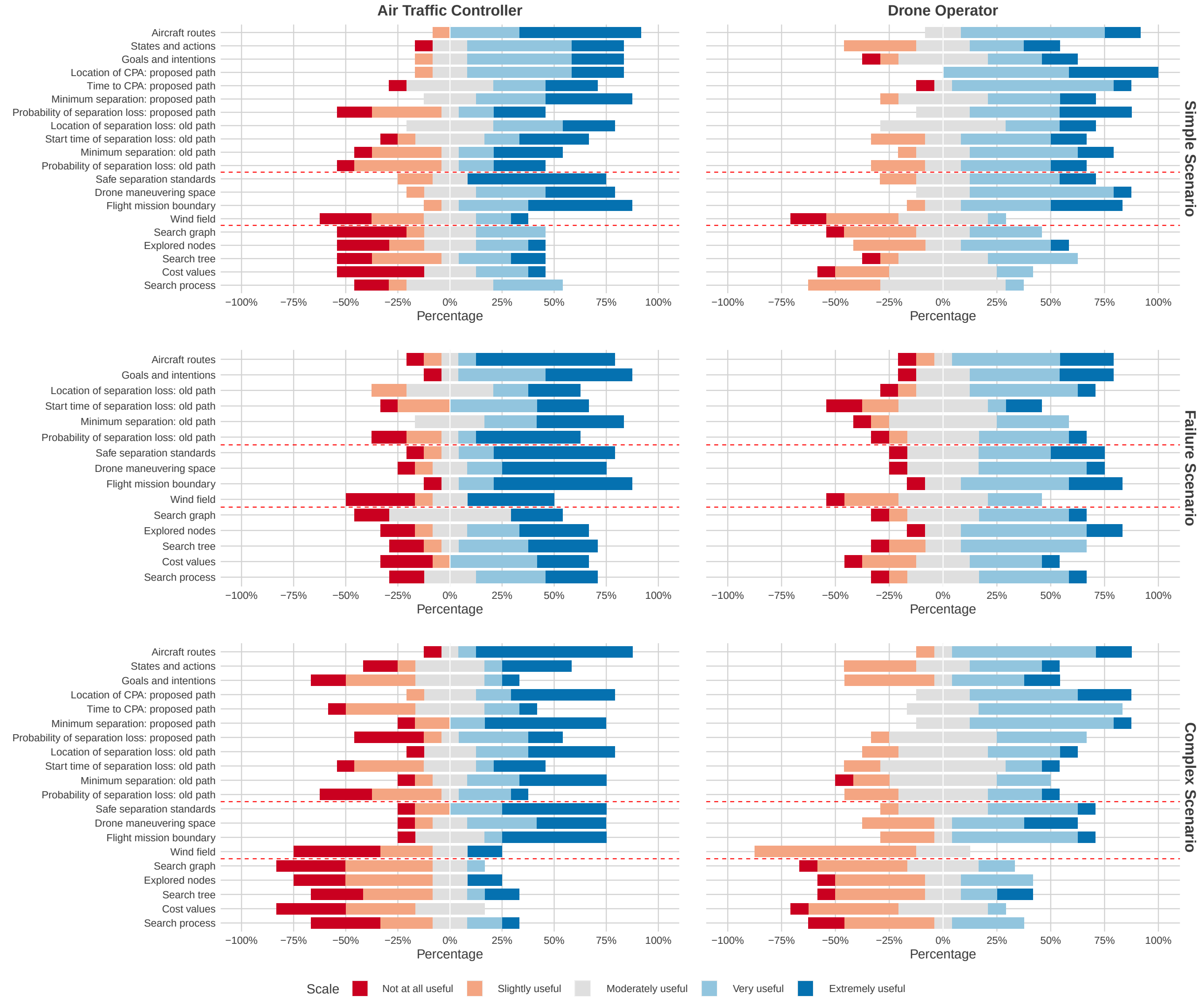


Figure 6. Likert scale ratings for the proposed transparency elements. The red dashed lines denote the operational, domain and engineering transparency categories. The transparency elements from the ”Solution” category are absent in the failure scenario because there is no solution in this case.

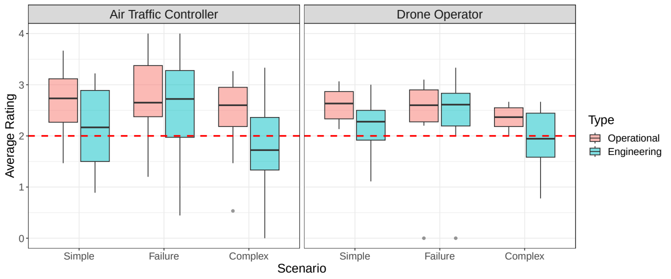


Figure 7. Average ratings for operational and engineering transparency based on “Not at all useful = 0” to “Extremely useful = 4”.

operations … the operational environment might be over engineered - these items should be more of things to revisit in hindsight”. Interestingly, we did not mention the concepts of operational and engineering transparency in the questionnaire, but judging from the results, participants seemed to distinguish between them very well.

The operational transparency encompasses two distinct categories of expected outcomes: one pertaining to the proposed path and the other to the old path. A drone operator suggested that “*a really simple table was needed to compare the main elements of two paths*”. This comment shares similarities with the TAPAS project which also utilizes tables to present various metrics. The expected outcomes of the old path are also considered relatively less useful. One expressed it as follows: “*I think the old path is not necessary for avoidance. The current states of both manned and unmanned aircraft and their predicted paths are more important*”. Another drone operator also remarked: “*The predicted states based on the proposed path matters more than the old path*”. This is probably because the proposed path is more relevant to the current situation.

As for the domain constraints, although a drone operator pointed out that "*Large wind or stormy weather will create critical situations for aircraft, especially drones*", the wind field is generally considered least useless compared to other constraints. A possible reason is that the wind field only presents basic environmental information, which is not directly associated with the goals of operators. It might be more effective to introduce no-fly zones determined by wind conditions, taking into account both wind speed and drone performance. In other words, presenting wind information in terms of how it impacts drones is considered more useful than simply presenting the wind condition itself.

Failure and Complex Scenarios. Friedman tests revealed significant differences among conditions (Three Scenarios × Two Transparency Types) in the ATCo group ($\chi^2(5) = 23.002, p < 0.001$), but no such differences were observed in the drone operator group. For the ATCo group, pairwise comparisons [29] (with Bonferoni correction) further revealed that the "Complex-Engineering" condition was significantly different from the "Simple-Operational" ($D = 33.5, p = 0.002$), "Failure-Operational" ($D = 35.0, p = 0.001$) and "Failure-Engineering" ($D = 30.5, p = 0.009$) conditions. It seemed that the failure and complex scenarios were distinctive.

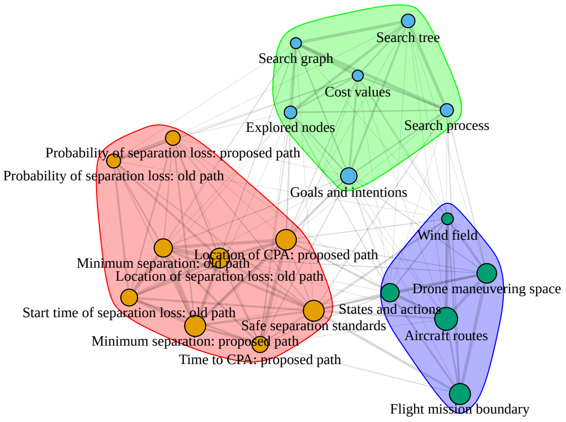
In the failure scenario, engineering transparency becomes more useful since operators need more information about the system's internal process to figure out what is going on inside the system. The information concerning constraints could be particularly helpful: "*If there's no good solution, this should come from some limitations from the dynamics of drones*". "*The waypoints, maneuvering space, and boundaries are the key to finding the desired path*". Actually, some operators indicated, "*that everything allowing to understand why the system fails is useful*". However, it is worth noting that the occurrence of failure scenarios should be minimized as much as possible. *Robustness* was repeatedly mentioned as one of the crucial factors influencing their acceptance of a highly automated UTM system. One operator stated, "*If there is no feasible path, it should never cross a route with manned traffic*". In the complex scenario, engineering transparency is relatively less useful, because "*too much information could overwhelm operators*." One respondent suggested that "*it is more important to only look at the conclusive information*". The transparency information indirectly related to safety and/or the situation should probably be hidden in the first place.

ATCos and Drone Operators. Generally, the needs for different types of transparency were found to be similar between ATCos and drone operators. Mann-Whitney U tests did not reveal any significant difference between the two operator groups. However, as evident from the figures, some minor distinctions still exist on specific elements. Among the four metrics indicating the expected outcomes, the probability of separation loss is found to be favorable by drone operators: "*I may pay more attention to … the predicted probability of separation loss*." The probability would indicate the uncertainties of the system. If the system's confidence in resolving the conflict is not high enough, operators may be required to intervene in the system. However, as one ATCo stated, "*ATC does not control considering probability*". Also, another ATCo expressed: "*To some extent, probability may not represent its level of danger very well. If I realized the separation was not enough, I thought my priority was to increase the separation to prevent it, not just to compare the probability*". In fact, the automated conflict resolution service should be robust enough to reduce the probability of separation loss to 'zero' in most cases. When the probability is not zero, the system should provide some additional explanations to indicate its limitations. For example, changes in wind conditions could lead to variations in flight duration, thereby increasing the probability of separation loss and triggering new conflicts. Furthermore, ATCos also emphasize the transparency information regarding predicted locations of separation loss and CPA and predicted minimum separation. As mentioned by an ATCo, "*Two elements are of utmost importance: which location will the separation loss be and to which location does it shift when a new route is proposed*." This preference can be clearly observed in the complex scenario (see Figure 6).

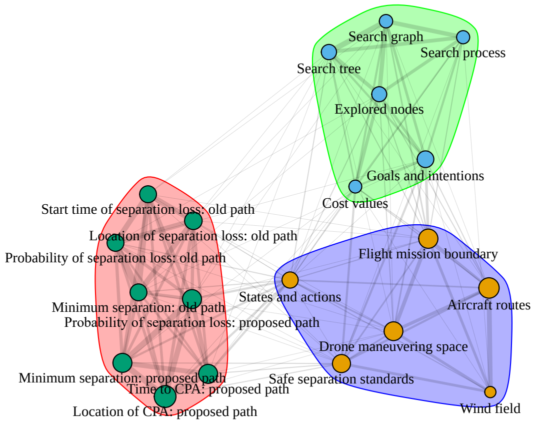
As shown in Figure 6 and 7, there is a notable discrepancy in the variance of ratings between ATCos and drone operators. It appears that ATCos tend to be more outspoken and strongly opinionated, often expressing their views at either end of Likert scales. There also seems to be a disagreement among ATCos, resulting in the increased variance. This phenomenon mainly exists within the tower and area controller groups. In contrast, drone operators tend to hold more conservative views, leaning toward the neutral side. There appears to be more consensus among drone operators. Since the sample size is not large, more data need to be collected to verify this observation.

B. Grouped Transparency (RQ2 and RQ3)

Based on the weighted adjacency matrix and the Walktrap community detection algorithm, the correlations between the proposed transparency elements can be computed, as shown in Figure 8. Both ATCos and drone operators categorize the proposed transparency elements into three groups. The classification of elements by drone operators is almost the same as that by ATCos. The sole distinction lies in how the safe separation standard is allocated: for ATCos, it is associated with the expected outcomes (red group) whereas for drone operators, it is linked to domain constraints and solutions (purple group). This is possibly because the goal of ATCos is to ensure that the outcomes meet the established separation standards. The safe separation can be regarded as a baseline or minimum requirement for the outcomes, which is very often presented in ATC decision-support tools. In the green group, the goals and intentions are closely connected to the cost values since cost functions should typically be designed in accordance with goals. In summary, the groups classified by operators can be labeled as follows: Expected Outcomes (red), Solution & Solution Space (purple) and Internal Process (green). This can be viewed as a more condensed variant of our proposed taxonomy. The correlations among the proposed



(a) Air Traffic Controller



(b) Drone Operator

Figure 8. The correlations between the proposed transparency elements. The vertex size corresponds to the average rating.

transparency elements can provide guidance and reference for further devising transparency levels and models, as they illustrate which elements operators prefer to see concurrently for understanding and supervision.

C. *General Opinions on Transparency*

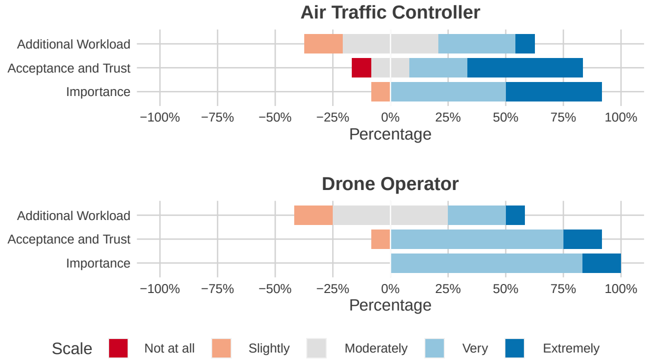


Figure 9. General opinions on transparency.

The general opinions of operators on transparency are presented in Figure 9. Most operators believed that transparency plays an important role in supervising the UTM system and will significantly influence their level of acceptance and trust. One ATCo held the view that transparency would not affect acceptance at all, because his/her main concern was around the number of aircraft in flight. One drone operator believed that transparency will have a slight impact on trust, because he/she would trust the UTM system overall once it will be fully operational. The additional workload that transparency could bring is considered to be relatively manageable. Over half of the operators thought that the additional workload would not be very high. This result should be interpreted with care, because this study did not feature a real-time, interactive human-in-the-loop simulation with dynamic traffic situations. As such, conclusions about transparency-induced workload warrants further research.

V. CONCLUSION

In this paper, we conducted a questionnaire-based user study to investigate the transparency needs of ATCos and drone operators for supervising the UTM system. A unified transparency taxonomy, covering operational and engineering transparency, was proposed, which formed the basis for twenty transparency elements that needed to be rated and grouped. The results indicate that the transparency needs between ATCos and drone operators are quite similar. Both suggest that the transparency elements associated with operational transparency are more useful compared to engineering transparency. The operators' grouping of the transparency elements is similar to the proposed transparency taxonomy, which could serve as a valuable reference for the future development of transparency models.

This research is the first step toward achieving transparency in UTM. To prevent any potential bias in operators' results caused by exposure to visual prototypes, we only provided textual descriptions of the proposed transparency elements in the questionnaire. The results reflect the original and natural opinions of ATCos and drone operators. Next, we will develop corresponding interface prototypes and further test the transparency needs and usefulness in both static and dynamic scenarios.

ACKNOWLEDGMENT

The authors would like to thank the financial support from the China Scholarship Council (CSC) No. 202106830036 and all respondents for their participation in this study.

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