From Emergence to Acceptance: Towards a Technology Acceptance Model for an Autonomous Large Modifiable Underwater Mothership (MUM)

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***Abstract* — Autonomous systems are seen as transformative across industries. In the maritime domain, they offer potential to extend operational reach and address personnel shortages. Still in development, the Large Modifiable Underwater Mothership (MUM) is a unique innovation in this field. While it holds great promise, its successful implementation depends not only on technical and legal feasibility, but also on operator acceptance. Without understanding the factors that influence acceptance, even advanced systems risk limited adoption. While user acceptance has been studied, research on the specific challenges of autonomous maritime systems (AMS) like MUM remains scarce. This conceptual article explores the factors influencing operator acceptance to identify the requirements for successful implementation. Drawing on qualitative interviews with potential operators, it proposes an adapted Technology Acceptance Model (TAM) tailored to the MUM**

Keywords—autonomous maritime systems, technology acceptance model, operator acceptance

I. Introduction

Developed through industry-academia collaboration, the Large Modifiable Underwater Mothership (MUM) introduces a modular, autonomous vehicle class for civilian use in offshore energy, marine research, and deep-sea mining [1]. Its unique features and ability to operate both on the surface and underwater enables the exploration of high-risk environments and remote areas, such as Arctic ice zones. Currently in the development stage, the MUM is set to become a market product in near future. As an emergent technology it introduces both opportunities and uncertainties in its practical implementation. The advent of the MUM could revolutionise underwater operations, reducing human risk and increasing efficiency. At the same time, new questions arise regarding the monitoring of the vessel with high latencies, and safety concerns due to the uncrewed operation of the system. While technical feasibility and legal frameworks are essential for the adoption of MUM, the diffusion of the technology is ultimately determined by the acceptance of its future users. This leads to the questions: Which factors will determine the acceptance of this emergent technology, and what requirements must be met to make the MUM acceptable to potential operators? This paper will focus on the first question, providing a basis to address the second.

II. Assessment of Technology Acceptance

The examination of user acceptance originally relies on quantitative methods and standardised models. The analysis varies depending on the technology in question, the stakeholders under consideration, and the definition of acceptance, e.g., as general approval or willingness to use. Among the existing models, Davis' Technology Acceptance Model (TAM) [2] is the most established framework for assessing technology acceptance. It has been further developed by various researchers, extending its applicability from generic technologies to intelligent and autonomous systems, such as [3, 4, 5]. As shown in *Figure 1* the model assumes design features of a technology as external stimuli, triggering a cognitive response in the potential user. This internal evaluation involves the users' judgments regarding how much the system can enhance their performance and how much effort is required to use the technology. Within the TAM these two central constructs are referred to as *perceived usefulness* and *perceived ease of use.* The assessment of these acceptance criteria shapes the user's attitude toward the system, which in turn influences their actual behaviour, i.e., their use of the system. Building on the TAM, extended models typically retain its original constructs while introducing additional acceptance criteria to better account for complex settings. The Unified Theory of Acceptance and Use of Technology (UTAUT) [6] for instance considers social circumstances or individual characteristics of potential users. In models addressing automated systems, *trust* is frequently incorporated as criterion of acceptance, see also [3].

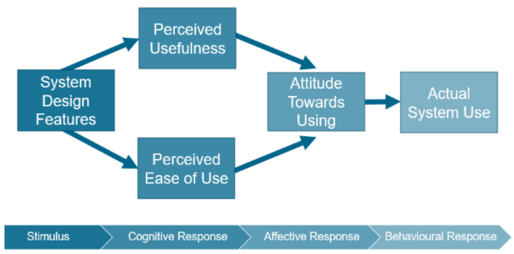

Figure 1: Technology Acceptance Model by Fred D. Davies [2]

Although previous research reflects on criteria, seemingly relevant for the adoption of the MUM, it does not address its specific intricacies. MUM's operational environment is characterised by instability, high risk, and limited control, creating a challenge of balancing the need to relinquish control to autonomous functions while maintaining oversight to stay confident in the role as operators. The MUM involves a yet unclear operator profile, as users interact with the system in highly varied roles, each with distinct needs and expectations. Lastly, technology acceptance models typically evaluate user acceptance retrospectively. Given that MUM is still in the design phase, such models provide limited insights at this stage. Therefore, instead of employing a quantitative approach an explorative approach has been adopted here to identify and comprehend key criteria for the operator acceptance of the MUM.

III. Methodology

This paper examines operator acceptance criteria as key factors for future market adoption of MUM. Focusing on criteria that can be directly influenced through design and manufacturer, criteria dealing with individual characteristics, or the social context of the operators have not been addressed. Given the wide range of potential use cases for the MUM, a broad spectrum of potential operators and their respective needs had to been considered. The experts consulted can be broadly categorised into the professional fields of Marine Research, R&D, Offshore Energy, Training and Simulation, Ship and Traffic Security and Remote Monitoring. These areas cover potential use cases and related occupational fields for implementation.

First, acceptance criteria were deductively derived from established theories. As a result, the criteria *perceived usefulness*, *perceived ease of use, task-technology compatibility, (perceived) security, locus of control, trust,* and *ethical concerns* regarding the MUM served as the basis for developing the interview guide. In total 21 interviews were conducted. Afterwards the acceptance criteria were refined inductively, based on insights from the expert interviews. The collected data was analysed using the systematic approach proposed by Gioia et al. [7], which organises insights inductively across three layers: First-Order Concepts, presenting the participants' direct quotes; Second-Order Themes, representing the researchers' interpretation and categorisation of these inputs; and Aggregated Dimensions, capturing overarching theoretical constructs (*see Table 1-3*). The method was chosen for its ability to generate theory from qualitative data while remaining grounded in the authentic voice of the participants. To ensure anonymity, participants were given a unique identifier for referencing their statements. German interviews were translated into English for consistency. Finally, the findings were translated into an adapted version of the TAM.

Qualitative research explores the depth of a phenomenon rather than aiming for statistical representativeness. The results of this study have limited generalisability and are not intended for direct replication. Instead, this approach uncovers, context-sensitive insights, and reveals subtle patterns that may be overlooked by quantitative methods. The value of this research lies in its conceptual and exploratory contributions: offering interpretative frameworks and generating grounded hypotheses to inform further investigations. By capturing the experiences and subjective meanings of potential users, qualitative research offers a deeper understanding of acceptance criteria that is vital for designing systems.

IV. Findings

The analysed data indicate three key acceptance criteria for MUM, each encompassing additional underlying aspects. These include *perceived usefulness* linked *to task-technology compatibility*, *perceived cost of use*, and the *complex of trust and control*, which encompasses, conflicting rationales between the need for autonomy and human oversight.

A) Perceived Usefulness

Perceived usefulness refers to the extent to which an operator believes that using the system will provide them with benefits, including but not limited to improved task performance. This concept is central to technology acceptance as it links the system's features directly to the practical advantages of users (*Table 1)*. In this study, participants associated MUM's usefulness with distinctive features that set it apart from existing technologies. A key prerequisite for *perceived usefulness* identified in the interviews is *task-technology compatibility* — the degree to which the system's capabilities aligns with the specific tasks users intend to perform. Whether MUM is seen as useful seems to largely depend on how well its features match the operational needs of potential users. Particularly in Arctic research, MUM is considered highly useful as its ability to perform task autonomously and the longitude of its propulsion enables it to access unexplored remote areas beneath the ice (*A5007*). In contrast, in other sectors, such as the offshore energy industry, the perceived benefit of MUM is met with greater scepticism, as existing systems already perform the required tasks satisfactorily (*T5656*). To realise any advantage from using MUM, operational processes would need to be adapted to align with MUM's operational framework, leading to additional costs for operators (*C7212*). This aspect is reflected beneath in the chapter *perceived cost of use*.

The interviewees frequently mention benefits arising from the system's modularity, which significantly enhances its overall applicability (*W6658*). Thanks to its modular design, MUM can be adapted to meet a wide range of operational requirements, for instance, addressing various research objectives across different missions (*U2324*). This flexibility also allows for multitasking across disciplines, enabling multiple tasks to be performed simultaneously or in parallel configurations. At the same time, modularity supports high specialisation, as individual modules can be tailored to very specific scientific or operational needs (*Y3558*). The concept also promotes efficiency: instead of investing in entirely new vehicles for each use case, operators can simply reconfigure MUM for different missions (*B4910*). Modules can even be prepared in advance while the vehicle is still deployed, minimising downtime between operations and allowing for continuous mission planning and execution (*O7123*).

Given the growing shortage of people willing to work at sea, the uncrewed operation of MUM is becoming increasingly relevant (*R7321*). It offers significant benefits for working conditions, as operators can remain on shore, while still performing essential tasks (*R7321*). One of the key advantages of uncrewed operation is also the improvement of safety, as it removes human operators from hazardous and high-risk environments (*R7321*).

Automation and autonomy were highlighted by interviewees as major contributors to MUM's perceived usefulness. Participants emphasised that autonomous systems are capable of carrying out a range of tasks either more effectively or at least more consistently than human operators. Key advantages include high precision (*W6658*), consistent performance (*V4679*), and increased efficiency (*R7321*), especially in repetitive (*L1539*) or data-intensive tasks (*C7212*). Furthermore, autonomy significantly expands accessibility by enabling operations in regions that are

DOI: 10.5281/zenodo.17120175

otherwise inaccessible for human presence, such as under-ice environments (*H6309*) or high-risk environments, e.g. the 500m safety zone. The participants' descriptions of tasks to which MUM is particularly well suited align closely with the so-called "four D" tasks, those that are *dirty, dull, dangerous, or dear*, where human involvement is seen either inefficient or poses risks. In addition, autonomous systems can be designed to comply reliably with legal and regulatory frameworks (*V4679*), reducing the risk of human error (*K9980*).

Aggregated Dimension	Second-Order Themes	First-Order-Concepts
Perceived Usefulness	Modularity	*"Modular design, i.e. efficient use, reusability. I think that's pretty good from a social point of view." (W6658)* *"Modularity is for us, I don't want to say it's the most important thing of all but we often develop devices for a very specific purpose. And often you can't buy these devices because they have special requirements that some scientist has thought about." (Y3558)* *"The advantage of a MUM […] is that you can do multi-disciplinary research with it. This means that you could serve a broader scope at the same time with one device." (U2324)* *"I would have to build a new ship every time. There are multipurpose ships, but not in the same way as with MUM, where I can put my units together depending on the mission or objective. The fact that this is the case is a huge advantage." (B4910)*
	Uncrewed Operation	*"I find remote control a very appealing option, because there is a shortage of young people who want to go to sea or want to stay at sea for longer." (R7321)* *"People can be endangered by ropes. In terms of safety, it's the attachment of devices into the water. MUM is actually very, very well thought out." (R7321)*
	Automation/ Autonomy	*"The autonomous system could actually increase precision, which a ROV operant might not be able to achieve." (W6658)* *"Compliance with the law – an autonomous vehicle can definitely do this better than humans.." (V4679)* *"Risk assessments, with standard procedure or standard problems – the machine acts more rationally, logically and systematically." (V4679)* *"There are dangerous tasks that autonomous vehicles, especially if they are equipped with the appropriate technology, can do much better or in areas where it would not be possible for humans to do so […] I could imagine them being used in areas that are hostile or dangerous or very tiring for humans due to the monotony of the work." (K9980)* *"Where you have tasks that wear out humans." (K9980)* *"It simplifies the operator's tasks. The ROV pilots, they are some of them are very good. Some of them are beginners. If you have a supervised autonomy where you have the intelligence in the MUM and you only have to say that, 'okay, now your position', 'you can continue the work', you just push a button. That really kind of take away the human factor, that varies because you have good pilots and bad pilots." (K9980)* *"We want to send the systems into a region or into areas where we can't go ourselves, where we can't get to with the ROV." (H6309)*
	Underwater Operation	*"It travels under water and is clearly heavy-weather unaffected. In research and offshore shipping, if you look at the North Sea. very expensive ships often stand at the quay wall because they only wait for good weather for their deployment." (R7321)* *"You could carry out wonderful research tasks that you can't do at the moment. So instead of freezing an entire icebreaker in the Arctic for a year, as in the Mosaic expedition, a certain proportion of these tasks could be achieved with long-range AUVs. If you say that they will travel back and forth through the Arctic and you could do a large part of at least the oceanographic tasks there and do them much better than you can do them today." (A5007)*
	Propulsion	*"A real bottleneck is the energy supply. And that's why the MUM project with the fuel cell really is a quantum leap for many applications and also in deep-sea research." (H6309)* *"The big challenge is how long can a vehicle be in the water and how are you going to place it in this area of interest […] This MUM can work like a submarine over a long time and maybe fly from shore. You don't need to transport it out. That is something that is different from most other systems today." (K9980)* *"An environmentally friendly propulsion would be desirable. But that is planned for the MUM." (V4679)*
	Size	*"It would be more practicable for you if it was bigger." (J2869)*

Table 1: Perceived Usefulness

Interviewees linked MUM's fuel cell propulsion system to several advantages. They emphasised its reliability, particularly because this technology has already been successfully implemented by established shipbuilders and is considered proven in practice (*N0386*). This reliability makes MUM a robust option for long-duration missions, enabling it to reach remote areas of interest and operate independently for extended periods (*A5007, H6309*). Its long operational range and endurance were highlighted as major benefits for applications that require persistent presence (*O7123*). Furthermore, the fuel cell propulsion was noted for its environmental friendliness, aligning with growing societal expectations for sustainable maritime technologies, and reinforcing the system's appeal from both a technical and ethical standpoint (*V4679*).

B) Perceived Cost of Use

The perception of cost of use plays a significant role in the acceptance of MUM, as it reflects the operational effort and technical challenges required to use MUM effectively and the financial and organisational costs associated with its adoption (*Table 2*). Several technical challenges were identified by interviewees as factors influencing the *perceived cost of use* of MUM. One key challenge is mission programming, which involves planning for a wide range of possible scenarios (*Y3558*). Due to the many variables involved, for instance ocean currents, interactions with other vehicles, and changing conditions, it is difficult to anticipate, simulate, and prepare for every situation in advance (T5656). Adaptive control presents a closely related issue: The system must independently react and adapt to unpredictable environmental and operational conditions during a mission, something that is difficult to fully prepare for, as not every scenario can be anticipated or trained in advance (*Y3558*).

Concerns were also raised regarding the vessel's naval architecture. Modifications in size or configuration resulting from the MUM's modular composition can substantially affect the system's overall driving behaviour, requiring continuous adjustments and testing (L1539). Additionally, interviewees highlighted the system's potential susceptibility to malfunctions, which arises from the integration of various modules (*U2324*) and the interplay of different new system components (*C7212*).

Another technical challenge lies in communication and data transfer. Given the significant constraints on underwater communication, it is unlikely that all necessary data can be reliably transmitted or received during operations (*R7321*). Therefore, it remains questionable whether and how comprehensive situational awareness can be achieved in the remote-control centre (*Y3558*, S5968). In this context the respondents emphasise the importance of usability and human-centred design in MUM (*C7212)*.

According to the experts, legal and regulatory issues pose additional obstacles to the operation of MUM. Current regulations are not designed to accommodate the changing characteristics of a modular vessel like the MUM. Regulatory frameworks would need to be developed or adapted to address these new features (*B4910*). Furthermore, legal uncertainty exists around the liability of AMS (*M4571*). Questions arise regarding who holds responsibility when decisions are made autonomously by the system, and to what extent a human operator can be held accountable for choices they are not actively able to make themselves (*R7321*).

Potential operators highlighted several operational challenges. Interviewees expressed uncertainty about how maintenance tasks can be effectively performed without personnel aboard or in close proximity. Assuming regular failures in complex systems, addressing them remotely or autonomously may be a major challenge (N0386).

Aggregated Dimension	Second-Order Themes	First-Order-Concepts
Perceived Cost of Use	Technical Challenges	*“Autonomous is a popular buzzword. There are different levels, whether a vehicle is only controlled, whether it really gets all the commands programmed beforehand or whether it really has a certain degree of autonomy and can make decisions itself, e.g. about the route it takes. Simulation becomes impossible in such a case, because there are a lot of scenarios, […] it gets very, very complicated very quickly. And because you can't simulate or foresee all eventualities, otherwise it simply becomes too much.“ (Y3558)* *“Communication with a shore control is also underwater communication. How does that work? Because just to send all the data from all the sensors ashore requires a large bandwidth or a good connection. That's probably not technically possible. You probably have to say ok this is critical data and we send it every second and the rest we only send every minute. It's probably not enough in certain areas.” (R7321)* *“There are forces at work that are barely tangible for humans. […] There's the whole side of the current that takes place underwater, the different ship hulls, which are also designed differently […] which can make a big difference. And such a body then moves in a somewhere constrained riverbed, where isn't enough water. […] And because it all interacts with each other; you have these effects of things sucking in and repelling each other. The ship makes a very interesting movement. And if you then add the component of any queer currents, which then take place due to the tides, then you see the whole vector confusion. […] There will be a lot more ships and drives and rudders. There will be a number of calculation models that would be necessary and […] to the extent that if such a system knows all the conditions that can arise and can then implement the whole thing somewhere in relation to the type of ship in terms of loading, condition and stability is also a very important criterion […] I do believe that the number of cases can it be infinite. […]. You have to have the sensors first and then you have to teach the system certain things somewhere. Of course, that brings us very quickly to AI.“ (T5656)* *“If it gets too big and becomes a kind of aircraft carrier, then I don't think anyone will want to tackle it, it will simply become too complex. The difficulties, at least in my experience, of bringing it all together into a working system, [will make it] very prone to failure.” (U2324)* *“If you want to make such a vehicle shorter or longer and then there are so many points in terms of control technology, naval architecture, there are already a lot of factors that then change my whole vehicle, the whole driving behaviour, the whole manoeuvring behaviour. That will be exciting and of course super, super interesting for someone who can develop it, but I think it will be very challenging.” (L1539)*
	Legal and Regulatory Challenges	*“We are not yet prepared for this in terms of the regulations, there is a tonnage certificate and a free-build certificate, which is always based on a certain length and so on, i.e. not only length, […] etc. And you would actually have to issue several measurement certificates and several free-build certificates depending on the modules. I think that the regulations would actually have to be adapted.” (B4910)* *“Who is liable for this, who is responsible afterwards, i.e. on the ship, if something happens, the captain is responsible. Who is responsible if damage is caused to an autonomous vehicle when it crashes into something?” (M4571)* *„I don't believe that a human being or anyone is prepared to take responsibility without having complete control over a machine. I don't know how legally that can be reconciled.” (R7321)* *„It's a good idea in my eyes, but is it after all legally feasible?“ (M4571)*
	Operation	*“And maintenance, which is then not possible? Something breaks with every use. That will probably also be the case in the future.” (N0386)* *“I rarely see it working in the first years of applying, because people need to adapt itself to new technology and a new way of working […] I think you should focus on the new operational mindset.” (C7212)*
	Personnel	*“I'm looking for a new pool of people, who have a skillset, who are stress-resistant, who can switch tasks quickly, who can prioritise, who are stable in their nature, but who are also somehow not too action-minded […] And now I'm trying to do that in training and I think the pool will get pretty small pretty quickly.” (L1539)* *“But how can an operator who has never been on an autonomous vehicle imagine what it does? How it works? They can't see it. He hasn't seen it either, he will never see it. It's actually completely abstract, unless he gets the opportunity to play with an autonomous ship himself in a simulator beforehand […]. And I think the operator has to have some kind of training for a partially autonomous or fully automated ship. He really has to know it inside out. He has to know the weak points or the limits of the system. And he must be able to assess the situation at all times.” (V4679)* *“I would imagine it's similar to wind farm monitoring. It's a mixture of being mega boring and being overwhelmed very quickly. This change in particular is very stressful for people and leads to wrong decisions being made or things being overlooked.” (W6658)*
	Financial Challenges	*“There is the contractual stuff because the existing companies that have invested heavily in vessels and big working class ROV systems.” (K9980)* *“That it is such a large, complex and expensive system makes it difficult to operate it consistently by one institution.” (P7781)* *“You need a technician to operate the whole thing, […] who have the corresponding time at sea to operate these devices. That's the crux of the matter, because in our research community in particular, we have a lot of money for material, but not much for personnel. And that makes it really, really difficult to operate such equipment on a permanent basis.” (A5007)* *“At the moment I don't see any institution in Germany that would take on such a burden. Because the others are already groaning under the weight of the devices they have now.” (U2324)* *“I'm worried that it's overambitious […], because then this whole problem with funding and other things can really only be managed by the military and will probably fall flat for research infrastructure and probably even oil companies.” (A5007)*

Table 2: Perceived Cost of Use

Operators emphasised the need for a shift in operational thinking. Offshore energy operations currently rely on specialised machines and divided tasks, while MUM is expected to perform diverse functions autonomously within one system—requiring a new operational mindset. (*C7212*).
The availability of highly trained individuals has been generally perceived as limited by the experts, particularly in light of the complex demands associated with operating the MUM *(L1539)*. There were widely differing ideas regarding the skills and qualifications required to do so. Many noted traditional maritime certifications like a captain's license, which include knowledge areas like the COLREGs (*S5968*). Others, however, questioned whether such qualifications would necessarily provide the skills needed in this operational context (*L1539*). Specific skills and competencies cited include, cognitive skills such as spatial reasoning (*Y3558*), applied maritime skills like underwater navigation (*R7321*), and technical expertise like dynamic positioning (*L1539*). Additionally, hands-on experience with seafaring (*W6658*), ROVs (*C7212*), and human-machine interfaces (HMIs) (*C7212*) was frequently mentioned as important. Assessments of the system's usability also varied greatly. Some interviewees felt confident they could operate MUM with minimal preparation (*A5007*), while others doubted their ability to do so even after specific training (*P7781*).
Concerns were raised about the workload associated with operating the vessel. Although MUM is seen to relieve humans of repetitive or dangerous tasks, some operators worried about new types of physical and cognitive strain. Situations involving long periods of monotony followed by the sudden need for rapid intervention were seen as particularly problematic (*W6658*). It was also questioned whether the responsibility for the system should rest with a single person (*V4670*), not only due to workload concerns (*W6658*), but also from social and psychological perspectives (*B4910*).
Financial challenges emerged as a significant concern among interviewees. Participants expect high cost of acquiring a MUM (*A5007*). As a large and complex piece of technology, it demands considerable investment, and securing funding for such capital-intensive infrastructure was described as difficult, especially in research contexts (*A5007*). Migration costs were mentioned as well, as switching from existing systems to MUM would likely require updates to infrastructure, procedures, and workflows (*O7123*, *C7212*). Moreover, operating costs emerged as a concern, since ensuring the long-term deployment and maintenance of MUM may be financially unfeasible for individual institutions *(U2324)*. Financing skilled personnel, e.g. system engineers, was highlighted as a major challenge for operating the MUM (*A5007*).

C) Trust and Control Complex

Trust and control form a central tension in the context of operator acceptance of MUM. On the one hand, some operations are only feasible through autonomy, making it necessary to delegate decision-making authority to the system. On the other hand, especially in high-risk or hard-to-access environments, operators express a strong need to retain oversight and maintain a sense of control.
Within the *trust and control complex* the potential operators identify a number of prerequisites for trusting the MUM.

DOI: 10.5281/zenodo.17120175

Trustworthiness is understood as a concrete set of interrelated system characteristics that must be met to justify such trust. These attributes were largely uncontested and mutually reinforcing. Importantly, *trustworthiness* extends beyond the technology itself to include the people behind it, manufacturers, service providers, and operators, placing specific demands on involved actors (*V4679, A5007*). A key characteristic of *trustworthiness* is *transparency*, which reflects the desire for a clear understanding of the system. As an example of *transparency*, participants stressed the importance of a clearly defined emergency protocol to ensure appropriate system responses and proper operator training in emergency situations (*P7781*). Closely related is the notion of *explainability*, which refers to understanding specific decisions made by the system. Interviewee *L1539* argues that to assume responsibility, the operator must comprehend how the system reaches each decision. Another critical component of *trustworthiness* is redundancy, both structural and functional. This included duplicating or even triplicating (R7321) key subsystems such as propulsion (V4679), tracking (Y3558), and sensor systems (L1539). Equally important, was the system's overall ability to continue its mission and return to a safe state, even in the event of individual component failures (G2405). These requirements were closely tied to expectations of reliability. Given the absence of onboard personnel, participants stressed that the MUM must function with a high degree of consistency and fault tolerance under demanding marine conditions (M4571). Even minor malfunctions were seen as undermining confidence in the system's dependability (W6658). Finally, competence was seen as a prerequisite for the MUM's trustworthiness. This included the need for rigorous testing, the use of proven components (C7212), demonstrations (P7781), and market adoption by other actors (Y3358).

Regarding the tension between the rationale for autonomy and that for human control, participants frequently expressed conflicting feelings revealing ambivalence within themselves. On the one hand, they emphasised the advantages of autonomy, such as increased efficiency (P7781), the ability to cover large operational areas (P7781), and the capacity to make decisions even in the absence of stable communication links (W6658). These features were seen as particularly valuable in remote or hazardous environments where human intervention is impractical (H6309). On the other hand, many participants stressed the importance of retaining human oversight, particularly in situations involving technical challenges, complex or unforeseen scenarios (G2405), or tasks requiring intuitive, experience-based judgment (V4679). In these cases, decision-making often relies on soft criteria, situational awareness, and interpersonal communication, which are difficult to replicate through automation. This ambivalence reflects a broader unease about delegating full control to machines in unpredictable or ethically charged contexts. It was especially apparent in discussions of *human-machine coagency*. while the concept of autonomy presumes minimal human involvement (*H6309*), many participants still preferred to retain monitoring and override capabilities (*P7781*). The participants were aware that technical constraints may not always permit this level of control, nonetheless continued to desire it (*W6658*). This reveals a fundamental contradiction. Perceptions of control varied among participants. For example, one potential operator described feeling in control even without the ability to intervene during the mission, because they had established the initial parameters like route planning (*Y3558*). Others expressed scepticism toward fully autonomous operations, especially when real-time monitoring was limited. Decision support systems were sometimes seen as intrusions into the human decision-making, complicating the sense of control and trust (*B4910)*.

Aggregated Dimension	Second-Order Themes	First-Order-Concepts
Trust - Control Complex	Trustworthiness	*"The traceability. What if I, as a human being, should still be in charge of this at all? If I'm supposed to give my opinion at all, then I should be able to understand how the system arrives at a certain decision." (L1539)* *"I think redundancies in a system are obligatory, redundancies in the sense of drive, navigation and not necessarily in the sense of function. I think it's important for these vehicles to always be secured in some way. In other words, safety for themselves, but also for other road users and other structures on land." (V4679)* *"Reliability is a very important aspect. How well can I rely on the technology? In other words, how often does it make mistakes? If it makes a mistake once a week, then that shatters trust." (W6658)* *"I would assemble the MUM with technology that's already proven in another field." (C7212)*
	Rationale for Autonomy and Human Control	*"I would say that many seafarers would rather stay with their families. So that's a clear advantage of autonomy. (...) Less chance of people getting hurt. It's still a dangerous working environment. Fewer people on board or none at all, that also means risk of injury is significantly lower or loss of human life is significantly lower." (R7321)* *"Thanks to the autonomy, it would be relatively efficient (...) to cover several interesting locations or even large areas or long distances. (...) Without the need for large numbers of personnel. And also much faster than usual." (P7781)* *"If the transmission is disturbed, you can still make decisions under water that would no longer be possible above water because you don't have the information." (W6658)* *"Deciding what a person does intuitively [...] simply does based on a gut feeling. What they don't find in the law is the most complex thing that needs to be mapped in an autonomous vehicle." (V4679)* *"Good seamanship is not a term that can be defined by hard values, but rather something like 'How would I feel if I were in their situation?'" (V4679)* *"If situations arise that have not been trained, you cannot ensure that the technical system will not fail. In other words, humans are much more resilient to external disruptions than a technical system. And this hurdle has to be overcome somehow." (G2405)*
	Human-Machine Coagency and Perceived Control	*"That clearly depends on the situation, on the area. If the vehicle is operating in an open area and cannot endanger anyone, then there is no need for human intervention. In my opinion, the vehicle can then operate freely." (V4679)* *"Human control is mandatory or at least the ability to take over when you think a human would be better than the robot, which in most cases it is. I think the human needs to have the mandate to take over at any moment. That would be mandatory within the most cost." (C7212)* *"My expectation would be, at least initially, that before a mission or deployment is launched, a lot is done, planned and considered. [...] Then you get to a point where [...] you just press a button and the mission starts." (O7123)* *"[The system can intervene in the human decision-making process], maybe [in form of] a warning of a wrong decision. But we already have something like that on our ships. So as soon as there are any close calls. Then there's an alarm." (M4571)* *"Humans still program them like we do determine, how the machine should decide." (H6309)* *"Do my conscience decisions or moral decisions change at some point? So as long as I still have a person behind me, the situation doesn't change." (B4910)*

Table 3: Trust-Control Complex

V. Discussion

The examination of existing technology acceptance models reveals that, while certain adoption-relevant criteria have been considered in prior research, the models overlook some of the specific operational and contextual complexities associated with MUM. Particularly noteworthy are the following aspects:

The context of AMS. MUMs application domain is characterised by unstable surroundings, high-risk and low-control environments. It introduces additional complexities to operator acceptance, including unpredictability,

DOI: 10.5281/zenodo.17120175

environmental constraints, and the demand for rapid and reliable decision-making. Operators may find themselves in a complex tension between the need for significant trust in the system and the desire for comprehensive control.

Unique aspects of the technology-operator relationship. Unlike operating conventional vessels, operators will not directly control nor work aboard the MUM. Instead, operators may range from marine biologists collecting samples with MUM, divers working alongside it on an infrastructure, observers in control centers, software developers programming mission plans, to maritime pilots guiding the vehicle through restricted zones. Consequently, there will be a variety of operator profiles, each with different needs, expectations, and operational requirements.

Challenges of assessing acceptance for emerging technologies. A shortcoming of existing technology acceptance models is their focus on post-implementation evaluation. Since MUM is still in its design process. with technical configurations unfinished and usage scenarios unclear, uncertainty remains high. This raises the question of how such uncertainty affects the acceptance of potential operators, whether it has a destabilising effect or fosters idealisation.

To address these shortcomings, a qualitative methodology was chosen, involving interviews with experts selected to reflect the wide range of user profiles. Based on these empirical insights, a preliminary adaptation of the existing TAM (*Figure 3*) to better reflect the specific characteristics of the MUM context was developed. Several factors emerged as particularly influential in shaping operator acceptance.

First, the nature of the intended operation seems to significantly affect how MUM is perceived among potential users. The operational context, when considered alongside system design features, shapes the task-technology compatibility of MUM. Whether the system is seen as offering added value depends heavily on the operational scenario and the specific tasks it is meant to support. The same technical features may be evaluated very differently depending on the mission.

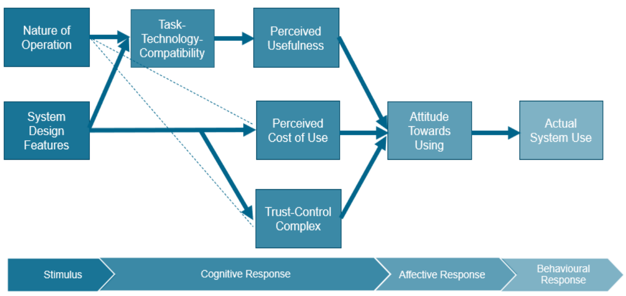

Figure 2: Preliminary Adaption of the TAM

Second, given the broad profile of potential MUM operators, *perceived ease of use* is too narrow a concept to capture their decision logic. The cost-benefit assessment involves not only usability but also broader considerations such as shifts in the changes in operational mindset, personnel shortages, and financial disadvantages. Therefore, the concept of *perceived cost of use* was introduced, which reflects both the effort required to operate the MUM and the wider organisational and economic challenges tied to its adoption.

Lastly, in the case of AMS like MUM, trust and control form a core tension. The interviews revealed that for many operators, this tension is not yet fully resolvable. While autonomy is designed to reduce the need for human oversight, many users continue to express a strong desire for observability and the ability to intervene, at least in the medium term. This underscores a key dilemma in balancing operational autonomy with retained human agency.

Despite these uncertainties, the experts were showing a generally positive attitude towards the MUM. Their proclaimed willingness to use suggests an underlying optimism that the identified challenges, technical, operational, legal, and human, can ultimately be resolved, paving a way from emergence to acceptance.

VI. Conclusions and Outlook

This study combined a deductive approach, deriving initial acceptance criteria from established technology acceptance theories, with an inductive-exploratory phase based on in-depth expert interviews. The mixed qualitative methodology provided rich, context-sensitive insights into the perspectives of diverse potential operators across multiple application domains, uncovering nuanced acceptance factors that quantitative methods alone might overlook. Using a qualitative approach, the intricacies of MUM were taken into account, a set of acceptance criteria was identified, and a preliminary adaptation of the TAM was developed for MUM.

To build on these in-depth findings and enhance their robustness, a quantitative survey should be conducted with experts from various fields. This phase will complement and validate the acceptance criteria, supporting the generalisation of results. Based on this comprehensive evidence, an action plan can be developed outlining measures to improve operator acceptance of the MUM, which should be reviewed and refined through expert validation. By integrating both qualitative depth and quantitative breadth, a comprehensive understanding of operator acceptance can be maintained throughout the design process, facilitating broader adoption of the MUM.

References

[1] The MUM-Project – Large Modifiable Underwater Mothership, Versatile and adaptable – MUM research project conquers the deep sea. [Online]. Available: https://mum-project.com/project/

[2] Fred D. Davis, "Perceived Usefulness, Perceived Ease of Use and User Acceptance of Information Technology" (1989), in MIS Quaterly, vol. 13 (3), pp. 319-340.

[3] Mahtab Ghazizadeh, John D. Lee and Linda Ng Boyle, "Extending the Technology Acceptance Model to assess automation" (2012), in Cogn Tech Work 14, pp. 39-49, DOI: 10.1007/s10111-011-0194-3

[4] Charlie Hewitt, Ioannis Politis, Theochairs Amanatidis and Advait Sarkar, "Assessing Public Perception of Self-Driving Cars: the Autonomous Vehicle Acceptance Model" (2019), in Proceedings of the 24th International Conference on Intelligent User Interfaces (Marina del Rey, CA, March 2019), pp. 518–527.

[5] Christelle Al Haddad, Manos Chaniotakis, Anna Straubinger and Kay Olaf Plötner, " Factors affecting the adoption and use of urban air mobility" (2020), in Transportation Research Part A: Policy and Practice 132 (2020), pp. 696-712, DOI: 10.1016/j.tra.2019.12.020

[6] Viswanath Venkatesh, Michael G. Morris, Gordon B. Davis and Fred D. Davis. "User acceptance of information technology: Toward a unified view" (2003) in MIS Quarterly, 27(3), pp. 425–478, DOI:10.2307/30036540.

[7] Dennis A Gioia, Kevin G. Corley, Aimee L. Hamilton (2013). Seeking Qualitative Rigor in Indictive Research: Notes on the Gioia Methodology. Organizational Research Methods 16 (1), pp. 15-31.

DOI: 10.5281/zenodo.17120175