B

GUIDANCE MATERIAL:

AUTOMATION

0 INTRODUCTION

The purpose of this annex is to provide recommendations on how to address automation especially when looking at its influence on the design and its safety-related aspects.

1 INTRODUCTORY MATERIAL

1.1 Definition

Automation is replacement of a human function, either manual or cognitive, with a machine function (usually a computer).

What is considered automation will therefore change with time. When the reallocation of a function from human to machine is complete and permanent, then the function will tend to be seen simply as a machine operation, not as automation.

1.2 Purpose of automation in ATM/CNS

Automation is viewed as a viable and a requisite approach to comply with the demands for increased efficiency and improved safety.

Automation is introduced in ATM/CNS:

- To improve safety and to lessen the risk of a human error by reducing the ATCO's high mental workload;
- To increase efficiency, in order to accommodate the foreseen growth of traffic.

1.3 Levels of Automation

Levels of automation - decision and control action

10 The computer decides everything and acts autonomously, ignoring the human.

9 Informs the human only if the computer decides to.

8 Informs the human only if asked.

7 Executes automatically, then necessarily informs the human.

6 Allows the human a restricted time to veto before automatic execution.

5 Executes that suggestion if the human approves.

4 Suggests one alternative

3 Narrows the selection down to a few.

2 The computer offers a complete set of decision/action alternatives

1 The computer offers no assistance: the human must take all decisions and actions

1.4 Potential Problems

Automation does not supplant human activity; rather it changes the nature of the human work – often in a way that is not intended by the designers of automation.

Automation demands use of different resources - resources that in some areas require fundamentally different skills, procedures etc. - could be considered as a more demanding role.

While the positive impact of automation on safety and efficiency is undeniable, some new and potentially serious issues may arise as a consequence of the way humans interact with automation.

The following items are some of the problems to be aware of in an automated environment:

- If the human operator is not aware of the automation level, loss of system awareness will occur.
- If the human approach to system operation is not considered during system design, it reduces the operator's monitoring possibilities. The "cognitive level" required to manage the level of automation is too high.
- If the human is not involved in the system design, it may have influence on the attitude to automation.
- If the human operator's relationship to the management suffers it may have influence on the attitude to automation.
- If a system fails there is a tendency not to discard the automation and take over manually.
- If the mental workload is high, systematic decision errors, generated of the individual human bias, may occur.
- If humans become confident that the system performs "reliable", there is an obvious risk that they become more tolerant of errors.
- If humans do not rely on automated systems, they will remain reluctant to interfere with them.
- If the automated system behaves different than expected or if the system operates in a not intended mode, it may lead to distrust.

- If introduction of an automated system leads to interaction between the human and the machine only rather than between the humans in the group, it may over time lead to isolating of the individual human experience to the human itself and the team function advantages may suffer.

2 HUMAN PERFORMANCES AND AUTOMATION

- *When, why and how does people decide whether to use automation or to disuse, misuse or abuse it?*
- *Do they make these decisions rationally or based on non-rational factors?*
- *Are automation usage decisions appropriate given the relative performances of operator and automation?*

2.1 Definitions

Use Of Automation

Use refers to the voluntary activation or disengagement of automation by human operators.

Misuse Of Automation

Misuse refers to over-reliance on automation and inadequate monitoring of automated systems.

Disuse Of Automation

Disuse refers to under-utilisation of automation.

Abuse of Automation

Abuse refers to an inappropriate application of automation by designers and managers or to inappropriate usage of automation by operators

2.2 Human and Automation

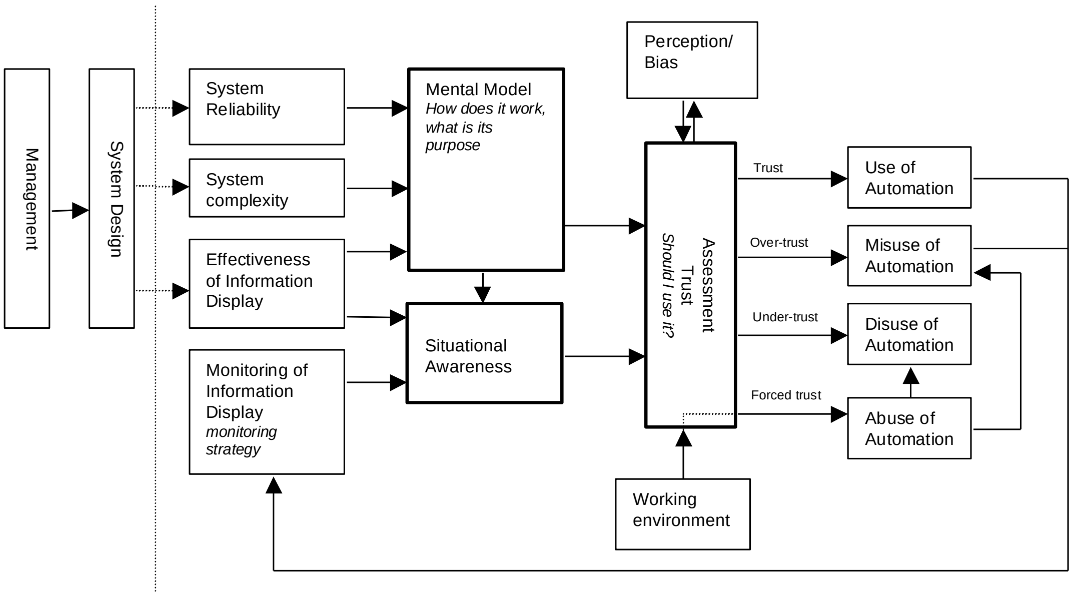
The figure below illustrates the relationship between the major elements of human interaction with automated systems:

- the mental model;
- the situational awareness and,

- the hence derived assessment.

Generally speaking, the mental model is the operator's understanding of how the automation works. The mental model is affected by the influence of the actual automated system reliability, the system complexity and the effectiveness of the information presented for the operator.

The mental model contributes to the operator's situational awareness, which is also affected by the operators monitoring strategy and the value of the information provided by the automated system.



The assessment, the decision of using automation, is affected by the outcome of the mental model and the situational awareness, and furthermore, by the operator's perception and bias and the working environment.

Perception and bias are the subjectivity in the assessment process and, for example, it could be affected by the operator's attitude towards automation, skill or self-confidence.

The working environment includes the management limitations, workload, working procedures, ergonomics of the design, etc., have an effect on the assessment as well.

The outcome of the assessment process of is a degree of trust or reliance on automation, which lead to a way to use automation: use, misuse, disuse or abuse of automation.

2.3 Why Automation is used, misused, disused or abused?

"*Human use of automation is complex, subject to a wide range of influences, and capable of exhibiting a wide range of patterns and characteristics. That* *very complexity makes the study of automation a large undertaking, but the growing importance of automation in systems makes such study increasingly imperative.*

Better understanding of why automation is used, misused, disused or abused will help future designers, managers and operators of systems avoid many of the errors that have plagued those of the past and present.

Application of this knowledge can lead to improved systems, the development of effective training curricula, and the formulation of judicious policies and procedures involving automation use."

Raja Pasuraman

2.3.1 Use of Automation

Automation use decisions are based on a complex interaction between many factors and subject to strongly divergent individual considerations. For example,

- ***Attitude Towards Automation.*** Automation use and attitude towards automation are correlated. Attitudes towards automation vary widely among individuals.

- ***Workload***. As automation is introduced to lessen the likelihood of human error by reducing the operator's workload, one would expect that an operator is more likely to choose automation when his or her workload is high than when it is low or moderate.

- ***Trust***. An important factor in the development of trust is automation reliability. If automation reliability is high, operators will rely on it. Another factor of trust is related to the ease to understand what automation is doing and why.

- ***Cognitive Overhead***. The ease of automation usage and learning contributes to automation usage.

- ***Skill, Confidence and other factors***. Skill and self confidence affect also automation usage. Fatigue could also a reason to rely on automation (with the danger to lead to over-reliance on automation).

2.3.2 Misuse of Automation

Automation may fail or behave unpredictably. Excessive trust on automation can lead to rely uncritically on automation without recognising its limitations or fail to monitor the automation's behaviour.

Over-reliance on automation represents an aspect of misuse that can result from several forms of human error, including decision biases and failures of monitoring.

- ***Decision Biases.*** Decision biases may result in omission errors, in which the operator fails to notice a problem (especially, when its occurrence is expected to be rare) or take an action because the automated aid fails to inform the operator.

- ***Human Monitoring Errors.*** Over-reliance on automation could also lead to poor monitoring of the automation performances, thus preventing the detection of occasional malfunctioning or failure of automation.

2.3.3 Disuse of Automation

When introduced into workplace, the operator may dislike, and even mistrust a new automated system.

As experience is gained with the new automated system, automation that is reliable and informative, will tend to earn the trust of operators.

An important cause of automation is disuse is related to the propensity of false alarms for alerting systems. Operator disabling or ignoring of alerting systems has played a role in several accidents.

Trade-off should be made between the frequency of false alarms and the detection efficiency of real hazardous conditions.

2.3.4 Abuse of Automation

Automation abuse is the automation of functions by designers and implementation by management without due regard for the consequences for human (and hence system) performance and the operator's authority over the system.

This lead to the concept of Technology Centred Automation. As the human operator is a major contributor of incidents and accidents, designers attempt to remove the source of error by automating functions carried out by human.

If designers tend to automate everything that leads to an economic benefit and leave the operator to manage the resulting system, several factors emerge:

- ***Automation simply replaces the operator with the designer***. To the extend that a system is made less vulnerable to operator error through the application of automation, it is made more vulnerable to designer error.

- ***The Technology Centred Automation may place the operator in a role which humans are not well suited.*** Indiscriminate application of automation, without regard to the resulting roles and responsibilities of the operator, has led many of the current complaints about automation.

- Automation abuse may lead to misuse or disuse of automation.

2.4 Practical Implications

"Many of the problems of automation misuse, disuse and, abuse arise from differing expectations among the designers, managers, and operators of automated systems.

Our purpose is not to assign blame to designers, managers, or operators but to point out that the complexities of the operational environment and individual human operators may cause automation to be used in ways different from how designers and managers intend.

Discovering the root causes of these differences is a necessary step toward informing the expectations of designers and managers so that operators are provided with automation that better meets their needs and are given the authority and decision-making tools required to use the automation to its best effect."

Raja Pasuraman

The question of how automation should be implemented directly addresses the principal issue of all automation: who should be in control? The question also touches upon the issues of how the automation affects the human operator's tasks, how the automation should operate and be controlled (distribution of functions between man and machine).

The overall system may benefit more by having an operator who is aware of the environmental conditions the system is responding to and the status of the process being performed by virtue of active involvement in the process, than by having an operator who may not be capable of recognising problems and intervening effectively, even if it means that system performance may not be as good as it might be under entirely automated operations.

Human capabilities and limitations shall be considered from the very early stages in the design process and system design needs to be evaluated in a simulated or secured operational environment by a representative extract of operators to ensure that as many occurrences as possible are predicted and considered in the system design.

Designers and managers should consider all factors determining use, misuse, disuse or abuse of automation. For example,

- ***Reliability.*** If automation reliability is relatively high, then operators may rely on automation, and occasional failures do not substantially deteriorate trust in automation (unless the failures are sustained).

- ***Complexity.*** Automation should not be difficult or time consuming to turn on or off. Simple, easy to understand automation should encourage automation usage and reliance on automation.

- ***Effectiveness and automation Status Information.*** Automation should provide sufficient information to maintain situation awareness of the ATCO and to detect degradation or loss of automated function.

- ***Mental Model.*** Better operator knowledge of how the automation works results in more appropriate use of automation. Training should also highlight the importance of some factors when considering whether or not to use automation.

- ***Perception and bias.*** Over-reliance and under-reliance antecedent conditions and consequences should be recognised by designers and managers.

- ***Working Environment.*** Poor relationships with management or poor interface design could affect automation usage. For example, workload should not be such that the operator fails to monitor automation effectively.

3 HUMAN-CENTRED AUTOMATION CONCEPT

"The ability of humans to recognise and define the expected, to cope with the unexpected, to innovate and to reason by analogy when previous experience does not cover a new problem is what has made the aviation system robust, for there are still many circumstances that are neither directly controllable nor fully predictable. It is a compelling reason to retain the human and the central position."

3.1 Why entering the human-centred concept?

Human errors have been identified as the primarily causal factor of incidents and accidents.

However, the experience shows that the so-called "human errors" are often induced by other aspects of the system.

By introducing the human factors from the design stage in system development, potential system induced human errors can be reduced.

Irrespective of the degree of automation, the operator is and will continue to be fully responsible.

As automated systems become more sophisticated, the risk of bypassing the operator increases. To oppose this trend the principles of Human-centred Automation must be implemented during the entire system life cycle.

A balance between the human and the automation shall be maintained and if compromises are needed it shall always be in the human favour – take into consideration the human characteristics – the weak points and the strong points.

3.2 Principles of Human - Centred Automation

The principles of Human-Centred Automation are given in the following Table.

The Human assumes the ultimate responsibility for the safety of the system.

Therefore:

- The Human must be in command.
- To command effectively, the Human must be involved.
- To be involved, the Human must be informed.
- Functions must be automated only if there is a good reason for doing so.
- The Human must be able to monitor the automated system.
- Automated system must, therefore, be predictable.
- Automated systems must be able to monitor the Human.
- Each element of the system must have knowledge of the other's intent.
- Automation must be designed to be simple to learn and operate.

3.2.1 The Human must be in command

- The responsibility for separation between controlled aircraft remains with the human.
- To assume responsibility for the safe separation of aircraft, the human must retain the authority to command and control those operations.

Potential Issues	Recommendations
• Managers and developers should recognise the essential unpredictability of how people will use automation in specific circumstances. • Training personnel should make	• Automation should be designed to assist the human in carrying out their responsibilities. • The human should be able to reverse to the pristine mode of non-automated functioning

operators aware of potential biases and influences in deciding to use or not to use automation.	whenever needed. • The human should be able to detect failure of the automated system, to correct their manifestations, to continue the operation safely until the automated system can resume their normal functions.

3.2.2 To command Effectively, the ATCO must be involved

- The human should have an active role, whether that role is to actively monitor the automated system.
- Keeping the human involved provides substantial safety benefits by keeping him/her informed and able to intervene.

Potential Issues	Recommendations
• If the human is not involved, it is likely that he/she will be less efficient in reacting to critical situations. • High levels of automation could result in over-reliance on automation, when the operator believes that the automation is 100 % reliable. • High levels of automation could also result in skill degradation, when the operator has little opportunity to practice the skills involved in performing the automated tasks manually.	• The decision to apply automation to a function should take into account the need for active human involvement, even if such involvement reduces system performances. • Adaptive tasks allocation may provide a means for involving the operator. Adaptive Task Allocation allocates functions between the operators and the automated system in a flexible way. For example, the operator can actively control a process during moderate workload, allocate this function during peak workload if necessary, and retake manual control when workload diminishes.

3.2.3 To be involved, the ATCO must be informed

- The human must have continuing flow of essential information to maintain situation awareness and to monitor the automation state.

Principle	Recommendations
• Over-reliance on automated solutions may reduce situation awareness. For example, advanced decision aids providing ATCOs with resolution advisories on potential conflicts, may lead to ATCOs accepting the proposed solutions as a matter of routine. This could lead to a loss of the "mental picture" in ATCOs, who tend to use automated conflict resolutions under conditions of high workload and time pressure. • Monitoring studies indicate that automation failures are difficult to detect if the operator's attention is engaged elsewhere. These studies suggest that attentional rather then purely visual factors underlie poor monitoring.	• The provided information must be informative enough to enable the human to intervene effectively. • Making automation state indicators more salient may enhance monitoring (e.g., integrated display).

3.2.4 Functions must be automated only if there is a good reason for doing so

- Automation can ***amplify*** human operator function, thereby allowing to the operator to be more efficient. When automation amplifies, its purpose is to aid the human operator in doing his or her job. When automation is used as amplification only, it leaves the human operator in control and makes the automation reversible, meaning that it should be possible for the human operator to reverse to the pristine mode of non-automated functioning whenever needed.

- Automation can ***substitute***, by taking over functions, from the human operator when automation could perform a function more efficiently, reliably or accurately than the human operator. Substitution can lead to problems when automation fails.

Potential Issues	Recommendations
• In situations where the automation perform tasks autonomously, it could be difficult for the human to remain aware of exactly what the automation is doing and why. • Such situation may lead to extreme distrust of the automated system	• Automation should generally be used to amplify Human performances: except in pre-defined situations, automation should never assume command. • In those situations in which the automation performs tasks autonomously, it should be able to be countermanded easily. • In contemplating where to introduce automation, it is necessary to analyse impact of any changes by all available means. One particular useful technique is to use dynamic simulations by using people in controlled conditions or interacting computer models.

3.2.5 The ATCO must be able to monitor the automated system

- The ability to monitor the automated system is necessary both to permit the human operator to remain on top of the situation and also because the automated systems are fallible.

Potential Issue	Recommendations
• Human monitoring tends to be poor in work environments that do not conform to well-established ergonomics design principle, in high workload situations, and in systems in which automation is highly autonomous and there is little experience with the automated tasks.	• The operator must be able, from information available, to determine that automation performance is, and in all likelihood will continue to be. • Feedback about the automation states must be provided, and it must be salient enough to enable the operator to intervene effectively.

3.2.6 Automated systems must be predictable

- The ATCO must be able to evaluate the performance of automated system against an internal model formed through knowledge of the normal behaviour of the system.
- Only if automated system behaves in a predictable fashion can the human operator rapidly detect departure from normal behaviour and thus recognise failures in automated systems.

Potential Issues	Recommendations
• Unpredictable behaviour of automated system may result in mistrust on automation and disuse of automation.	• Better human knowledge of how the automation works results in more appropriate use of automation • The design of the automated system should include means for the detection of potential failures of the automated system. • Procedures should be designed to recover from automated system failures and to continue the operations safety until the automated system can resume normal functions. • Human should be trained on the safety consequences of specific failures of the automated system.

3.2.7 Automated systems must be able to monitor the human operator

- Human are fallible also and their failures may likewise be unpredictable.
- Because human operators are prone to errors, its is necessary that error detection, diagnosis and correction be integral parts of any automated systems.

Potential Issues	Recommendations
• False alarms may result on operator's under-reliance on	• The design of the automated system should integrate human

automation.	error detection features (e.g., detection of wrong inputs). • The design of the automated system should be able to tolerate some human errors. • The design of alerting systems should take into account not only the detection threshold for these systems, but also the frequency of hazardous condition to be detected. • Alerting automated function should indicate when a dangerous situation is possible, rather than encouraging the operator to rely on the alarm for taking corrective action.

3.2.7 Each element of the system must have knowledge of the others' intent

- In highly automated operations, one way to keep the operator actively involved is to provide him or her with information concerning the intent of the automated system.
- Conversely, the automated system must be aware of the operator intent.

Potential Issues	Recommendations
• Lack of information of automated system intent may result in under-reliance on automation. • If the automated system cannot understand the human operator intent, it will be unable to monitor the human performance and to detect departure from normal behaviour.	• When automation is granted a high level of authority over system functions, the operator requires a proportionately high level of feedback so that he or she can effectively monitor the intent of automation and intervene, if necessary. • The more removed of the operator is from the operations, the more feedback must compensate for this lack of involvement. • It must overcome the operator's complacency and demand attention, and it must compensate the lack of awareness once the attention is gained.

3.2.9 Automation must be designed to be simple to learn and to operate

- Automation must be simple to use.
- Automation must be simple to learn.

Potential Issues	Recommendations
• If the operator perceives that the advantages offered by automation is not sufficient to overcome the cognitive overhead involved, then he or she may simply choose not to use the automation and to do the task manually. • If an automated system cannot be made to appear reasonably simple to the human, the likelihood that is will be misunderstood and operated incorrectly increases significantly.	• Better knowledge of how automation works results in more appropriate use of automation. • Knowledge of the automation design philosophy may also encourage more appropriate use. • The design should provide simple and intuitive automation that permit reversion in case of automated system failure

4 HUMAN FACTORS – RECOVERY FROM AUTOMATION FAILURES

Less than perfect reliability means that automation-related system failures can degrade system performance. System failures are both explicit and implicit and concern also failures introduced during system design; system fabrication, test, and certification; and during system maintenance.

Failure recovery in an automation perspective is the operator's ability in case of automation failure:

- to manage unexpected failures of the automation
- to continue the operation manually.

4.1 Potential Issues

Observation of the performance of automation have discovered a series of problems with human interaction with automation, with potentially serious consequences for system safety.

Most of them relate to human response when automation fails because implicitly, the automation assists the operator in maintaining the situational awareness and hence the operator's ability to manage higher traffic capacity, density and complexity.

As discussed in previous chapter, design and management influence on automation is an important factor. Poor design can have unfavourable influence on the system performance and contribute to failures, which require manual recovery and management decisions on operation; e.g. procedures and lack of authorisation to use or to disengage automation, may prevent the operator from using the automation effectively.

If automation fails it is reasonable to anticipate that manual take-over will be less efficient and with a safety impact on on-going operations. Automation will therefore require introduction of new procedures for recovery and as well for training and practice.

Several factors have influence on and are essential to an efficient failure recovery:

- the ***time required*** to respond to an unexpected failure;
- the ***ability to intervene*** with manual control skills (training aspects);
- how ***noticeably*** the failure is,

The time available is dependent on the current traffic load and the current traffic density – the human's situation awareness without assistance of automation.

How noticeable the failure is, is dependent on the failure characteristics according to the following example:

- abrupt: little time to prepare for intervention, but ***noticeable***;
- graceful: degradation of system capabilities in a way that is ***not noticeable***;
- intermittent: difficult to diagnose because of the difficulty in confirming the diagnosis.

The inability of operators to develop mental models (the operator's memory storage of experience, his basis when planning strategy – the basis for performing his job) appropriate to the system and task in order to maintain situation awareness is one of the most significant causes of unintended use of or reaction to automation.

Furthermore, it is likely to anticipate that the human's skills may degrade for most automated functions. As a result of the degradation human is likely to react more slowly to emergency situations if they require use of those manual skills during the recovery.

However, skill degradation has only impact on safety as far as it concerns automated advanced functions (i.e., decision-making and active control functions) and only if the human finds the new automation effective and reliable, their own skills may become degraded.

The combination of deteriorated situation awareness and skill degradation can result in the operator's inability to respond adequately to the failure of the automation.

4.2 Recommendations

Failure recovery in automation is the extent to which the human can act as a backup in the event of failure. The more helpful the automated assistance is when it is functioning normally, the more difficult it becomes for the human to compensate for it if it fails.

Each new automation feature should be evaluated for its impact on situation awareness.

Human should be trained to maintain proficiency in tasks that have been automated when they will be expected to be able to perform those tasks in response to automation failures.

The capability of human to manage the complexities permitted by automation should also be evaluated.

Neither traffic density, nor traffic complexity should be so high to preclude the safe performance of failure recovery tasks.

In order to maintain the operator's ability to separate traffic manually, *at least until all aircraft present in the sector have landed or left the area of responsibility*, it is necessary that:

- the traffic **density** is never so great that human cannot make decisions timely to ensure **separation**;

- traffic **complexity** is low enough so that the human can maintain **situational awareness**.

The system functionality should be designed so that failure recovery will not depend on skills that are likely to degrade. However, degradation of skills shall be considered together with the positive benefit of the actual automated function. The manual problem solving ability will decline but the automated elements will be more efficient from a safety point of view and cumulatively it will lead to a net gain in overall control ability.

5 VERIFICATION, VALIDATION AND EVALUATION

Verification, Validation and Evaluation of automation is critical and an important issue due to the serious impact any design failure can have. Special attention is needed because of the many different, and to a certain extent unpredictable variables contained in advanced automated functions.

Verification is the task of determining that the automated function is built according to its specifications: ***To confirm the automated function is built right.***

Validation is the process of determining that the automated function actually fulfils the purpose for which it was intended: ***To confirm that the right automated function were implemented.***

Evaluation reflects the acceptance of the automated function by the end users and its performance in the field: ***To confirm the usefulness of the automated function***.

5.1 Verification

As stated above, verification asks the question "is the automated function built right?"; verification is checking that all the predictable variables in the automated function are exposed and that the unpredictable variables will be managed properly during operation (i.e., alerts, decision-making and active control functions).

Issues addressed during verification of an automated function include:

- To be defined

5.2 Validation

Validation answers the question "is it the right automated function?", "are all the predictable variables exposed and will the unpredictable variables be managed correctly during operation?" or "is the automated function doing the job it was intended to do?"

It is practically impossible to test an automated function under all the rare events possible. Therefore during operation, it is important that the automated function can manage “lack of design” in the form of active self-monitoring (i.e., alerts, decision-making and active control functions).

Issues addressed during validation of automation:

- To be defined

5.3 Evaluation

Evaluation addresses the issue "is the automated function valuable?" This is reflected by the acceptance of the automated function by its end users and the performance of the function in operation.

Relevant issues in evaluation are:

- Is the automated function user friendly, and do the users accept the function?

- Does the automated function offer the intended improvement?

Although the automated function is known to produce the correct result, it could fail the evaluation because it is too cumbersome to use, does not really save any effort, solves a problem rarely needed in practice, or produces a result not useful in operation.

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