Not all or nothing, not all the same: classifying automation in practice

by Dr Luca Save

Different Levels of Automation

Since the seminal work of Sheridan & Verplanck[39] it has become apparent that automation is not 'all or nothing', that is, automation is not only a matter of either automating a task entirely or not, but to decide on the extent it should be automated. The well-known 10-points scale proposed by these authors was successful in representing a continuum of levels between low automation, in which the human performs the task manually, and full automation in which the computer is fully autonomous. But the practical experience of classifying automation shows that the two extremes of this scale are somewhat rare in complex transportation systems, at least as we know them nowadays. A fully manual task is difficult to find as much as a fully automated one. Keeping away from science fiction, functions with no human intervention at all are difficult to design, especially in 'open' systems like ATM. Even when considering examples of advanced automation, such as the modern driverless metro lines, it is interesting to note the tendency to protect or isolate the infrastructure to reduce the risk of external interferences which may put at risk the safety and efficiency of operations (the images below show an example of the platform doors adopted in most of the modern metro stations and a well isolated track of the same metro, in a section which is not underground). When these or similar solutions are more difficult to adopt, like for a tram running on street traffic or in a traditional railway network with several junctions and intersections, the presence of a driver is normally required. In addition, removing the driver does not imply a complete elimination of human monitoring, which remains necessary even if operated in a remote and centralised form and with the support of sophisticated technologies

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Two images of a 'driverless' metro line in Toulouse (France)

Hence the range of options between 'automation' and 'no automation' is a wide one and it is worth considering the advantages and disadvantages of each of them.

Qualitative differences in the automation

Over the years, research on automation has also highlighted an important aspect of the changes delivered by automation. Introducing automation means bringing qualitative shifts in the way people practice and not just delegating a set of pre-existing tasks to a machine[40]. No matter how much emphasis is put on this transformation e.g. modifying existing tasks or introducing radically

39- Sheridan, T. B., & Verplank, W. (1978). Human and Computer Control of Undersea Teleoperators. Cambridge, MA: Man-Machine Systems Laboratory, Department of Mechanical Engineering, MIT.
40- Dekker, S.W.A. & Woods, D.D. (2002). MABA-MABA or Abracadabra? Progress on Human -Automation Co-ordination. Cognition, Technology & Work, 4(4), 240-244.

new ones, it should be clear that different tasks involve the use of different psychomotor and cognitive functions, which in turn implies the adoption of different automation solutions. For example, expanding human capabilities to monitor a certain process (e.g. a Remote Tower) is not the same as replacing the human in the execution of a certain action (e.g. the aircraft auto-braking system). Similarly supporting the analysis of a complex dataset, such as that involved in predicting the risk of a traffic conflict, is not the same as identifying the best solution to resolve the conflict.

Some of these differences have been captured in the 'Model for Types and Levels of Automation' by Parasuraman, Sheridan and Wickens[41], which was probably the most significant evolution of the famous 10-point scale. Their model introduced the idea of associating levels of automation to 4 generic functions, derived from a four-stage model of human information processing:

1. Information Acquisition,
2. Information Analysis,
3. Decision and Action Selection
4. Action Implementation.

A consequence of having four functions – different in nature – is that each function can be automated at different levels.

41- Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. IEEE Transactions on Systems, Man, and Cybernetics – Part A: Systems and Humans, 30, 286–297.

Not all or nothing, not all the same classifying automation in practice (cont'd)

The experience of classifying automation in SESAR

In the context of a SESAR project named 'Good Practices for HP Automation Support', we took the lesson of Parasuraman et. al. seriously. We decided to consider different automation levels inside each function as a means to derive guidelines for the identification of effective automation solutions[42]. One of the main challenge we were facing from the beginning was the lack of a specific taxonomy to distinguish different levels for the different functions. As also explained by the authors, the original 10-point scale was essentially focused on "Decision and Action Selection" and the concept required significant adaptation in order to also work for the other three generic functions, including the need to consider a different number of levels within each of them. We therefore opted for the development of a new **Level of Automation Taxonomy (LOAT)** which was presented as a matrix[43].

In its final version the taxonomy uses 4 columns, corresponding to the 4 generic functions. Each one has a different number of automation levels – 5 for "Information Acquisition" and "Information Analysis", 6 for "Decision and Action Selection" and 8 for "Action Implementation". The development resulted from a combination of theoretical work investigating the different ways of sustaining human practices and the analysis of 26 examples of automated functionalities, from both ground and aircraft-related systems.

From INFORMATION to ACTION →

INCREASING AUTOMATION ↓

A INFORMATION ACQUISITION	B INFORMATION ANALYSIS	C DECISION AND ACTION SELECTION	D ACTION IMPLEMENTATION
A0 Manual Information Acquisition	**B0** Working memory based Information Analysis	**C0** Human Decsion Making	**D0** Manual Action and Control
A1 Artefact-Supported Information Acquisition	**B1** Artefact-Supported Information Analysis	**C1** Artefact-Supported Decsion Making	**D1** Artefact-Supported Action Implementation
A2 Low-Level Automation Support of Information Acquisition	**B2** Low-Level Automation Support of Information Analysis	**C2** Automated **Decsion Support**	**D2** Step-by-Step Action Support
A3 Medium-Level Automation Support of Information Acquisition	**B3** Medium-Level Automation Support of Information Analysis	**C3** Rigid Automated **Decsion Support**	**D3** Slow-Level **Support** of Action Sequence Execution
A4 High-Level Automation Support of Information Acquisition	**B4** High-Level Automation Support of Information Analysis	**C4** Low-Level Automatic **Decision Making**	**D4** High-Level **Support** of Action Sequence Execution
A5 Full Automation Support of Information Acquisition	**B5** Full Automation Support of Information Analysis	**C5** High-Level Automatic **Decision Making**	**D5** Low-Level **Automation** of Action Sequence Execution
		C6 Fulll Automatic **Decision Making**	**D6** Medium-Level **Automation** of Action Sequence Execution
			D7 High-Level **Automation** of Action Sequence Execution
			D8 Full **Automation** of Action Sequence Execution

A condensed version of the LOAT matrix

42- SESAR Joint Undertaking (2013). Guidelines for Addressing HP Automation Issues. P16.5.1 Deliverable 04.

43- For a detailed version of the matrix including the definitions of individual automation levels refer to Save, L. Feuerberg, B. (2012) Designing Human-Automation Interaction: a new level of Automation Taxonomy. In De Waard, D. et al (Eds.) (2012), Human Factors: a view from an integrative perspective. http://www.hfes-europe.org/human-factors-view-integrative-perspective/

SOME CLASSIFICATION EXAMPLES

A few examples of the findings derived from the study are briefly described, each one associated with an illustrative scenario.

1 Automation is not just substitution.

Only in very few cases automation is about completely replacing the human. As already noted, this is unlikely in 'open' and complex systems like ATM. We reflected on this aspect when analysing the example of the AP/FD (autopilot/Flight Director) TCAS mode developed by Airbus. This innovation has consisted in enhancing the current TCAS RA (Traffic Collision Avoidance System Resolution Advisory) functionality in the case of corrective RAs by directly connecting it to the autopilot. Provided the autopilot is already engaged, once a TCAS RA is annunciated, it is then flown by the autopilot. It is interesting to observe how this may have led to misconceptions by those not actually in the flight deck in relation to its actual nature. Examples of these misconceptions are apparent in statements such as: "the pilot is no longer in the loop" or "the risk of pilot error has been eliminated, as the aircraft is now flown by reliable automation".

A more careful consideration revealed that the role of the crew remains a central one, even if pilots are not actively involved in the execution of the manoeuvre. Annunciation of a corrective TCAS RA normally requires the pilot to disconnect the autopilot and follow the RA based on visual indications whereas, with the new arrangement, the manoeuvre is performed by the autopilot. The crew must still monitor the manoeuvre and, as always, can disconnect the autopilot and fly the aircraft manually if deemed necessary. So in practice the new situation does not relieve the crew from remaining in the loop just as before since the crew needs to monitor the situation and be ready to communicate with the ATC and carry out the necessary actions once 'Clear of Conflict" is activated by the TCAS. In terms of the LOAT taxonomy, both the manual and automatic TCAS RA response represent "Decision and Action Selection" support at a level C4 ("Low-Level Automatic Decision Making). While a difference is more obvious in the case of "Action Implementation" support, which passes from a level D2 ("Step-by-step Action Support) to a level D6 ("Medium Level Automation of Action Sequence Execution). It is a higher level of automation, but it is important to note that it is not yet the highest one.

2 The highest possible level is not always the best level.

This was observed when comparing the automated functionalities of different MTCD (Medium Term Conflict Detection) tools. In some cases these are designed to activate only on controller's request as with the what-if function used to detect potential conflicts before issuing a clearance). In other cases the functionalities automatically trigger an alert as soon as the alerting logic of the tool detects a conflict. Both processes are "Information Analysis" functions. However the functions in the first group correspond to a lower level than those in the second group.

Analysis of different validation reports highlighted the fact that a higher level of automation offered a better support when the operational environment and the airspace concerned were of limited complexity. On the other hand, a lower level of automation represented the best compromise in the case of traffic flows characterised by an elevated number of vertical evolutions, which also implied a limited accuracy of the trajectory prediction. In such cases the lower level of automation was still offering a useful support to the conflict detection task, but minimised the number of nuisance alerts which, by contrast, tended to jeopardize the usefulness of the higher level functions.

3 A lower level of automation might be better than no automation.

Failing to identify the best level of automation may also imply renouncing the benefit of an automation. In line with the previous example, this emerged when comparing two different configurations of an AMAN (Arrival Manager) tool, which were both "Decision and Action Selection" functions. The first configuration provided advisories to the controller at a lower level of automation. For example a "G" advisory on the track label indicated the need to gain 2 minutes or more with respect to the predicted arrival of the concerned aircraft. While an "LL" advisory ("lose lose") corresponded to the request to lose 6 minutes or more. The other configuration was

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based instead on more directive advisories. These included a precise indication on the track label of the desired ground speed (e.g. "286") and of the time to start the "Top of Descent" (e.g. "9.30").

In principle, the second configuration ensured the creation of a more orderly and stable sequence of aircraft, provided that controllers strictly followed the advisories when communicating with each aircraft. However, in the specific environment in which the functionality was tested, the characteristics of the ATS geography, as well as the terrain in the terminal area, imposed a number of different operational constraints on controllers. For example it was not possible to systematically apply the continuous descent approach, which in principle would have been the most efficient and cost effective profile. The controllers therefore preferred the first configuration, since the lower level advisories left them with a choice between different ways of achieving the same goal. For example, a delay of a few minutes could have been created by either reducing the speed and remaining at the same level until the top of descent or by anticipating the descent and issuing clearances for a staged or non-continuous descent. The selection of a different course of action from the one indicated by the AMAN advisories was of course also possible with the higher level configuration of automation. However, if controllers then failed to follow the indications precisely, there was no alternative to just bypassing / ignoring the automation.

4 Pilot and Controller tasks are not automated in the same way.

Aircraft automation is sometimes considered to be more advanced than ATC automation. This perception is only partially true, as it seems to disregard the different nature of pilot and controller activities, at least to the extent that non-pilots sometimes understand them. Pilot tasks are much more "Action Implementation" oriented than controller tasks, for which the emphasis is more on monitoring, planning and communicating. Therefore, the replacement or support of a human action – which is normally perceived as "real" automation – is inevitably more successful when pilot tasks are concerned.

In the limited number of automated functionalities we examined in our SESAR study, there was a prevalence of "Information acquisition" and "Information Analysis" functions in ATC-related automations. Examples of this were the Multi-Radar Tracking system display, the STCA (Short Term Conflict Alert) system, the MTCD (Medium Term Conflict Detection) system and the TCT (Tactical Controller Tool). On the other hand there was a clear prevalence of "Action Implementation" functionalities among aircraft automations. For instance, in addition to the above mentioned automated TCAS RA response, we looked at the Autopilot following an FMS trajectory, the Autobrake system and the ASAS-ASPA (Airborne Separation Assistance – Airborne Spacing system) capability.

Finally a more balanced distribution between ground and aircraft was observed for the "Decision and Action Selection" automations, although the ATC functionalities were generally less mature and were providing a lower level of support. AMAN, which is a good example of ATC "Decision and Action Selection" functionality, is increasingly prevalent but in most of the cases it provides just a useful reference that the controller may decide to follow or not, depending on operational circumstances. This kind of support is at a considerably lower level than that offered, for example, by a TCAS RA which indicates to the pilot one single and directed action to avoid possible collision with conflicting traffic.

It is interesting to note that some of the aircraft functionalities we analysed also included "Information Acquisition" and "Information Analysis" components. However these were generally acknowledged to be less sophisticated than the ATC-related ones (consider the example of the TCAS Traffic Display which is known to be of limited functionality relative to controllers' radar displays and well known to be unusable by pilots as a means of self-separation).

Much more sophisticated "Information Acquisition" functionalities are beginning to be introduced for the flight deck and we looked at ATSAW-SURF (Air Traffic Situation Awareness for Surface Operations) – which uses ADS-B IN capability. More than just a simple technological improvement, this will, subject to the development of operator procedures, make possible a partial delegation to pilots of tasks which have previously been an exclusive prerogative of ATC.