Allocation of Function Method to support future nuclear reactor plant design

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ABSTRACT

Current Allocation of Function methods require significant levels of judgement and interpretation and there is an opportunity to develop an improved capability for Allocation of Function for the context of the Nuclear Reactor Plant. This paper presents the development and application of an Allocation of Function method that provides a flexible and configurable set of tools which can be selected in accordance to the design stage and project requirements. The Allocation of Function method has been designed to be used in an iterative manner throughout the different stages of design development and used to engage with different engineering teams. The method draws upon existing and well-established HF methods to investigate and capture human-system interactions associated with function delivery. It also focuses on cognitive tasks to ensure introduction of automation continues to provide support to the operator. Particular emphasis is placed on mapping and understanding the cognitive processes employed in function delivery to ensure that all functionality and information requirements are captured in future automation design. The method also informs assigning and selecting a Level of Automation to a function. The Allocation of Function method enables integration with Systems Engineering to trade HF requirements against the engineering requirements for provision of automation.

KEYWORDS

Allocation of Function, Automation, Systems Engineering, Nuclear

Introduction

This Human Factors (HF) study is part of the Rolls-Royce Nuclear Propulsion Plant (NPP) Research and Technology (R&T) strategy. The strategy addresses the R&T items that are associated with improving plant understanding with a means of managing Safety Cases through life and making process changes to improve future designs with respect to nuclear safety.

As part of the strategy, the aim of this HF work-stream is to enhance HF capability development across a range of topics to understand, assess and facilitate the impact of changes to future propulsion plant designs.

A step change in HF design support and assessment capability is required to deliver this challenge. Allocation of Function (AoF) is a key input into the decision on how much automation should be included in the design, and where human input is required to maintain safe operation. A function is a process or activity that is required to achieve a desired goal, and it can range from a very high level plant function to the function of an individual component.

Current AoF methods require significant levels of judgement and interpretation and there is an opportunity to develop an improved capability for AoF for the context of the Nuclear Reactor Plant (NRP).

One of the HF challenges of designing large complex systems is how to define human roles and human-system interface requirements early in the design process when a system is not well specified and is continually evolving. This challenge is compounded by the fact that the majority of HF tools often depend on having a well-defined system.

Historically, allocation of function has been a straightforward method, following the principle that humans are better than machine for some functions and vice versa. However, with the advancement of technology, traditional 'human tasks' can now be automated. The traditional approach to AoF is now overly simplistic and the degree to which functions are automated should be informed by a systematic analytical process that is integrated within the design process (ONR 2017).

In order for HF to have an impact, the work needs to be timely and coupled with other elements of the system design process. Analyses need to be conducted and recommendations made in parallel with, and as inputs to, design decisions regarding system purposes, functionality, automation capabilities, and staffing levels.

Currently existing methods, such as the 'guidance for the design and use of automation in Nuclear Power Plants' method by the Electric Power Research Institute (EPRI 2005), are utilised to evaluate future NRP projects.

Limitations of using the EPRI method, include requirement for a significant level of judgement and interpretation, lack of detailed specification of automation solutions and the failure to consider important human factors issues (e.g. workload, situation awareness, decision making).

Development of the AoF method has been based on initial expansion of the original EPRI flowchart method (EPRI 2005). Additional information has been added to the flowchart to provide more resolution in the initial AoF decision.

EPRI has also produced updated guidance on AoF application as part of a wider report of guidance for Control Room and Digital Human-System Interface Design (EPRI 2015). The EPRI flowchart method provides early screening of functions.

The AoF method provides a step change to the EPRI method by providing further HF analysis and removing the significant level of judgement and interpretation, providing detailed level of automation and making considerations for important human factors issues (e.g. workload, situation awareness, decision making).

Method Development

Stakeholder requirements captured at the early and late stages of the method development, with HF and Control and Instrumentation (C&I), ensured stakeholder input shaped the development of the AoF method. It was considered crucial to explore, understand and capture their requirements, challenges and considerations for future work.

Extensive literature of existing HF theories and methodologies in relation to AoF was reviewed. The literature included, but was not limited to, academic literature, cross-industry methods and existing standards on automation and AoF.

The literature review was used to inform the development of the AoF method. Method development included examining HF issues related to AoF in the design of automated systems, evaluating existing AoF and automation theories in relation to NPP, and selecting appropriate methods and theories of AoF and levels of automation. Key references included, but were not limited to, Li et al (2017), Nehme et al (2006) and Scott et al (2006).

Method testing was based on selection of a generic design scenario for a Pressurised Water Reactor (PWR) design. A Loss of Coolant Accident (LOCA) scenario was identified to test and validate the methodology that was developed, using a HF technical specialist and ex-operators. The testing and validation activities used paper-based materials and output data that was produced was collected and analysed, and used to inform the AoF method.

Worked examples of the outputs of the AoF method using a LOCA scenario were produced to demonstrate that the AoF method is an appropriate method for the nuclear work domain.

The EPRI method used to inform AoF method development includes a set of questions, which were reviewed in relation to the AoF method. Clarification questions were provided as a summary of the full question set in the original EPRI report (EPRI 2005).

Knowledge elicitation methods have been reviewed and identified to support the generation of the different stages of the AoF method.

Method Description

The AoF method has been developed as a flexible and configurable design support package. The EPRI flowchart has been embedded into the new AoF Method framework.

The AoF method consists of the following steps:

- Function definition
- Task definition
- Identification of candidates for automation
- HF checks
- Identification of level of automation (LoA) options
- Ranking Automation Options
- Identification of Detailed Design Requirements

Tools identified in this study are summarised for each stage of the AoF method in Table 1.

Table 1: AoF Method Summary

Stage	Tool	Description
Function Definition	Abstraction hierarchy	Mapping new design concepts, in relation to system goals, functions and related sub-systems and components. Used to examine AoF in relation to higher functions and goals of the wider system. Illustrates relationship between the physical elements in the system and goals/purposes of the system. Provides greater benefit in early design when information is limited. Drives integration with engineering teams.
Task Definition	Scenario task flow overview & Event flow diagram	A cognitive task analysis, which adds value to hierarchical task analysis (HTA) and operational sequence diagram (OSD). Provides understanding of current and future procedures, in normal and abnormal operations.

Stage	Tool	Description
		Links phases, goals and sub-tasks into logical sequences. Used to understand operator knowledge and information processing activities. Identifies operator processes, monitoring and decision making activities. Can be used to focus and direct new task analyses, or make use of existing HTA & OSDs if available.
Identification of Candidates for Automation	EPRI	Initial AoF decision using the EPRI flowchart. Identifies candidate automation functions. Output assigns function to human, partial automation or full automation.
HF Checks	HF table & list	HF checks with C&I checks in parallel. Includes consideration of mental workload checks Provides HF explanation of design option selection
Identification of LoA Options	Function Allocation (FA) taxonomy	Identifies detailed LoA solutions against stages of information processing and C&I automation design options. Selection of different automated options from candidate items. Can be used to link operators' cognitive strategies and demands to LoA.
Ranking Automation Options	Ranking of Automation Options	Selection of preferred design options based on requirements and weightings, using Systems Engineering Toolkit. Considers mental workload assessment (MWL). Ranks and prioritises AoF recommendations.
	Reasons for the LOA	Used to link LoA to design decisions and requirements. Provides reason for the shift of LoA step (due to design change or introduction of new technology) in a table. Provides configuration control of design decisions.
Identification of Detailed Design Requirements	Decision ladders (DL) & FA mapped onto a DL	Detailed mapping of operators' cognitive strategies and demands. Used to link operator's cognitive information processing strategies and demands to LoA.

Stage	Tool	Description
		Provide HF support for detailed design of automation e.g. number of automated functions an operator can effectively monitor, or whether a protective safety measure is triggered by human input or automation? Can feed into future training of operators. Example DL from worked example can be used as a starting point and adapted.
	Situation Awareness (SA) & information requirements	Identifies information requirements. Particularly useful in HMI design. Informs HMI decisions such as number of screens, when to hide/present information etc. Support identification of verification and validation requirements. Provides details of time-critical information for the operator. Provides minimum requirement to keep the operator 'in the loop' in normal and abnormal operations. Breaks down information requirements into 'perception', 'comprehension' and 'projection'. Highlights any additional information required by the operator, and can feed into future training of operators. Can be used in conjunction with the communication link diagram.
	Communication link analysis	Design aid to check communications between different agents are considered in the introduction of new technology. Can feed into future training of operators.

Method Application

The resulting AoF method can be applied at any stage in the design development. For a new design entering early concept definition, the emphasis is on definition of system functions, with application of the EPRI flowchart method to provide an initial AoF decision for each function. Initial automation options can be identified by application of the selected function allocation taxonomy. It identifies detailed Levels of Automation (AoF) solutions against stages of human information processing and C&I automation design options.

The initial AoF decisions are subject to detailed design by iterative application of the investigative tools in the AoF method. Delivery of the functions in the AoF decision is investigated using scenario task flow and event flow tools. Situation awareness and information requirements are identified against the processes and decisions in the selected scenario. DL are used to map information onto the decision making process, and a communications link analysis is used to identify communication centres and ensure communication requirements are captured in the design solution.

The detailed information captured in the investigative tools is reviewed in the context of the selected function allocation taxonomy. Automation options are included in the consideration of other design requirements, and are ranked in the application of Pugh matrices as part of the Systems Engineering approach to design.

Knowledge elicitation methods have been identified to support the generation of the different steps of the AoF tool.

A flow chart presenting the application of the AoF method in the design development lifecycle is shown in Figure 1.

Discussion

The AoF method developed in this study provides a flexible and configurable set of tools which can be selected in accordance to the design stage and project requirements. The AoF method has been designed to be used in an iterative manner throughout the different stages of design development and used to engage with different engineering teams.

The AoF method has been developed, tested and validated with a range of experts. The method supports the process of identifying which tasks should be undertaken by humans and those which can be automated, based on HF assessment methods. It specifically provides informed HF evidence to support NRP design decisions.

The literature review process allowed a thorough analysis of AoF and related issues, as well as the appropriate HF methods to support tool development. This review demonstrates that the AoF method has been built on solid theoretical HF foundations, within the nuclear context.

The AoF method provides several steps which can be selected in accordance with the design stage and project time scales. It is intended that the tools in the method be used in conjunction with the EPRI flowchart method output to narrow the scope of analysis. The outputs of the AoF method can be used to support the design of future automated technology. Furthermore, the outputs can be used with the Systems Engineering Toolkit (2018) to help down select design options based on specified requirements.

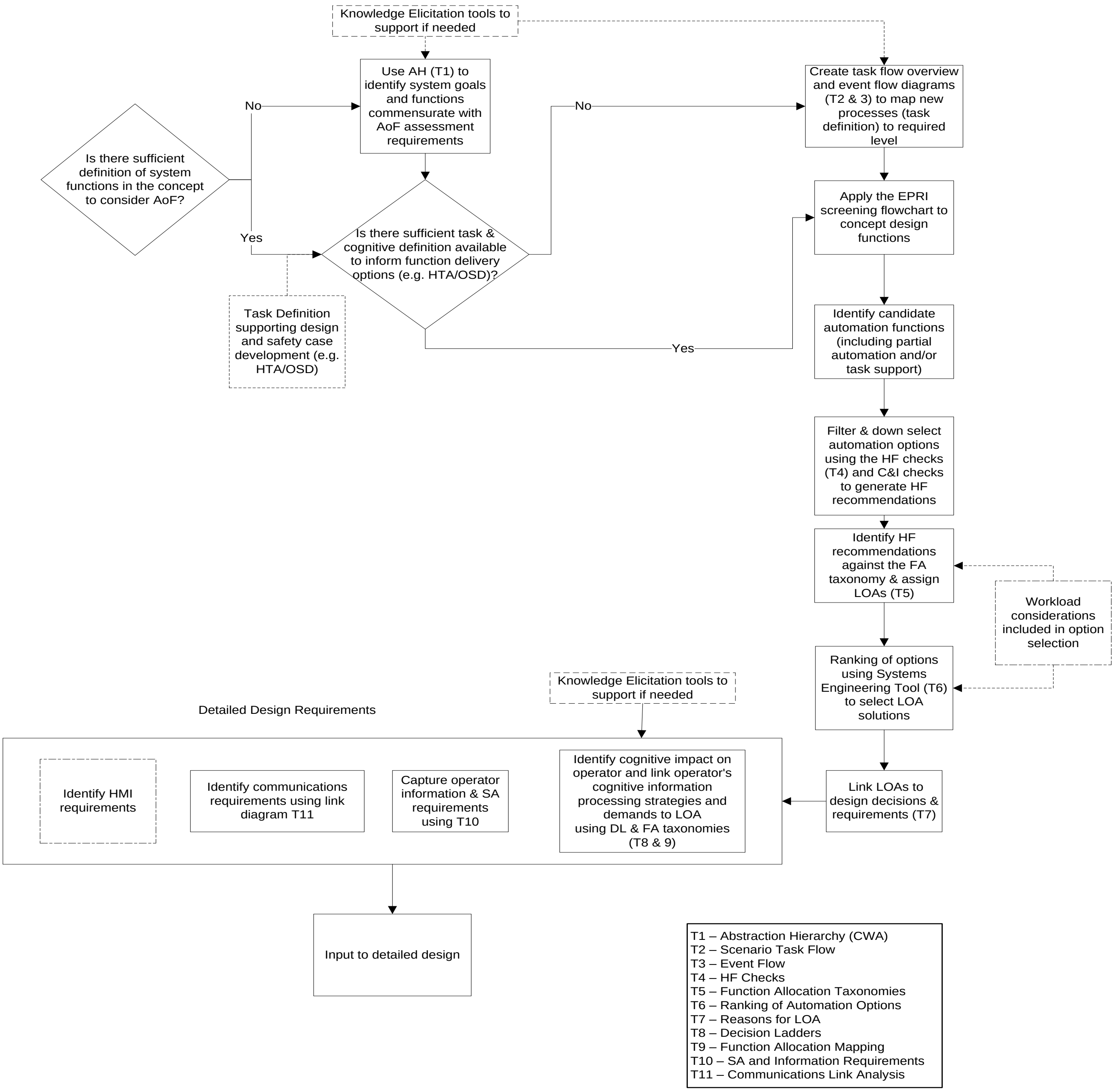

Figure 1: Method Application in the Design Development Lifecycle

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