Ability Requirements for Air Traffic Controllers and Pilots in future ATM Systems: Results from the DLR Project Aviator 2030

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Abstract

Improvements in air traffic management (ATM) and aircraft systems as well as organisational structures have become one of the key challenges of aviation in the 21st century. This is especially important with regards to the considerable increase in air traffic. To allow maximum capacity and safety as well as minimum impact on environment and cost, Single European Sky (SES) will be implemented to coordinate the traffic in Europe.

The key question of the project 'Aviator 2030' dealt with changes that will concern pilots and air traffic controllers introducing SES. Results from an integrative workshop with pilots and controllers as well as from a series of low-fidelity linked board/ground simulations (AviaSim) with subject matter experts both indicate somewhat higher ability requirements for pilots in future ATM systems, whereas for air traffic controllers the requirement levels do not change much. What can be foreseen are pilot and air traffic controller profiles assimilating with regard to cognitive abilities mostly linked to the task of airborne separation. However, when looking into the top-ranked ability requirements for both professional groups a new sequence is envisaged, with the top ranks pointing towards 'Operational Monitoring' becoming a core requirement for future ATM systems.

Keywords: future ATM, SES, Aviator 2030, ability requirements, operational monitoring, FJAS

1 Introduction

Improvements in air traffic management (ATM) and aircraft systems as well as organisational structures have become one of the key challenges facing aviation in the 21st century. To allow maximum capacity and safety as well as minimum impact on environment and cost, Single European Sky (SES) will be implemented to coordinate the traffic in Europe.

According to SESAR 'The current system can be characterised as mainly ground based and managed by humans (controllers)'. SESAR proposes a redis-

tribution of functions between air and ground and between human and automation. '... As a result of the comprehensive transition process foreseen, the jobs, responsibilities and supporting technologies of approximately 200,000 people will significantly change' (SESAR, 2007a, p.2). According to this document, in civil aviation an estimated 15,000 air traffic controllers (including supervisors) and about 35,000 pilots at ATPL-level will be affected by the transition process across Europe. As for the next 10-15 years these figures are assumed to remain stable, new ATM staff has to be recruited and selected.

The key question of the project Aviator 2030 was to describe ability requirements for pilots and air traffic controllers in future ATM systems. To identify potential changes in ability requirements in advance would allow for timely adjustment of selection profiles. In order to tackle this question, researchers from various DLR units with backgrounds in aviation psychology, operational medicine, flight physiology and system ergonomics teamed up. At the start of the project, existing concepts were reviewed to gain an overview of new ATM developments. However, as no potential future system was described in detail at that time, the project had to find an approach to identify future operators' tasks, roles and responsibilities. The following innovative elements were combined to reach our goals:

1. Based on domain experts' points of view, anticipated changes in the ATM system were described using a special workshop technique taken from sociological research. The 'Future Workshop' concept (Jungk & Muellert, 1987) was used for the first time in a high-tech environment such as aviation. A set of workshops with pilots and air traffic controllers successfully described scenarios of future ATM, providing a valid basis for further research.
2. A standard tool for job analysis (F-JAS, Fleishman 1992a) was tailored to aviation-related research by integrating aviation anchors for the current job conditions of air traffic controllers and pilots. In addition, new scales were developed in a similar style to measure requirements not covered in the original material. Applying the F-JAS Aviator 2030 with aviation anchors allowed for an interpretation of whether job incumbents anticipated an increase or a decrease in ability requirements in future ATM systems.
3. A low-fidelity integrated simulation platform (AviaSim) was developed following a bottom-up approach by combining two off-the-shelf simulators to meet the requirements of high realism, low cost, high adaptability, and full controllability for experimental purposes. Besides all normal functions, the ATC environment provides a short-term conflict alert (STCA), various flight plan visualisations for mid-term conflict detection, and interactive labels for data link communication. The cockpit environment was upgraded by a data link window and a traffic visualization system (Cockpit

Display of Traffic Information, CDTI) to provide information about the proximate traffic situation and aircraft intent to the pilots. Using AviaSim in a linked simulation allowed for the examination of new tasks, such as the transfer of control between air and ground as well as airborne self-separation in free flight airspace, as suggested by workshop participants.
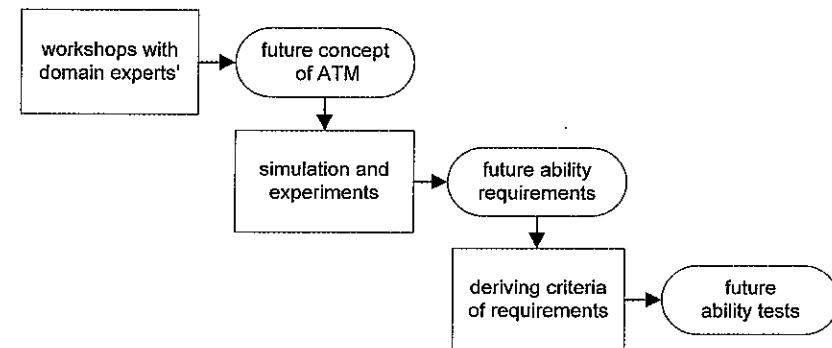

Figure 1: Flowchart of the project Aviator 2030.

2   Future Workshops

Workshops with experienced air traffic controllers and pilots have been conducted separately to obtain job incumbents' expectations regarding their future tasks, roles and responsibilities. Each future workshop started with an information session. Participants were informed about the general idea of the project, the goals of the 'Vision 2020' for European aeronautics and the Concept of Operations for the Single European Sky (SESAR CONOPS, Sesar 2007b).

Participants and controllers were then asked for their criticisms about 'Vision 2020' and SESAR CONOPS. Both ATCOs and pilots emphasised the risk of a single workplace replacing teamwork, shift of competencies or incapacitation and inappropriate system design. Upon collecting risks about future aviation, participants were asked for their ideas about future aviation. Visionary scenarios dealt with the process of negotiation of 4D-trajectory, tactical planning and operating of flights, improvements of human resource planning, first draft of a virtual workspace and a new approach to line and recurrent training.

About four months later an integrative workshop with the same pilots and air traffic controllers was conducted to exchange the ideas and concepts. Mixed groups consisting of ATCOs and pilots elaborated several ideas: a concept of trajectory negotiation, procedures for operating flights in the future and an integrated training system for pilots and air traffic controllers. Finally, participants derived future scenarios which should according to their background be simulated and tested in the ongoing project. A detailed description of the lay-

out and the outcome of the workshops is provided by Bruder, Jörn & Eißfeldt (2008).

To obtain a first impression of potential changes in ability requirements in a more standardised way, participants of the workshops were asked to rate the ability requirements for the future ATM system. To do so participants teamed up in pairs with always one of each background to enable a mutual understanding of scales to be rated and to support the exchange of views. Each participant then gave his rating for his professional role in the light of his understanding of the future ATM system.

Finally, workshop participants designed future scenarios which should, according to their background, be simulated and tested in the ongoing project. This process is reported in detail elsewhere (Bruder et al., 2008). The resulting simulations as well as the deduction of experimental scenarios are documented in the final report (Eißfeldt, Grasshoff, Hasse, Hoermann, Schulze Kissing, Stern, Wenzel & Zierke, 2009). Only the results obtained with the F-JAS in a free flight simulation will be reported here to further evaluate potential shifts in ability requirements.

3   Method

The Fleishman Job Analysis Survey (F-JAS; Fleishman 1992a) was used to depict ability requirements for the future ATM system. The F-JAS is a survey measuring human abilities, providing detailed definitions and anchored rating scales for 72 scales covering the domains of cognitive, psychomotor, physical and sensory abilities as well as interactive/social and knowledge/skills scales, the latter of which is still under research. With the F-JAS job incumbents are asked to use a 1 to 7 scale to 'rate the task on the level of the ability required, not the difficulty, time spent or importance of the ability' (Fleishman 1992b, p.7).

It comes with a detailed 'Administrators Guide' (Fleishman, 1992b) and the 'Handbook of Human Abilities' (Fleishman & Reilly, 1992), providing some theoretical background and lists of validated tests measuring certain abilities including reference data of test providers. A typical example scale is shown in Figure 2. In 1996 the F-JAS Kit Part 2 was published covering 21 social/interpersonal abilities. The F-JAS has been used at DLR in a number of studies with high rates of success (Eißfeldt & Heintz, 2002; Goeters, Maschke & Eißfeldt, 2004).

During the integrated workshop of the Aviator 2030 project a special version of the F-JAS was used, including not only the original scale material but also anchors representing the requirements of current pilots and air traffic controllers. This version is described in detail elsewhere (Eißfeldt 2009). Figure

2 shows an example scale, with integrated anchors for air traffic controllers (small box left of scale axis) and pilots (small box on the right).
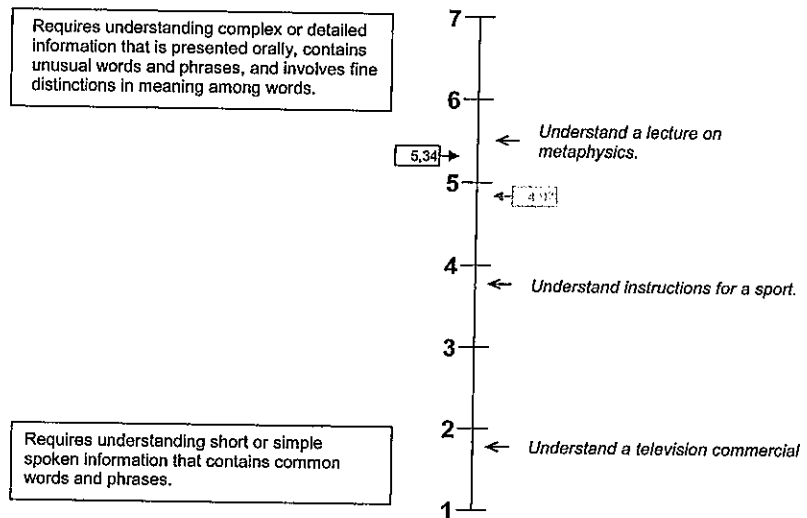

Figure 2. Example scale F-JAS Aviator: Oral comprehension with added anchor scales for air traffic controllers and pilots. Adapted from Fleishman (1992a), with permission.

4   Results

Many of the scales in the cognitive domain were rated very similarly for the future ATM system as for the current job requirements. For air traffic controllers, a strong increase was found with 'problem sensitivity' and 'speed of clo-

sure'; a strong decrease was rated for 'originality', memorization' and 'spatial orientation'. For pilots, a strong increase was indicated for 'deductive reasoning' and a strong decrease was found in 'number facility'. Given that 'abilities with mean ratings of four or greater are generally considered to be important for the job' (Fleishman & Reilly, 1992, p.10) the impression based on the findings from the Aviator 2030 integrative workshop is that the overall profile of cognitive ability requirements will not change significantly in future ATM concepts for both professions, with some minor adjustments being proposed.

Secondly, we looked at the similarity of ratings for pilots and controllers: in the domain of cognitive abilities, most of the ratings are not much different for the two groups. Only two of the cognitive scales showed significant differences between pilots and air traffic controllers: 'spatial orientation' and 'visualization'. As air traffic controllers need to have a mental 'picture' of future movements on the radar screen, 'visualization' is amongst those factors rated above six on the 7-point scale, whereas for pilots this cognitive ability is rated slightly above five for the current job conditions. With the future ATM concepts there was a slight increase for 'visualization' in both groups, as was seen with a lot of the cognitive abilities. Also 'oral comprehension', 'oral expression', 'problem sensitivity', 'deductive reasoning', 'inductive reasoning', 'category flexibility', 'speed of closure', 'perceptual speed' and 'time sharing' all showed a slight increase with the future ATM concepts for both professional groups.

With 'spatial orientation' it was different; here the rating for the current job condition was very high (>6) for pilots and a bit less for air traffic controllers. With the future ATM concepts there was a slight increase in relevance for the pilots and a sharp decrease for the air traffic controller group. A similar but only slight tendency was found in the ratings for 'selective attention' and 'information ordering'.

There was not a single cognitive ability showing an opposite pattern: decrease of relevance with pilots and increase with air traffic controllers.

In a third pattern of results the relevance of abilities decreased with the future ATM concepts for both professional groups. 'Written comprehension', 'written expression', 'originality', 'memorization', 'mathematical reasoning', and 'number facility' all showed decreasing relevance with future ATM concepts, as discussed in the Aviator 2030 workshops.

Concerning the sensory / perceptual abilities somewhat surprising results evolved: Speech-related abilities were rated with higher relevance for future ATM in both groups of workshop participants, although in future ATM a significant reduction in voice communication through data link is expected. Overall for most scales only small changes for pilots and controllers are observed. The only significant increase is found for Visual Colour Discrimination, for both controllers and pilots, reflecting the high demand in decoding colour-coded information presented on the radar screen.

Most of the social / interactive abilities rated by the participants of the integrative workshop are from the original F-JAS set of abilities, although some were developed by DLR to cover the content of resource management trainings in Aviation (Goeters et al, 2004).

The general finding for these scales is the increasing importance of social / interactive abilities for future ATM systems for both professions in general: in eleven out of these 18 ability scales, the required level increases slightly for pilots and controllers. For pilots there is an increase in all but two ability scales, and the only significant increase is for 'resilience'.

Results of the F-JAS presented in this section reflect the opinion of experienced aviation professionals after several days of detailed work on the future of their jobs. Using F-JAS rating scales with special aviation anchors, workshop participants in general indicated neither relief nor much intensification of cognitive and sensory / physical ability requirements. What can be foreseen is pilot's and air traffic controller's profiles assimilating with regard to cognitive abilities mostly linked to the new task of airborne separation. If there is an increase in requirement levels this can be stated for pilots rather than for controllers.

However, the F-JAS instrument was applied at different stages during the Aviator project. At a later stage a reduced set of scales was administered repeatedly with additional research scales to reflect the experience of skilled aviation professionals during the baseline and future scenarios of a free-flight simulation.

4.1 AviaSim study

The AviaSim study used a low-fidelity integrated simulation to look into potential shifts in ability requirements for ATCOs and pilots with future ATM concepts. Based on proposals from the Aviator integrative workshop a free-flight scenario was set up with special emphasis on the transfer of control authority as shown in Figure 3 (Hoermann, Schulze Kissing & Zierke, 2009). The simulation platform AviaSim was configured for one controller position and up to eight cockpit positions for pilots. The ATC environment provides a Short-Term Conflict Alert (STCA) function, Mid-Term Conflict Detection (MTCD) as well as various flight-plan visualizations, interactive labels, and data link communication. The cockpit environment is basically the Microsoft Flight Simulator© with a B737-800/900 layout in combination with a self-developed traffic visualization system (Cockpit Display of Traffic Information, CDTI) displayed on a special 9 inch screen. Also a transparent area is projected into the cockpit window on which the ATC instructions, transmitted via data link, can be displayed. In order to study the transfer of control in free flight airspace it was important to ensure a highly realistic execution of the en-route flight

phase. This means that the autopilot system must have a broad functionality and that the Flight Management System (FMS) must have realistic programming possibilities. For the purpose of self-separation in free flight airspace the TCAS was functional in all aircraft participating in the experiment.

The simulation experiment was conducted at the DLR human factors laboratory in Hamburg. Twenty male operators participated in the study, five of whom are centre controllers of the Deutsche Flugsicherung (DFS) with an average of 30 years work experience, and 15 licensed Lufthansa pilots with an average experience of 1394 flight hours. The subjects were examined in five groups, each consisting of one controller and three pilots. Each group was tested on a separate occasion. During the simulation runs participants were seated in separate rooms with all simulated positions linked via LAN (Local Area Network). One confederate experimenter controlled an additional aircraft in order to enrich the scenarios with a certain number of difficult situations.
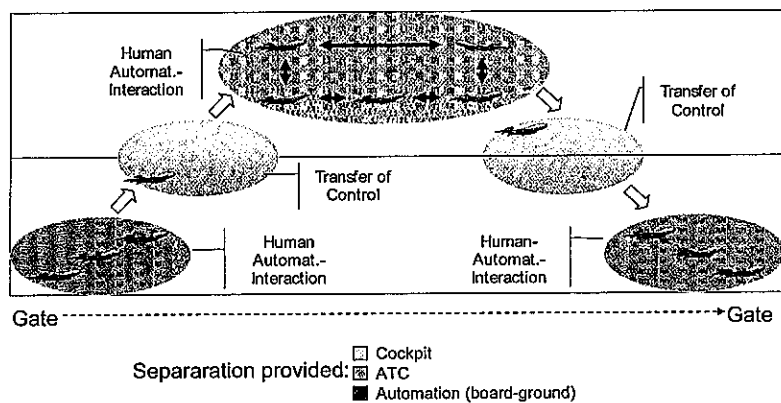
AviaSim

Figure 3. Responsibility for separation tasks in distributed air-ground teams.

Each subject group participated for two days in the experiment. Day 1 served as a familiarization day with a general briefing followed by some hands-on training on the simulators. Finally, the group of subjects participated jointly in a one hour training run. Day 2 started with an introduction of the concept of transition zones and the required procedures for transitions from managed airspace to free flight airspace and vice versa. Then three en-route scenarios of about 45 minutes in duration were exercised jointly. The task in each of the scenarios was to manage the traffic and operate the aircraft safely and effi-

ciently. Subsequent to each scenario, subjects completed the relevant questionnaires with the F-JAS among them. The study is described in full detail elsewhere (Eißfeldt et al., 2009).

4.2 AviaSim findings F-JAS

With AviaSim a reduced set of scales was administered repeatedly with additional research scales to reflect the experience of participants during the baseline and future simulation scenarios. Only the cognitive abilities have been applied identically to the original with 21 scales. All other domains have been reduced down to 5 or 6 scales deemed relevant for the special setting of the study as proposed in the test manual.

In general the AviaSim results reflect the findings of the integrative workshop well; pilot ratings are for most scales lower compared to air traffic controller ratings, for the baseline as well as for the future scenario (see Eißfeldt et al., 2009).

Figure 4 shows the mean ratings for air traffic controllers and pilots on the ability domain level for the baseline and the combined future scenarios. For both professional groups, ratings during AviaSim are lower compared to the ratings of the integrated workshop. This can be explained by the specific task reflected in the AviaSim exercise (i.e. en-route traffic separation), not covering other aspects of the general job of a pilot or air traffic controller. More interesting, however, is the development of magnitude from baseline to future scenario: the pilot ratings show an increase in required level consistently over all domains, whereas the ratings of the air traffic controllers do not vary systematically. For the cognitive domain this effect for the pilots is strongest, however failing shortly to reach significance ($p = .056$).
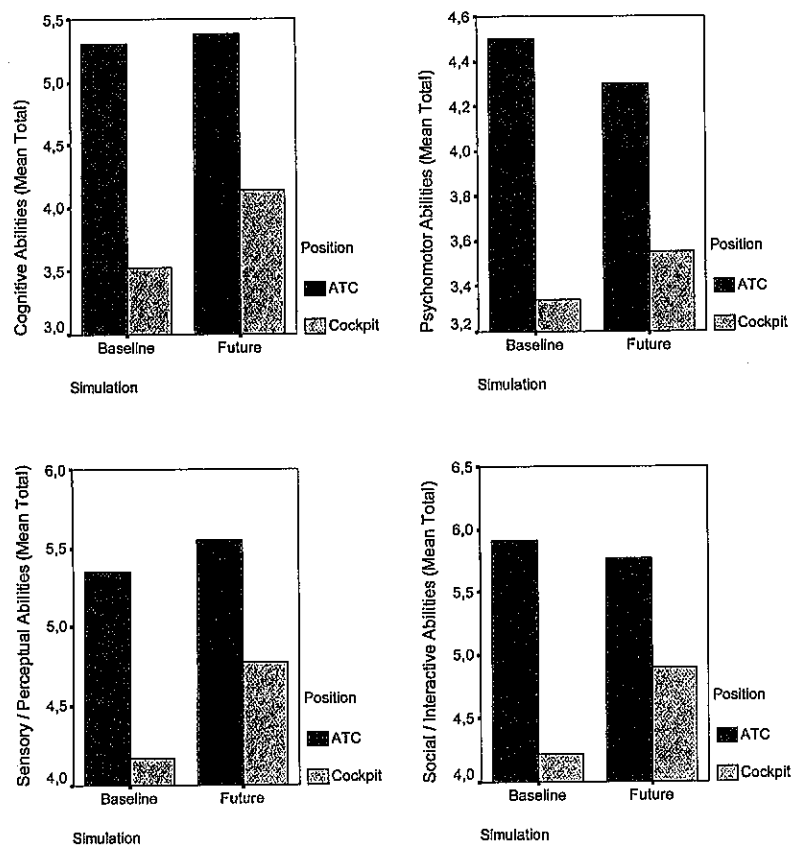
Figure 4. Mean scores by F-JAS ability domain as rated by air traffic controllers and pilots during AviaSim.

Analysing the AviaSim results for abilities being rated significantly different for baseline and future scenario by either controllers or pilots underlines this finding. For the pilots eight scales show significant differences, namely 'fluency of ideas', 'originality', 'inductive reasoning',' information ordering', flexibility of closure', 'selective attention' plus the research scales 'situation awareness' and 'control of impulsiveness'. All show an increase in requirement from baseline to future scenario. For the air traffic control side only four scales show significant differences: 'oral comprehension', 'written expression', 'originality' and 'speed of closure', with three of them (not: 'written expression') showing a decrease in requirement level. So it can be stated that the results for the future scenario consistently show an increase in requirement levels for pilots, whereas

the requirements for controllers seem to remain stable if not decreasing in a few scales.

A final look on the F-JAS ratings concerns the ranking of scales. Figure 5 lists the top ten ability requirements as rated in the AviaSim study for the future scenario. The numbers in brackets refer to the ranking position for the baseline scenario and are well in line with other applications of the F-JAS (e.g., Goeters et al 2004). On the controllers side the positioning of 'time sharing' at the bottom of the top ten list is remarkable as for air traffic controllers this has been the top rated ability requirement in all studies of current ATC so far. For pilots this scale has moved upwards a bit in the free flight scenarios. A common upward trend can be noted for a variety of abilities: 'perceptual speed', 'speech recognition', 'stress resistance', 'decision making' and 'problem sensitivity' all are becoming more relevant for both professions with the free flight scenario. Pilots and air traffic controllers share eight of the ten top future rankings underlining the notion of profiles assimilating in free flight scenarios. The abilities not in common are: 'selective attention' and 'resilience' rated high for ATC but not for pilots, whereas 'spatial orientation' and 'auditory attention' are among the top ten for pilots but not for ATC. Among the top rated scales for both professions were also 'situation awareness' and 'trust in automation', however representing concepts rather than ability requirements these research scales are not listed here. If both lists were aggregated into one 'Aviator Free Flight Profile' according to their rankings, 'problem sensitivity' would come first followed by 'decision making' and 'vigilance' and 'visualization'.

ATC future	Cockpit future
1. Problem Sensitivity (2)	1. Spatial Orientation (5)
2. Decision Making (3)	2. Vigilance (2)
3. Selective Attention (14)	3. Visualization (7)
4. Stress Resistance (9)	4. Problem Sensitivity (12)
5. Speech Recognition (15)	5. Decision Making (9)
6. Resilience (4)	6. Time Sharing (10)
7. Vigilance (5)	7. Speech Recognition (8)
8. Visualization (6)	8. Stress Resistance (11)
9. Perceptual Speed (16)	9. Auditory Attention (1)
10. Time Sharing (1)	10. Perceptual Speed (15)

Figure 5. F-JAS AviaSim: Top ten ability requirements for AviaSim future scenario as rated by pilots and air traffic controllers.

5   Discussion

The most demanding change in ability requirements for pilots is seen to be 'visualization', as in the future, the task of conducting airborne separation in free flight airspace requires 'having a picture' of relevant elements of air traffic similar to that of air traffic controllers. This new requirement is not reflected in today's selection profiles of pilots.

It can be assumed that different ability levels concerning 'visualization' within the present pilot population exist, as this requirement is not directly tested in many ab-initio pilot selection systems. It will be interesting to see how effective pilot training for self-separation can compensate for these differences in the future.

Other results need to be treated carefully. For instance the high requirement level for 'vigilance' with pilots might be due to single pilot operation in our scenarios. However, findings from the workshop debriefings as well as from other work in the project suggest a new requirement to be crucial for humans operating in man-machine settings: 'operational monitoring'. Operational monitoring includes using one's senses to follow up meaningful information from various sources (e.g. an automated system) responsibly without direct need for action. It involves being prepared to fully take over the handling of a system at any time, for example in the case of malfunction. In view of the AviaSim findings, operational monitoring would be marked by some of the ability requirements rated highest by pilots and air traffic controllers for the future scenario: problem sensitivity, situation awareness, decision making and vigilance all merge in this requirement when it comes to working with automation.

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