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Expected teamwork attributes between human operator and automation in air traffic control

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Abstract

To meet the increasing demands within the air traffic control (ATC) industry, automation is seen as one solution to increase efficiency, safety, and capacity. In ATC, teamwork between air traffic controllers (ATCO) is a key component to safely direct the aircraft. With increasing automation, the human-automation teamwork will become even more important to keep the human operator in the loop and contribute to the operator's involvement in decision-making. However, operators can be cautious to new automation due to experience has taught them to be cautious and the willingness to accept automation can relate to the purpose of the automation. Therefore, this study presents how ATCOs want to work with an automated tool in the future, what qualities the automation should have, and what the human should be able to do when working with an automated system. Through an online questionnaire, 113 operational ATCOs answered questions about ATCOs' experiences and expectations of current and future ATM systems, as well as teamwork between the ATCO and automated systems. For this paper, the teamwork aspects of the questionnaire are presented and discussed. The ATCOs believed that they should be able to trust the automation, know the reasoning behind the automation's suggestions and decisions, and be able to always take control of the situation from the automation. The results will be used in early development processes of automation, in both the ATM domain but also in other control domains, that faces similar challenges.

Keywords: air traffic control, automation, teamwork

1. Introduction

To meet the increasing demands within high safety / high critical domains such as within the air traffic control (ATC) industry, automation is seen as one solution to increase efficiency, safety, and capacity. However, as long as there is a cognitive system [1] with both human operators and automation working together, where the human operator has the responsibility (as in ATC), there need to be successful human-automation teamwork approaches [2, 3]. However, there is a problem when implementing automation due to operators' (non-existing) acceptance of automation [4, 5]. Within the ATC industry, there is a belief that air traffic controllers (ATCOs) can be skeptical of automation [6, 7], especially if they do not know its purpose or intent of it [8]. If the automation is not understood or used correctly it can cause risks and automation surprises [9, 10] for the operator, e.g., a mismatch between the automation's actions (or none actions) and the human's awareness and interpretation of the automation. An automation surprise can result in a skeptical attitude towards automation. Parts of the problem with automation surprise and lack of user acceptance are that the developers of new systems do not consider human factors and the end-users [9, 11-13].

To mitigate automation surprises and increase the automation's efficiency, previous research has suggested lists of function allocation, or "Men Are Better At – Machines Are Better At" lists [14-16]. However, such lists imply that humans and automation have fixed strengths and weaknesses,

meaning that automation does a certain amount of tasks and humans do a certain amount of tasks [17]. Dividing work tasks in such a way can contribute to out-of-the-loop problems and, even though one aim was to reduce automation surprises, it can result in more automation surprises. It is, therefore, essential to look beyond only function allocation lists and instead focus more on the detailed human-automation interaction, human-automation teamwork, and operator's acceptance of automation needed for effective performance [18, 19]. Even though there is previous research regarding ATCOs' acceptance of new automation [6, 20], there is still a knowledge gap regarding ATCOs' view of working with future automation. Hence, this study contributes with:

- one of its first ever national coverage of human-automation teamwork in ATC in Sweden,
- an updated and in-depth description of ATCOs' expectations of teamwork and task allocation when working with automation, and
- knowledge regarding human-automation teamwork

2. Method

An online questionnaire was distributed to operational ATCOs in Sweden, working in area control, approach control, and tower control. 113 ATCOs responded to the questionnaire (68 male, 41 female, and four did not disclose gender). The age of the respondents was in general 40 years or older: 30 years old or younger (*n* = 1), 30 to 39 years (*n* = 21), 40 to 49 years (*n* = 51), and 50 years or older (*n* = 40). The mean experience of the respondents was 20.9 years, ranging between 2 and 35 years.

The questionnaire consisted of 50 questions and statements divided into four sections: (1) ATCOs' experiences of current ATM systems, (2) ATCOs' expectations of future ATM systems, (3) teamwork between the ATCO and future automated systems, and (4) demography. The (3) teamwork questions, that are the main focus of the present study, is presented in Table 1. Likert scales [21] ranging from 1 = 'very low' or 'very much disagree' to 5 = 'very high' or 'very much agree' were used, and open-ended questions. The respondents could move back and forth in the questionnaire.

I should…	… be able to **trust** the automation
	… know what the automation is **doing** all the time
	… know the reasoning behind the automation's **suggestions**
	… know the reasoning behind the automation's **decisions**
	… be able to **take control** of the situation from the automation whenever I want
	… be able to **delegate** control to the automation whenever I want
	… be able to communicate **verbally** with the automation
The automation should…	… know my **stress** level
	… know my **workload**
	… know what my **focus** is, what I am looking at
	… know what I am **doing**
	… only provide **suggestions** for me to choose from
	… make **decisions** without my involvement
	… be able to **take control** from me if necessary
Questions	What kind of automation would you like to have/work with?
	How would you like to work with an automation? (For example, when solving an everyday problem, when making a decision, when monitoring a simple task etc.?)

Table 1. The statements and questions for the section about teamwork in the questionnaire.

Kruskal Wallis H (χ2) post-hoc tests and Friedman two-way ANOVAs with Bonferroni correction for multiple comparisons were applied to the quantitative data, and thematic analysis was performed on the responses to the open-ended questions.

3. Results

There was a strong correlation found between age and work experience ($r(113) = 0.889$, $p < 0.001$) and based on this the respondents were divided in three groups corresponding to their age and work experience: Less experienced ($n = 22$), Experienced ($n = 51$), and More experienced ($n = 41$). There was a significant difference in amount of work experience between these groups ($F(2, 110) = 225.757$, $p < 0.001$), and post-hoc tests with Bonferroni correction for multiple comparisons showed a significant difference between all of these groups (all $p < 0.001$), see Figure 1. The results from the two sets of statements (*I should* and *Automation should* were consequently analyzed for differences in attitudes for each individual statement, to explore if differences in age and experience resulted in differences in attitudes.

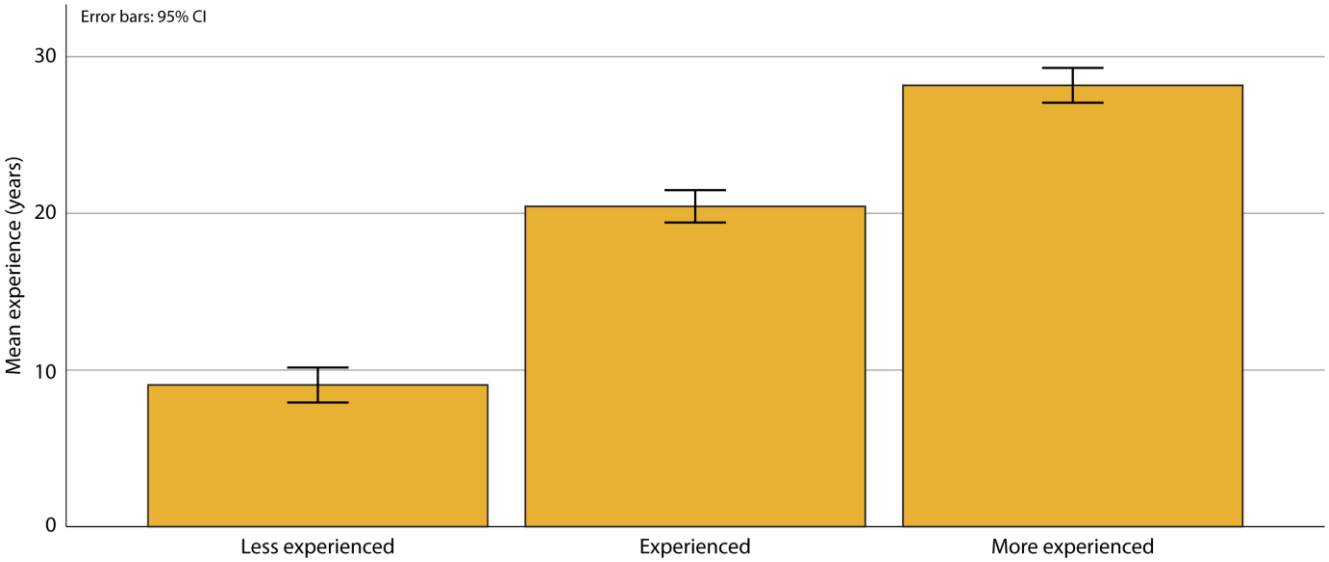

Figure 1. The respondents were divided in three groups (Less experienced, Experienced, and More experienced) based on their age and work experience.

3.1 Analysis of respondent ratings

According to a Kruskal-Wallis test, no statistical differences were found for the I should statements between the groups, even if the analysis showed a tendency towards statistically significant difference for *I should be able to use verbal communication* ($p = 0.055$) and to some extent also for *I should be able to trust the automation* ($p = 0.097$), see Figure 2. Therefore, for completeness of the analysis, both the total of all respondents as well as the individual groups are presented in the figure.

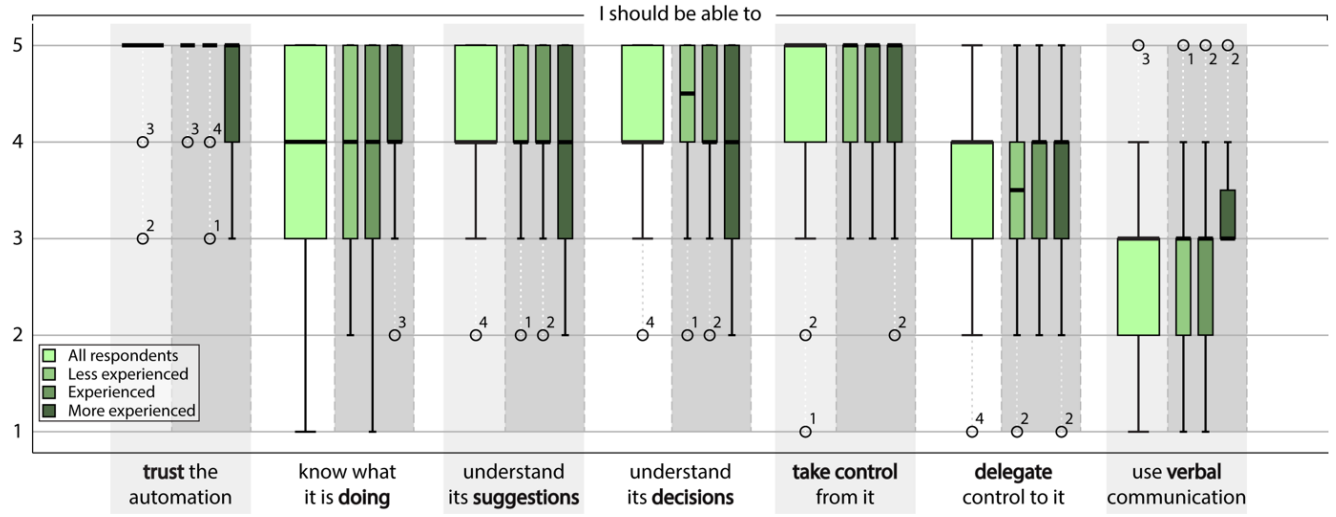

Figure 2. The ratings for the "*I should*" statements for all respondents (bright green), as well as the three groups. In general, "*I should be able to trust the automation*" was rated as most important, while "*I should be able to use verbal communication*" was rated as least important. Also, for these two statements, there was a tendency of difference between the groups.

As is shown in Figure 2, the statement *I should be able to use verbal communication* did the respondents agree to the lest compared to the other statements, which was also supported by the statistical analysis, see Table 2 for the statistical analysis. The statement *I should be able to trust the automation* was, in general, rated as the most important aspect together with *I should be able to take control from it*.

I should	verbal	delegate	take control	decisions	suggestions	doing
trust	< 0.001	< 0.001	= 1.000	< 0.001	< 0.001	< 0.001
doing	< 0.001	= 1.000	< 0.001	= 1.000	= 1.000	
suggestions	< 0.001	= 0.148	= 0.012	= 1.000		
decisions	< 0.001	= 0.062	= 0.032			
take control	< 0.001	< 0.001				
delegate	< 0.001					

Table 2. The statistical analysis, related-samples Friedman two-way ANOVAs with Bonferroni correction for multiple comparisons, of differences in ranking between all "I should" statements.

For the *Automation should* statements, there were no statistical differences between the groups according to a Kruskal-Wallis test. As shown in Figure 3, there seemed to be one set of statements that, in general, was ranked as more important than the others were. These were the statements that the automation should know the operator's workload, focus (what the ATCO is looking at), knowledge about what the operator is doing, and provide the operator with suggestions. Consequently, the respondents, in general, agreed less to that the automation knows the operator's stress level, and that the automation can take decisions and take control. This was also supported by the statistical analysis, see Table 3.

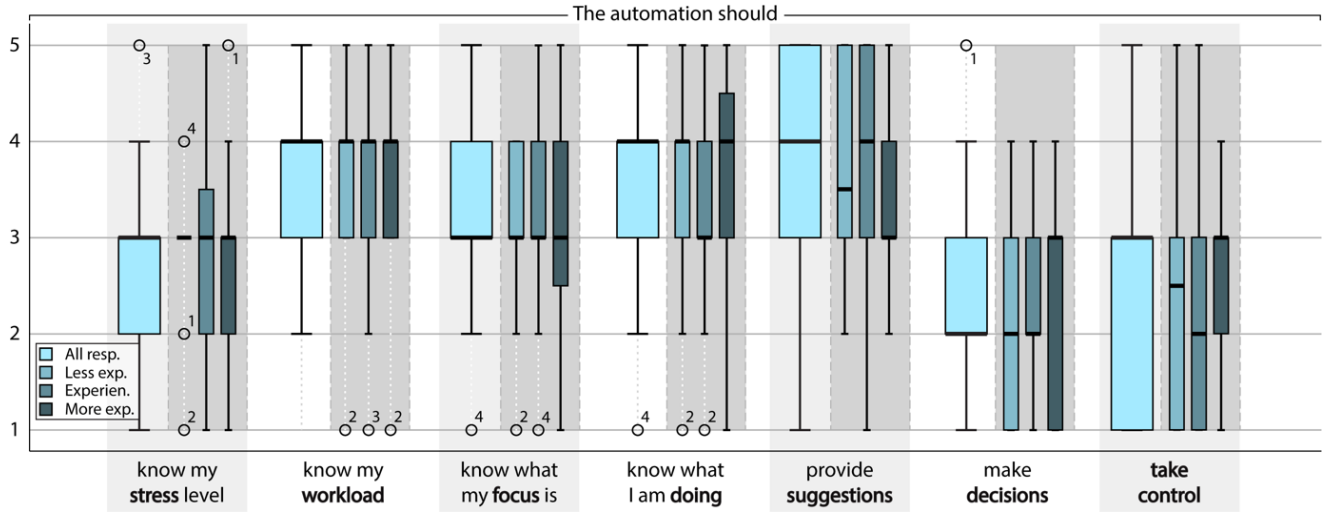

Figure 3. The ratings for the *Automation should* statements for all respondents (bright blue), as well as the three groups.

Automation should	**take control**	**decisions**	**suggestions**	**doing**	**focus**	**workload**
stress	= 1.000	= 1.000	< 0.001	< 0.001	= 0.097	< 0.001
workload	< 0.001	= 1.000	= 1.000	= 1.000	= 0.046	
focus	< 0.001	< 0.001	= 1.000	= 1.000		
doing	< 0.001	< 0.001	= 1.000			
suggestions	< 0.001	< 0.001				
decisions	= 1.000					

Table 3. The statistical analysis, related-samples Friedman two-way ANOVAs with Bonferroni correction for multiple comparisons, of differences in ranking between all *Automation should* statements.

3.2 Analysis of the open-ended questions

For the open-ended question *What kind of automation would you like to have/work with?,* thematic analysis were applied to the responses. Some respondents gave detailed examples, and some respondents provided more overall functions that can be used within ATC. The results from the analysis are presented in Figure 4. There were no statistical differences between the answers and age or experience.

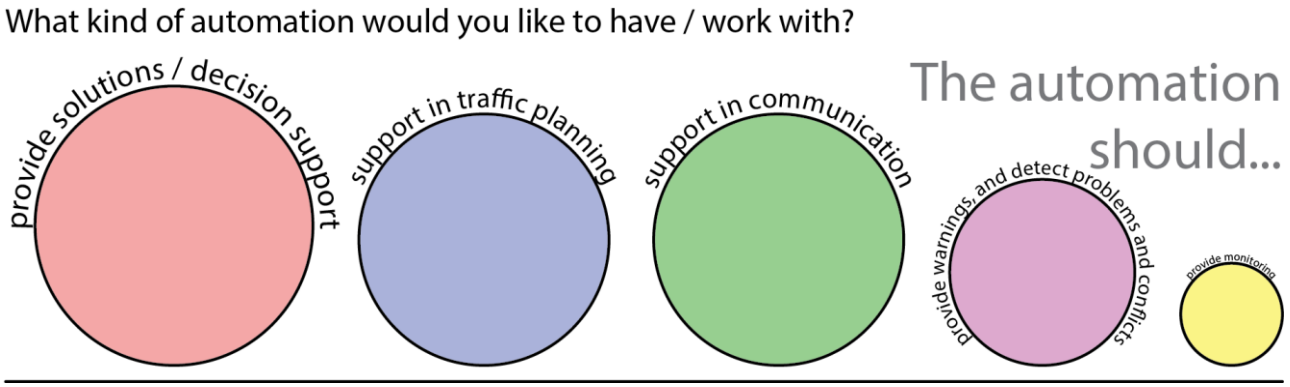

Figure 4. Thematic analysis of the question *What kind of automation would you like to have / work with?* The circles represent the frequency of each identified theme; provide solutions / decision support (red), support in traffic planning (blue), support in communication (green), provide warnings, and detect problems and conflicts (purple), and provide monitoring (yellow).

In general, the respondents wanted automation that assisted them with suggestions/solutions and decision support. They also wanted support in traffic planning, such as sequencing, sector changes, and heading/speed changes. Support in communication with the air traffic control system and the pilot was also often listed as automation they want to have. For example, many respondents gave examples of more advanced Controller Pilot Data Link Communication (CPLDC) and automatic identification of the aircraft messages. The participants also wanted conflict detection tools and tools that could do monitor simple tasks for the ATCO.

The respondents seemed to be comfortable with automation that could perform actions, but only if the ATCO accepted the command first. One citation from the questionnaire answers: "*Conflict tool that gives options to solve conflicts (for both air, runway, and taxi). If possible, a future overall "smart" system tool that makes system-wide calculations based on every available piece of information and presents clear options for me*."

The participants also wanted the automation to be customized depending on the environment based on observations of the work of the ATCOs. The participants believed that developers and researchers could not develop automation to fit all ATCOs or ATC environments. One respondent wrote: *"The important is not to have as many tools as possible, the important thing is to have the right tools and that they are trustable and easy to use and learn at high workload".*

There was also resistance toward automation among some participants. For example, one respondent wrote: "*No, I'm too old to learn major changes in the way to work or think*". Some respondents did not want more automation at all. One respondent wrote: *"Current system support is enough"* while another wrote: *"The less human involvement within a system the less room for human error".* But there was also uncertainty amongst the responses. One respondent wrote: *"Don't know. I do not know what opportunities there are. I like the craftsmanship of being an air traffic controller".*

For the second open-ended question *How would you like to work with an automation?*, the majority of the respondents wanted to work with an automation that provided them with solutions and decision support (see Figure 5). One respondent stated that: "*Automation suggests some decisions to me, if I choose to accept it performs them for me"*.

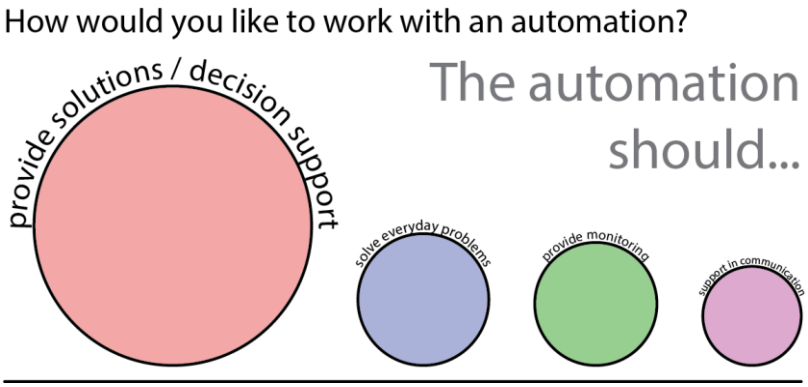

Figure 5. Thematic analysis of the question *How would you like to work with an automation?* The circles represent the frequency of each identified theme; provide solutions / decision support (red), solve everyday problems (blue), provide monitoring (green), and support in communication (purple).

There were clear indications that the respondents wanted automation to be a support system to the ATCO and not the other way around. One citation from the questionnaire answers: "*Working together. As a team all the time. It shouldn't be the person or the computer doing the work but a teamwork."* Several respondents wanted a system that can help them solve everyday problems and monitor tasks. One citation from the questionnaire answers: "*Automation does things and I monitor. I do not want to discuss with the automation. I want to know what functions it do and what I should do*." However, there were also indications that the ATCOs do not want to monitor the automation. One citation from the questionnaire answers: "*I will not become a monitor over the system"* while another wrote: "*Just let me monitor".* Hence, the opinions differ regarding how much of monitoring of the automation there should be for the ATCO.

Through the HMI, mouse, keyboard, and eye-tracking (with examples of double-blinking for 'click' or voice) were suggestions of ways for interacting with the automation.

4. Discussion

The results from the present study show that trust is the most important aspect of human-automation teamwork. For decades, it has been known that trust in automation is important but also something that can be difficult to achieve [8, 22, 23]. The level of trust for an automation depends on several factors, and some of these could be found in the results from the questionnaire study, which will be discussed further below.

In general, most of the respondents expressed that taking control from the automation was more important than delegating control to it. These results align with previous studies where ATCOs want to remain in the decision-making position and are reluctant to resign responsibility for decision-making or control to the automation [8, 20, 24, 25]. This could be a sign of low trust in automation, as the respondents would not want to delegate control to it. However, the level of control was not clarified within the questionnaire. Hence, the respondents could interpret the statement as either all control or some control. However, it can be assumed that it is acceptable for the human operator that automation has some control, as long as the operator can take all of the control whenever the operator wants.

This study shows that ATCOs may accept automation that provides suggestions for the ATCO to choose from, which is in line with previous results [8, 24]. However, the respondents did not want the automation to take decisions without their involvement; instead, they wanted to know the reasoning behind its suggestions and decisions. The ATCOs do not wish to be left out of the control loop but rather understand what the automation is doing. Hence, the automation needs to be transparent of its actions toward the human operator and offer teamwork [25, 26]. Having transparent automation is relevant for the operator to know what the automation base its suggestions and decisions on. For

example, the operators need to know which source of data the automation uses, not only providing the operator with one source [19] (which can be faulty, even though the automation uses a source with correct data). Transparency is also essential when technical systems are provided from different vendors [19].

The results from the present study have also shown that it is not as important for the respondents that the automation knows what the ATCO focuses their attention on. One reason for this could be that for the automation to know what the operator is looking at; the respondents might have assumed that additional equipment, like eye-tracking devices, would be necessary as part of the work environment. Equipment like that can be intrusive for the user, and negatively affect work and performance. In addition, some people might also believe that it can intrude on personal integrity.

The respondents stated, in general, that automation should know what the ATCO is doing. This is already implemented in current ATC systems since the ATCO is typing in commands in the system through the HMI that the system responds to. Still, the system does not have the concept of "mind" in today's ATC environments, and if the system then "knows" what the ATCO is doing is for another paper to discuss. What the ATCO is doing within the different ATC systems is thus known for the organization. However, more research is needed regarding integrity and ethics within the ATC community and how much "knowledge" the automation should have about the human operator.

The results show that it was also not as crucial for the respondents that the automation would know the ATCO's stress level. The respondents agreed more to that the automation knows the ATCO's workload. However, workload and stress levels are related [27], and if there is a high workload, the stress level might increase. Thus, knowing the workload and the stress level of the human operator can increase safety since the automation can intervene or acknowledge the management if there is a very high workload of the human operator that the human seems not to be able to handle.

The respondents did not rate verbal communication with the automation as important. Even though the questionnaire did not state what was meant by verbal communication, it can be interpreted as the ATCO can give system inputs by, for example, speech recognition. However, few respondents agreed to verbal communication and only one respondent gave voice as an example for how they would like to work with an automation in the future. If the questionnaire had given more examples of what was meant with verbal communication, the responses might have been different.

Several respondents expressed an uncertainty regarding what kind of automation they would like to work with. Many respondents wrote "*Don't know*" for the open-ended questions. The reason for this could be lack of time for answering the questionnaire, or that they thought the Likert-scale answers were sufficient as answers. It can also indicate a lack of knowledge, unfamiliarity, unconcern or even ignorance about technical development within the industry due to lack of information transparency and knowledge dissemination regarding automation research within ATC.

For this study, the questionnaire was distributed amongst ATCOs working with tower control, en-route control, and approach control. However, several ATCOs can operate in either tower control or en-route control and approach control simultaneously. Consequently, no comparison could be done for analysis of different endorsements. Further studies should be conducted to investigate the differences between tower control, en-route control, and approach control regarding automation expectations. The level of development progress at different ATC sites differs within Sweden. Hence, the attitude, expectations, and acceptance of automation may differ between ATCOs working at various ATC sites.

5. Conclusions

Through an online questionnaire, 113 operational ATCOs in Sweden answered statements and questions about teamwork with automation. The present study fills a knowledge gap regarding ATCOs' view of working with future automation and the study has contributed with:

- one of its first ever national coverage of a human-automation teamwork in ATC in Sweden with a mixed quantitative and qualitative approach,

- an updated and in-depth description of ATCOs' expectations of teamwork and task allocation when working with automation, and
- knowledge regarding human-automation teamwork in ATC.

The results show that ATCOs agreed more to knowing the reasoning behind the automation's suggestions, decisions, and be able to always take control of the situation from the automation, compared to being able to verbally talk to the automation and giving control to the automation.

The results will be used in early development processes of automation within ATM but can also be used within other domains that face similar automation challenges.

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7. Copyright Statement

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