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Automation in Human-Machine Networks: How Increasing Machine Agency Affects Human Agency

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Abstract. Efficient human-machine networks require productive interaction between human and machine actors. In this study, we address how a strengthening of machine agency, for example through increasing levels of automation, affect the human actors of the networks. Findings from case studies within air traffic management, emergency management, and crowd evacuation are presented, shedding light on how automation may strengthen the agency of human actors in the network through responsibility sharing and task allocation, and serve as a needed prerequisite of innovation and change.

Keywords: Human-machine networks, automation, innovation and improvement, human agency, machine agency

1 Introduction

In the hyper-connected society, computing technology as part of human-machine networks (HMNs) is ubiquitously available for tasks previously dependent on human skill or expertise. In so doing, machine agency in the network is increased [3]. Machine actors typically do not replace human actors but rather take on dedicated tasks or support human actors in, e.g., information acquisition, analysis, or decision making.

We understand agency as the capacity of humans or machines in terms of what they can do and achieve in the network [6]. Increasing levels of machine agency has raised concern regarding the need for human adaptation and flexibility [11], as well as its potential negative effects on human agency due to changes in situation awareness of human operators [13] and challenges to maintain human operator competency [4].

The existing research is limited in that it typically concerns the effect of increasing machine agency in established systems with set goals and performance indicators. For example, in a meta-study on the effect of automation [13], the included studies typically concern whether automation can help reach existing

goals in a more efficient manner, rather than how automation can motivate extending or changing the scope and goals of the HMN.

In this study, we address this limitation by conducting an integrated analysis of human and machine agency in the context of three case studies. Specifically, we investigate how increased machine agency impacts the involvement and agency of human actors and the capacity for innovation or change in the HMN. The findings from the three cases constitute a first step towards a perspective in which the effects of automation is considered at the level of the entire HMN, in its current and envisioned future states, rather than limited to specific processes or existing goals. The paper thereby contributes a needed reframing of automation as an interplay of human and machine agency in the context of human-machine networks. This reframing opens up for new perspectives and research opportunities in the field of man-machine interaction.

2 Background

2.1 Agency in Human-Machine Networks

Eide et al. [3] presented a typology of HMNs which is useful for understanding the potential effects of automation in such networks. Human-machine networks (HMN) are understood as "assemblages of humans and machines whose interaction have synergistic effects" [16], accentuating the potential for novel and improved outcomes enabled by such networks. The typology address the human and machine actors of the network, the relations between these actors, the extent of the network in terms of its size and geographical reach, and the network structure.

For the purpose of this paper, the typology dimensions concerning the agency of the network actors, as well as their relations are of particular interest. Drawing on the theory of double dance of agency [14], these dimensions serve to pinpoint the networked roles and interactions between humans and machines, and explore how a strengthening of machine agency may affect the agency of human actors and the capacity for innovation and change in the HMN.

2.2 Automation - Changing the Balance in Human and Machine Agency

Automation implies a change in balance of agency between human and machine actors in a HMN, as automated agents take planning and problem solving tasks. Much research has addressed the costs of automation. In the short term, increased automation may negatively affect situation awareness and performance under unexpected conditions or system failure; referred to as an out-of-the-loop syndrome [13]. In the long term, automation may negatively affect human expertise or competency [5].

Wickens [8], however, argue that the trade-offs typically associated with automation may not be inevitable. Mitigations to the challenges has been sought by, e.g., distinguishing between levels of automation [4], introducing adaptive automation [10], and dynamic task delegation [12].

2.3 Automation and Impact on Innovation and Change

Automation is also seen as driver of innovation and change. Across nearly all sectors, machines are replacing humans for an increasing range of tasks, improving work effectiveness and efficiency. Such innovation and change is often seen as threatening for current employment patterns. However, in a recent canvassing of technology experts [15], about half were optimistic concerning the impact of artificial intelligence and robotics on working life, suggesting that such technology may pave the way for innovation and growth. This extends Bainbridge's [2] view that humans, due to automation, increasingly take on new tasks such as those related to system improvement. Likewise, Autor [1] suggests that automating parts of a production process often serve to increase the value of the remaining parts, positively affecting the value of human skill and knowledge.

Hence, a fruitful perspective on automation may be to consider the interaction between increased machine agency on the one hand and the resulting effects on human agency on the other. A mere substitution on human actors with machine actors through increased automation would clearly reduce human agency. However, as new technology likely imply new opportunities for human actors, it may potentially strengthen rather than reduce human agency.

3 Research Questions

On the basis of the background presented, we see the need to extend our knowledge base concerning how increased levels of machine agency in general, and automation in particular, may affect human agency in HMNs. Specifically, we need to investigate how increased levels of machine may produce synergetic effects with human agency in the network. For this purposes, we formulate the following research questions:

- RQ1: How may the interrelation between human and machine actors be characterized in human-machine networks?
- RQ2: How can automation be set up to strengthen synergy of machine and human actors of a human-machine network?
- RQ3: How can automation be explicitly designed in order to strengthen capacities for innovation and change in the human-machine network?

4 Method

To address the research questions, three case studies were conducted (see Table 1). Data collection and analysis were structured according to the HMN typology of Eide et al. [3] and set up so as to provide in-depth insight into the three research questions on the basis of each of the cases. Specifically, given the exploratory character of the three research questions, it was seen as critical to gather data through qualitative methods such as semi-structured interviews and focus groups. Furthermore, in line with the exploratory aim of the study, identify themes of relevance for the research questions were identified through a thematic analysis [7] and validated in the context of project workshops.

Table 1. Overview of cases and data collection methods

Case	Human-machine network	Data collection methods
1	Decision support system for air traffic management	Semi-structured interviews with four project representatives and subsequent workshop involvement with project team
2	System for public sector crisis management	Semi-structured interviews with six development representatives and six end-users and subsequent workshop with development representatives
3	Decision support system for crowd management during emergency	Qualitative focus groups with a total of eight project representatives

5 Findings

In this section we present the findings for each of the three cases, structured according to the three research questions.

5.1 Case 1 Air Traffic Management

Case 1 is a research project aiming to develop automated decision support for operational air traffic management at airports. The stated aim of the project is to increase efficiency through automation while not compromising situation awareness and operator competence. The analysis contrasts current decision management in the domain with the envisioned automated decision support system.

The interrelation between human and machine actors (RQ1): The interviewed researchers described human agency as low in current operational air traffic management, largely determined by procedure and rules of thumb due to the complex and safety critical character of the domain. The operators' main objective is to schedule and oversee the safe arrival and departure of the airplanes. They, hence, have limited capacity and incitement for optimizing this schedule according to global performance criteria. Also, the machine agency of the current system was described as low. The operators have support systems for scheduling and monitoring of arrivals and departures, but while providing situational awareness these systems have low levels of intelligent decision support.

Low levels of intelligent decision support, combined with a highly procedural approach for scheduling and monitoring was reported to imply a critical decision making challenge, where decision making is skewed towards local optima rather than a global optimum. Typically, a smooth sequencing of airplanes at the airport is implicitly prioritized above working towards maximum global efficiency in the network at large. As stated in one of the interviews: *"In air traffic control, there are multiple operators working in sequence. And choices made early in the line may seem great there, but may force those later in the sequence to make suboptimal choices."*.

Strengthened synergy of human and machine actors (RQ2): The HMN typology was used to investigate how increased automation could support

the transformation of decision making processes. Specifically the participants discussed how to enable dynamic adjustment of human and machine agency and optimise for global rather than local goals, while at the same time preserve human operators' oversight and governance. To strengthen the uptake of the decision support system, and keep up operator competence, the interviewed researchers reported that the relation between operators and the automated decision support should be one of collaboration. One vision for this collaboration is that automated decision support becomes a form of team member where humans and machines at times hold the same level of agency albeit at different levels of decision-making.

Strengthened capacities for innovation and change (RQ3): Rather than to increase machine agency at the expense of human agency, the interviewed researchers suggested it necessary to redefine the air traffic management process and allocate different responsibilities to human and machine actors. As stated in one of the interviews: *"It is a gradual introduction of automation in the smaller decisions, so that the human can focus on larger, more critical, tactical, or strategical decisions."*

Specifically, an increase in machine agency, through increasing automated decision making at the local level and automatic negotiation of detail scheduling across locations, would allow operators to work more at a longer term tactical or strategic level across localities, allowing for exploring options with respect to a broader range of goals than today. Furthermore, such increase in machine agency is seen as instrumental for providing the human agency needed for change and innovation in air traffic management procedure.

5.2 Case 2 Public Sector Crisis Management

Case 2 concerns a system for public sector crisis management that draws on information from multiple sources to facilitate dynamic coordination across the actors of a potential crisis situation. Information flow and obtaining shared situational awareness is considered crucial for decision-making. The analysis concerns user and provider experiences with an implemented system.

The interrelation between human and machine actors (RQ1): The crisis management system and its users comprise a HMN in which human agency was assessed as high in consequence of highly varied and contextually dependent tasks. Machine agency in the current system was considered low, with a need for manual configuration to adapt the system to the organizational context. One system representative summarized this as follows: *"I would say that the human actors have a quite high degree of freedom in the system. All decisions, mostly [...], are made by humans. What happens automatically in the system is almost entirely a result of the actions that people make."*

The interviewed users reported that, although people within public sector crisis management are professionals with great knowledge and experience in preparing for and handling emergency situations, many lack the technical knowledge needed to configure the system adequately in response to a particular organizational context.

Strengthened synergy of human and machine actors (RQ2): The users reported a need for strengthening the synergy between human and machine actors, and suggested this could be accomplished by increasing machine agency in the network. For example, the system could support emergency managers by automatically retrieving relevant action plans, contingency plans, and check lists relevant for an incident. As expressed by one of the users: *"We would like to automate the incident potential based on the action plans [...] We want smart systems that can do some of the thinking for us, but that also gives room for improvisation, meaning that we can stop it [the system]."*

The users also expressed that having the system gather, structure, and share information related to the course of the emergency, could potentially support emergency managers in making better decisions and obtaining situation awareness.

Strengthened capacities for innovation and change (RQ3): The participants suggested that a higher degree of automation could streamline and make HMNs for emergency management more efficient. By assigning suitable tasks to the system, the emergency managers would be given greater leeway to perform activities of a more tactical or strategic nature, such as making decisions or other tasks requiring analyses based on the human actors' experience and knowledge.

5.3 Case 3 Crowd Evacuation

Case 3 focuses on a decision support system for effective crowd evacuation during emergency situations at venues such as airports and sport stadiums. The system aggregates and makes available real-time sensor data in support of operational staff. The case study looked in particular at trust implications: operators were concerned about job security; evacuee agency needs careful management; and collaborative models need to respond to dynamic changes in the different actors.

The interrelation between human and machine actors (RQ1): The HMN manifests two distinct states: (a) during normal operation when a venue is being monitored, and (b) during an emergency. Both human and machine agency are low but increase significantly from the first to the second state. The interviewed participants report that there is little need for human actors to intervene when monitoring, with machines reviewing data only to identify possible issues and human actors merely checking. By contrast, during an emergency the agency of operational and possibly emergency staff must increase along with greater machine processing to facilitate safe evacuation. Agency increases differentially, though, with greater real-time processing and two-way sensor control as well as increasing human decision making. For safety reasons, the staff seek to control the agency of evacuees; and for ethical reasons, of machines.

Strengthened synergy of human and machine actors (RQ2): Increasing automation may depend on the type of venue. Airports, for instance, tend to rely on more rigid emergency processes, whereas at the other extreme, sports stadia still depend largely on manual intervention by stewards and other staff.

Despite these domain differences, participants reported that automatic identification of emergent processes could significantly enhance the effectiveness of the system: *"[...] you could also do an emergent real time [process for] your evacuees, if you identify an emergent movement you could actually focus your attention as a civil protection agency and guide them then because everyone is following. Thats not something you could identify at design time [...]."*

Furthermore, as new evacuation routes for instance are calculated by the system, smart signage or smart use of lighting could allow this information to be presented to evacuees immediately, preferably including explicit and transparent reasons such as blocked corridors.

Strengthened capacities for innovation and change (RQ3): Increasing the synergy between the different actors in the network like this also leads to innovation and changes in the procedures, paving the way for other benefits: evacuees themselves might become active participants in the network. Further, though operational staff may fear that in certain circumstances they may be replaced by technology, increasing machine agency and thereby providing more information allows them more efficient and effective decision making.

The emergent real-time processing discussed above, allows significant change and innovation in evacuation processes, which could increase safety levels. However, the participants reported that there were caveats here. On the one hand, HMN owners may maintain staffing levels whilst increasing safety through better decision support, or alternatively reduce staff and save costs without reducing current safety levels. One of the participants made a note of a concrete example demonstrating how the decisions for increasing automation could be motivated by, e.g., enabling staff to monitor a greater number of CCTV cameras from a financial perspective: *"[...] if I want to reduce cost what I might want to do is enable each member of operational staff to monitor five times more cameras, for instance."*

In either case, the trust relationship between the decision support system and operational staff is key, as the staff need to rely on the information for their decision making that they are ultimately responsible and accountable for.

6 Discussion

The three presented cases provide complementary insight into the three research questions. In this section, we discuss findings across the cases and relate these to the existing literature.

6.1 The Interrelation Between Human and Machine Actors (RQ1)

From the cases we have presented above, there are four clear types or considerations in respect of synergistic interworking between human and machine actors within HMNs. These include collaboration and responsibility sharing; the allocation of tasks; and trust. All three cases highlighted that increasing agency would promote opportunities for human and machine actors within the network to

work together to achieve common goals. This would require careful distribution of responsibilities, as seen in cases 2 and 3.

However, it is also about recognising that increased agency provides not only for offloading repetitive tasks to machine nodes (as seen in Case 2), but rather to allow both humans and machines to focus on what they do best, providing mutual support and enabling an extension of the range of relevant goals and tasks, as seen in Cases 1 and 3. This is an interesting outcome that warrants further investigation, especially as the increase in dependency on machines is considered to having increased risks should they fail [13].

Extending the range of relevant goals and tasks opens up greater a scope for effective collaboration between human and machine actors, which is consistent with the existing literature exploring human and machine agency [6, 9, 14]. Although this requires some level of trust, it may well help to maintain and even increase trust as human actors begin to appreciate machines as particularly valuable contributors to the effectiveness of the whole HMN rather than as competitors.

6.2 Strengthening the Synergy Between Machine and Human Actors Through Automation (RQ2)

Increasing levels of automation inevitably leads to an increase in machine agency [6]. The question is how that, in turn, affects human agency. The three cases suggest that task automation may provide a number of benefits. In the first instance, it provides support to human actors and thus increases and strengthens their agency as shown in Cases 1 and 3. Decision support systems will typically aggregate information from multiple sources as well as provide some level of analytical summary. In so doing, this provides valuable input for human actors to evaluate their options and reach more informed decisions.

Beyond this, as all three cases show, the appropriate allocation of tasks to machine actors within the HMN means that human actors can focus more effectively on what they do best: working at a tactical or strategic level, making reasoned choices of how to act and respond with a clear ethical and affective perspective.

Automation correctly thought out will therefore support and enhance human agency, but also introduce a collaborative interplay on the basis of what different actor types do well. In the case of the machines, this does go beyond simply increasing the amount and speed in which data can be processed as seen in the above case studies and recent literature [16], being able to solve increasingly complex data analytics problems. This ultimately provides an opportunity for innovation and emergent behaviours as we will describe in the following section.

6.3 Strengthening Innovation and Change Through Automation (RQ3)

While much research on automation in human-machine contexts have considered the possible costs of automation and how to mitigate these [5, 13], parts of the

literature also accentuate the role of automation for innovation and change [1, 15]. Our case findings serve to expand on how automation can take this role. Strengthening machine agency through automation may allow human actors to shift activities from the level of detail data collection and local procedure to higher level tactical or strategic tasks, which is seen in both Case 1 and 3. These cases exemplify Autor's [1] point that automation does not reduce the need for human work, but serves to change its content; from the procedural towards the knowledge-based.

However, innovation and change due to automation may not only concern changes in work practices. Case 2 serves to illustrate how lack of automated support in knowledge-based work, such as the local adaptation of emergency management, may compromise current work practices due to a lack in technical knowledge. Here, strengthened machine agency may serve not only to change work processes but to improve their quality.

6.4 Limitations and Future Work

The present study is based on a small number of case studies that have similar characteristics; all three studies address domains concerning decision support. The findings related to the research questions need to be further validated. In future studies, attention should be put on exploring the proposed research questions within other types of HMNs, such as social media networks, knowledge creation networks, and sharing economy networks.

Furthermore, several questions reminds and need to be addressed in future research, e.g.: When and why can automation lead to strengthened synergy between human and machine actors of a human-machine network? When does the costs of strengthened machine agency outweigh the benefits? What are the contextual requirements and constraints? Answering these and similar questions will be able to provide a better understanding of how automation influences human agency and under which conditions.

Despite the limitations of this study, we argue that it serves as an initial step towards increased understanding of the interaction between human and machine agency, and has the potential to motivate future research on how to design for such interaction in HMNs.

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References

1. Autor, D.H.: Why are there still so many jobs? The history and future of workplace automation. The Journal of Economic Perspectives 29(3), 3–30 (2015)
2. Bainbrigde, L.: Ironies of automation. Automatica 19(6), 775–779 (1983)

3. Eide, A.W., Pickering, J.B., Yasseri, T., Bravos, G., Følstad, A., Engen, V., Walland, P., Meyer, E.T., Tsvetkova, M.: Human-Machine Networks: Towards a Typology and Profiling Framework. In: HCI International. Springer, Toronto, Canada (2016)
4. Endsley, M.R.: Level of automation effects on performance, situation awareness and workload in a dynamic control task. Ergonomics 42(3), 462–492 (1999)
5. Endsley, M.R., Jones, D.G.: Designing for situation awareness: An approach to user-centered design. CRC Press, 2nd edn. (2016)
6. Engen, V., Pickering, J.B., Walland, P.: Machine Agency in Human-Machine Networks; Impacts and Trust Implications. In: HCI International. Springer, Toronto, Canada (2016)
7. Ezzy, D.: Qualitative Analysis. Practice and Innovation. Routledge, Oxon, UK (2002)
8. Hancock, P.A., Jagacinski, R.J., Parasuraman, R., Wickens, C.D., Wilson, G.F., Kaber, D.B.: Human-automation interaction research: Past, present, and future. Ergonomics in Design 21(2), 9–14 (2013)
9. Jia, H., Wu, M., Jung, E., Shapiro, A., Sundar, S.S.: Balancing human agency and object agency: an end-user interview study of the internet of things. In: Proceedings of the 2012 ACM Conference on Ubiquitous Computing. pp. 1185–1188. ACM (2012)
10. Kaber, D.B., Endsley, M.R.: The effects of level of automation and adaptive automation on human performance, situation awareness and workload in a dynamic control task. Theoretical Issues in Ergonomics Science 5(2), 113–153 (2004)
11. Lee, J.D., Moray, N.: Trust, control strategies and allocation of function in human-machine systems. Ergonomics 35(10), 1243–1270 (1992)
12. Miller, C.A., Parasuraman, R.: Designing for flexible interaction between humans and automation: Delegation interfaces for supervisory control. Human Factors: The Journal of the Human Factors and Ergonomics Society 49(1), 57–75 (2007)
13. Onnasch, L., Wickens, C.D., Li, H., Manzey, D.: Human Performance Consequences of Stages and Levels of Automation: An Integrated Meta-Analysis. Human Factors: The Journal of the Human Factors and Ergonomics Society 56(3), 476–488 (2013)
14. Rose, J., Jones, M.: The Double Dance of Agency: A Socio-Theoretic Account of How Machines and Humans Interact. Systems, Signs & Actions 1(1), 19–37 (2005)
15. Smith, A., Anderson, J.: AI, Robotics, and the Future of Jobs. Tech. rep., PEW Research Center (2014), http://www.pewinternet.org/2014/08/06/future-of-jobs/
16. Tsvetkova, M., Yasseri, T., Meyer, E.T., Pickering, J.B., Engen, V., Walland, P., Lüders, M., Følstad, A., Bravos, G.: Understanding Human-Machine Networks: A Cross-Disciplinary Survey. ACM Computing Surveys 50(12), 12:1–12:35 (2017), http://doi.acm.org/10.1145/3039868