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The Ecosystem of Trust (EoT): Enabling effective deployment of autonomous systems through collaborative and trusted ecosystems

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Abstracts. An autonomous, zero-emission ferry can be an innovative transport and mobility system solution to tackle environmental challenges for twin transitions by, for example, reducing road, tunnel and bridge construction, and eventually air pollution. Nevertheless, deploying such autonomous systems to increase inhabitant mobility especially in cities surrounded by water is not necessarily a straightforward process. We propose an ecosystem of trust (EoT) as a framework to increase the success rate of deploying technology into society so that it can create value for sustainability. Here, an EoT is defined as a complex and interdependent system where trust is present among and between stakeholders (e.g. passengers), technologies and infrastructures, institutions and governance, and the artificial and natural environments, while creating and delivering value for all living creatures within it. These interdependencies (i.e. ripple effect) are key to the EoT framework, implying that if a change is impacting one element, it has an impact to others as well. These interdependencies are also connectors that can identify actors or elements that may not necessarily be identified otherwise (e.g. more vulnerable or minority stakeholders). A real-world use case of an autonomous, zero-emission ferry developed originally in Trondheim, Norway, is used to demonstrate EoTs from stakeholders' perspectives. EoTs aim to achieve epistemic justice so that technology can be deployed successfully by focusing on and addressing all stakeholders' concerns, interest, and motivation equally as well as ensuring that risk is managed, trust is shared and value is created. Our paper contributes to the debate on just transitions of mobility systems from the perspective of an industry actor.

Keywords: autonomy, artificial intelligence, sustainability, complex systems, trustworthiness, adoption

1. Introduction

1.1.*Ecosystems*

"Ecosystems" exist everywhere we go. The term was first defined by botanist A. G. Tansley (1935) to describe the idea of "the whole physical system including the whole complex of physical factors forming an environment of the biome, the habitat factors in the widest sense, in which organisms cannot be separated from their special environment, with which they form one physical system" (p. 299). Since then, the term has been broadly applied beyond biology to describe economic, digital, socio-technical, and socio-ecological systems (Auerswald and Dani 2018; Ahlborg et al. 2019; van de Hoven et al. 2021). At its core, an ecosystem is a complex, interdependent system.

We propose an Ecosystem of Trust (EoT) as a human-centric approach to understand and shape an ecosystem by fostering trust among and between stakeholders (i.e., people, communities, organizations), technologies and infrastructures (e.g., digital technologies, automation, and physical systems), institutions and governance (i.e., any structure of law, regulation, culture, and/or norms), and the artificial and natural environments that depend on each other so that the ecosystem's stakeholders and other living creatures can create, deliver, and receive value. Mayers et al. (2006) define trust as the willingness of a party (the trustor) to be vulnerable to another party (the trustee) based on expectations of value, regardless of monitoring or control. These interdependencies and interactions between entities in an ecosystem are

fundamental to the EoT approach; if a change impacts one entity, it has an impact on others as well. Consequently, trust between these entities is a prerequisite for an ecosystem to function, that without trust, chaos is guaranteed. While natural ecosystems can operate through competition and self-regulation, human-centric ecosystems, especially those shaped by technology, rely on trust to coordinate actions, manage risks, and sustain cooperation. Without trust, stakeholders may disengage, resist collaboration, or act in ways that fragment the system, leading to inefficiencies and disorder.

Ecosystems typically form organically; however, trust may not necessarily be present between all entities, preventing some value being created. The absence of trust can become a problem because all entities within an ecosystem need to work together so that its stakeholders and other living creatures can achieve their objectives. The EoT approach is even more important when a new technology is being deployed because deployment changes many of the dynamics of the ecosystem in question, especially the trust needs of the stakeholders (Hopster 2021).

1.2.*Deploying technology using the EoT approach*

Autonomous systems aim to address global challenges such as resource conservation and equitable quality of life (Duong et al. 2020; Greco et al. 2020). However, deploying such technologies is fraught with risks, as complex systems in unpredictable environments can lead to unintended consequences such as discrimination and ecological disruption (Buolamwini and Gebru 2018; Tita A Bach, Kristiansen, et al. 2024).

These risks raise significant trust issues for stakeholders, such as concerns about safety, accountability, and regulatory compliance (Tita Alissa Bach et al. 2022; DNV 2022). Technology deployment is not only a technical challenge but also a human-centric one, requiring alignment between stakeholders and ecosystems (Sherry et al. 2020). Addressing these concerns require fostering trust among all parties to unlock technology's potential while minimizing harm.

We propose an EoT approach that focuses on onboarding stakeholders early to engage in trustworthy and responsible practices (Tita Alissa Bach, Kaarstad, et al. 2024), fostering trust among and between stakeholders and technology (Glomsrud and Bach 2023). Engaging stakeholders early helps align diverse objectives toward common goals such as sustainability, while understanding the ecosystem ensures technology is fit-for-purpose, as outcomes can vary across contexts. This approach encourages stakeholders to address each other's trust needs, recognize interdependencies, and anticipate ripple effects of changes across the ecosystem. Such approach can also reveal overlooked stakeholders or entities (e.g., vulnerable groups) and unpack motivations or barriers to interaction. A detailed understanding of the ecosystem enables the creation of deployment strategies that are more likely to succeed, covering both pre- and post-deployment phases. The EoT approach is ideally applied from the development stage through to the deployment and post-deployment of technology to increase the likelihood that technology being developed creates value as expected with minimal negative consequences.

We will illustrate the EoT approach using a use case of an autonomous, zero-emission ferry, in which the EoT approach guides the assurance process from concept to deployment, engaging local stakeholders and aligning with Sustainable Development Goals (Pantelatos et al. 2023; Pantelatos and St.Clair 2022; Jacobsen and St.Clair 2023). Beyond deployment, the EoT approach addresses critical issues such as privacy and data security, identifying interdependencies and mitigating risks associated with interconnected digital systems (Avoine et al. 2014; Amro and Gkioulos 2022). By understanding ecosystem dynamics and trust needs, the EoT approach lays a foundation for sustainable, inclusive technological innovation.

2. Use case: The autonomous, zero-emission ferry

The idea of an autonomous, zero-emission ferry emerged from public opposition to new bridge and road projects to improve transportation in a city with many waterways in Trondheim, Norway, as residents and university professor and researchers sought alternatives that preserved vintage boats and the environment, while improving urban mobility. This led to the

development of the Autoferry research program ("Autonomous all-electric passenger ferries for urban water transport (Autoferry)"), the start-up Zeabuz (Zeabuz), and collaborations among technology providers, regulators, and assurance experts in a RCN-funded project, the TRUstworthy, Safe and Sustainable Transport for all (TRUSST), in which the first author (JAG) was the PM. The learning in the TRUSST project has led to the development of the EoT approach. The ferry reimagined waterways as opportunities for enhanced transport and living spaces, inspiring similar initiatives such as a ferry in Stockholm currently in testing (Jacobsen and St.Clair 2023). While these ferries are not yet fully autonomous, they represent a step toward sustainable, innovative urban mobility ("Assuring Trustworthy, Safe and Sustainable Transport for All" ; TRUSST).

2.1. *The stakeholders of the ferry*

The ecosystem in our use case consists of three groups of stakeholders categorized by the level of impact a stakeholder will experience if an incident or a near miss happens to the ferry:

(i) First-hand stakeholders: those interacting directly with the ferry (i.e., passengers, onshore or remote operators, other waterborne vehicles, swimmers, and kayakers, and inhabitants of the city and surroundings when the ferry's traveling patterns expand).
- Main trustees: second and third hand stakeholder groups.
- Trust needs: safety, security, comfort, a better transport option.
- Risks: injury, death, emotional distress, delays.

(ii) Second-hand stakeholders: those involved in the manufacturing and development including software and product developers, technicians and engineers, and vendors or suppliers.
- Main trustees: technology, each other, third-party vendors/suppliers, first-hand stakeholder group.
- Trust needs: passengers use the ferry as intended, and that technology, vendors and suppliers, and development teams provide outcome as intended and expected.
- Risks: liability, public responsibility.

(iii) Third-hand stakeholders: those invest in the ferry and its infrastructure and expect success of the ferry (e.g., investors, regulators, insurance companies, and other funders, and when the traveling patterns expand include the city governments, real-estate business and development, and the construction industry).
- Main trustees: second-hand group, each other, and first-hand group to some extent.
- Trust needs: fit-for-purpose regulations, accurate cost-benefit analysis, compliant manufacturers and operators.
- Risks: reputation and monetary loss.

We use the passengers' or the first-hand stakeholder group's point of view throughout the use case in this paper because passengers are the key stakeholder group that holds the highest risk and are the end users of the ferry who can stop or enable such technology. This importance is highlighted in a study by Pantelatos and St.Clair (2022) with the objective to understand passengers' potential concerns related to using an unmanned ferry. The study reveals that potential passengers expressed concerns not only about safety but also security, particularly regarding the lack of an authority figure on an unmanned ferry. This led to discussions on the need for camera surveillance systems and the ability to contact an onshore operator for assistance. However, such systems must comply with privacy regulations and be safeguarded against cyberattacks. Additionally, the passengers in this study emphasized the importance of inclusivity for vulnerable and minority groups (e.g., children and disabled passengers), suggesting solutions such as safety markings, audio and visual communication, braille, wheelchair access, and child-proof design. In an ideal scenario, the ferry will create a new ecosystem that provides its first-hand stakeholders with efficient and sustainable transport that businesses can profit from and a more sustainable city with less (ideally no) environmental impact (Fig 1).

Fig.1. Illustrated ecosystem of the ferry that includes passengers waiting in two Harbors separated by a waterway, other waterborne vehicles, buildings that are connected by the ferry, and the interconnected technology to operate the ferry.

3. The EoT approach fostering the "correct level of trust"

Trust acts as a facilitator of interactions in ecosystems, shaping how stakeholders and technologies interact (Taddeo 2017). Without trust, interactions are hindered, while overtrust or undertrust can disrupt the ecosystem. Undertrusting, often stemming from mistrust or distrust (Citrin and Stoker 2018), can result in misuse, disuse, or strict supervision, creating inefficiencies and tension. For example, passengers undertrusting an autonomous ferry might avoid using it altogether, abandoning the ferry and preventing the ferry to create value as intended.

However, overtrusting presents a more deceptive challenge. While undertrusting is an expected reaction to new technology and often addressed, overtrusting can lead to automation complacency and neglect of safety standards (Aroyo et al. 2021; Taddeo 2017). Autonomous systems, including ferries, can blend seamlessly into routines, making overtrust appear harmless. For example, overtrust could result in an operator skipping safety checks, assuming the ferry's technology is infallible (Dixon 2020; Rodriguez et al. 2019). Addressing both undertrust and overtrust is essential to fostering "a correct level of trust", a balanced and responsible trust within ecosystems. Nevertheless, trusting at a correct level is much more than just preventing undertrusting or overtrusting (Taddeo 2017).

3.1.*Trusting at a correct level is based on confidence*

Trusting at a correct level within an ecosystem is based on **assurance: grounds for justified confidence originated from evidence, knowledge, experiences and/or skills (St.Clair 2022)**. The challenge for an ecosystem is how to ensure that the correct level of trust is present at all times, especially during interactions among and between stakeholders and technology in the ecosystem (Taddeo 2017). In brief, trusting something or someone at a correct level means that although we trust someone or something in an ecosystem, we still diligently follow assurance mechanisms such as rules, norms, good practice, standards, and relevant guidance (Scott 2008). This is the correct level of trust that the EoT approach focuses on fostering.

We emphasize that confidence is different from trust. Trust integrates cognition, emotions, and motivations, relying on diverse information and being meaningful only when risks are present (Adams 2005). For example, trust in a ferry's safety involves considering passenger feedback, safety mechanisms, and personal risk perception. In contrast, confidence is task-specific, based on past observations, relies solely on cognition, and does not require risks (e.g., confidence that a ferry will be punctual because it was on time yesterday). While confidence is just one aspect of trust, it is crucial for fostering the correct level of trust. By extrapolating evidence and experience into justified confidence, individuals can develop trust thoughtfully. For example, after hearing safety explanations, an individual may use reasoning and motivation to integrate this knowledge, build confidence, and decide to trust the ferry while continuously evaluating its safety.

3.2.*Communicating grounds for justified confidence*

Trusting the ferry itself is not enough to make the ferry system truly trustworthy (Jacovi et al. 2021). Importantly, any information about the ferry, such as its safety mechanisms, should be communicated in the language that target users understand and will interpret as intended to help them make informed decisions.

Glomsrud et al. (2019) state that explanations are a human need, and that explainable AI is one effective method to make the complexity of autonomous systems understandable to their

target users. Felzmann et al. (2020) suggest a guidance to concretize Transparency by Design by, among other methods, optimizing communication with different stakeholders and embedding relatable and concrete measures into design and implementation. Pantelatos et al. (2023) and Pantelatos and St. Clair (2022) have investigated how the passengers felt on our autonomous ferry use case in a trial study. The study findings show the importance of ensuring that the passengers of the ferry understand the ferry's behaviors.

Communicating the mechanisms of the ferry is one important step, but it is even more important to ensure that the receivers understand the information accurately and that receiving this information has the intended positive effect, such as reducing their uncertainties and concerns (Felzmann et al. 2019). It is thus important that the information being communicated, and the expectations of the ferry are consistent with reality (Pantelatos et al. 2023; Jacovi et al. 2021). For example, passengers being presented the ferry's safety measures, reinforced by visible safety certificates and clear oral communication from a remote operator, is important to foster grounds to form passengers' confidence to build the correct level of trust in the ferry.

4. Discussion

Assurance (i.e., grounds for justified confidence originated from evidence, knowledge, experiences and/or skills) plays three key roles in enabling the EoT approach. First, assurance can help foster a correct level of trust. Assurance is different from merely confidence. Assurance implies that evidence or knowledge used as grounds for justified confidence is collected, analyzed, interpreted, and communicated in *a systematic, targeted, and meaningful way*. An assurance process should be completed using a holistic point of view (i.e., a systems perspective) (Haugen 2022), including identifying target stakeholders and their pains, gains, and motivation. Assurance must be compliant with regulations and follow relevant standards, guidelines, and/or approaches.

It must also adequately communicate the assurance mechanisms and results to the target stakeholders. This communication should be tailored to different stakeholder groups because they are likely to have different trust needs and risk perceptions. Assurance should be able to provide satisfying confidence to all stakeholders equally. Although assurance cannot guarantee trust, it builds a very strong foundation. We argue that assurance is the only proven and available way to help foster and maintain the correct level of trust in an EoT.

Second, assurance can help overcome the fact that trust is not only situational and context-dependent (Tita Alissa Bach et al. 2022), but also changeable over time (Elkins and Derrick 2013). These trust characteristics can be a challenge for an ecosystem which cannot function optimally unless the correct level of trust is always present, or at least during interactions among and between the stakeholders and technology. Assurance mechanisms should be created with involvement from all relevant stakeholder groups to ensure fit-for-purpose solutions and reduce stakeholder uncertainties and concerns at crucial moments (e.g., when another ferry is coming toward, or when there is a big wave or bad weather).

Identifying the crucial moments, specific trust needs, and perceived risks of the three stakeholder groups will allow the creation of assurance mechanisms that should reduce the negative consequences of trust characteristics (i.e., situational, context-dependent, and changeable). For some passengers, for example, one crucial moment onboard may be when there are big waves coming to the ferry. Identifying this could lead to the creation of an assurance mechanism, for example, one that requires communicating to the passengers what is happening and the strategy to deal with the waves, including the predicted timeline of the waves.

Another potential crucial moment can be when two ferries are in the same pathway. An assurance mechanism could instruct the autonomous ferry to keep distance, slow down, move away, or even stop, while communicating the reasoning for the ferry's behaviors to the passengers (Pantelatos and St.Clair 2022). An assurance process thus can identify specific trust needs and perceived risks so that the appropriate information and solutions can be communicated to the target stakeholders.

Third, enabling the EoT approach through assurance is an iterative process from development, to deployment, to value creation as a result of the deployment, through to continuous monitoring of the deployed autonomous system (Fig. 2). Stakeholders are at the center of the iterative process because their feedback is fundamental to the continuation of the operation of autonomous systems. Following Heraclitus' quote "change is the only constant in life", it is almost unrealistic to expect that the only change in an ecosystem is the deployment of technology. Even if the deployment of technology makes the biggest ripple effect to the ecosystem, the original deployment strategy may not be relevant over time and will need continual adjustment through continuous monitoring.

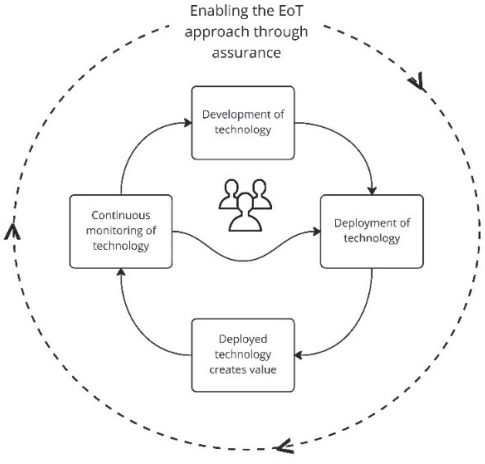

Fig.2. Enabling the EoT approach through assurance mechanisms from the development phase, deployment, through to continuous monitoring of technology using an iterative process

As another example, automation complacency and bias that may occur over time as autonomous systems become embedded into society (Rodriguez et al. 2019; Dixon 2020), thus it should be monitored to prevent undesirable consequences (Aroyo et al. 2021). This changing dynamic of ecosystems is one reason why monitoring should be continuous, using more frequent checks and/or real-time data (Dodero et al. 2021; Minkkinen, Laine, and Mäntymäki 2022; Yin, Rodriguez-Andina, and Jiang 2019). Accordingly, deployment cannot just be a one-off activity; outcomes of deployment should be used as feedback to continuously improve and adjust the technology and deployment strategy. This may mean starting slowly. For example, there may initially be an operator onboard who is gradually phased out as more data, experiences, and feedback are gathered.

5. Future work and conclusions

While this paper focuses on an autonomous system, the EoT approach is applicable in various contexts where complex, interdependent stakeholders, systems, and technologies aim to create value amidst risk. The approach can be used to identify trust needs and expected value in settings like sustainable business models or hospital departments, highlighting the importance of trust for patient safety.

We summarize the high-level steps for the EoT approach (Fig.3). Given that ecosystems are dynamic, once evidence for assurance is established (step 5), ongoing efforts are still required by continuously identifying whether the same ecosystem still has same interdependencies, stakeholders, trust needs and risks (step 1-2), or whether adjustments are necessary. EoT thus can be maintained using such iterative approach.

Fig 3. High-level EoT steps

Future work should explore additional use cases across industries to further investigate how the EoT approach fosters trust in technology deployment. The EoT approach is one of many

tools for ensuring value creation in risky environments, alongside methods like technology acceptance models, human-computer interaction, and sociotechnical systems. Future research should examine which approaches work best in different situations and how to combine them to overcome limitations. Additionally, the scope of the EoT approach requires careful consideration, particularly regarding interdependencies and the introduction of new stakeholders, such as competitors. Since trust is central, further research is needed to understand its interaction with regulations, culture, and diversity, and to develop strategies for maintaining and recovering trust over time. Ultimately, successful deployment of autonomous systems depends on aligning various factors, and the EoT approach offers a foundation for creating a deployment strategy that manages risk, fosters trust, and creates value.

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