
THE USE OF NPP SIMULATORS FOR APPLIED HUMAN FACTOR STUDIES

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Abstract: The simulator-based Halden Man-Machine Laboratory (HAMMLAB) has, since its establishment in 1983, been the main vehicle for the human-machine systems research at the OECD Halden Reactor Project. The human factors programme relies upon HAMMLAB for performing experimental studies, but the laboratory is also utilised when evaluating computerised operator support systems, and for experimentation with advanced control room prototypes. The increased focus on experimentation as part of the research programme at the Halden Project, has, over the last few years, resulted in an upgrade programme with extended simulation capabilities.

This paper describes the main features of the HAMMLAB laboratory, the type of human factors studies performed in the laboratory, and which requirements this brings upon the laboratory infrastructure and simulation capabilities.

The aim of the human factors research at the Halden Project is to provide knowledge about the capabilities and limitations of the human operator in a control room environment. These results can later be used by member organisations to enhance safety and efficiency in the operation of nuclear power plants.

1. INTRODUCTION

The Halden Man-Machine Laboratory, HAMMLAB, was established in 1983 in order to serve as the main environment for performing realistic experiments within the Man-Machine Systems Research of the OECD Halden Reactor Project (HRP). Since its establishment, HAMMLAB has been the experimental focal point of the research within Human Factors, as well as the main test bed for computerised operator support systems being developed both at the Halden Project and at members organisations.

The NORS full-scope simulator has since the establishment of HAMMLAB been the laboratory's simulator basis. NORS is based on the Loviisa nuclear power plant in Finland (1).

HAMMLAB has undergone several upgrades and improvements since 1983, a major one was performed in 1996 with the introduction of a new unified human-machine interface and a new control room set-up (2,3).

2. HAMMLAB

The studies being performed in HAMMLAB are of different size and complexity, ranging from large scale human factors experiments to small scale studies and tests. Due to this, the requirements to the laboratory vary a lot, and a flexible infrastructure is a necessity. The current control room is equipped with two operator stations and one supervisor station, as indicated in Fig. 1. All stations are situated on desks having wheels in order to ease shuffling around and varying the degree of compactness of the control room. In this way it is extremely easy to restructure the control room for one or more operators. Another key issue is that all information is available on all screens, thus allowing for tests using single operators and few screens.

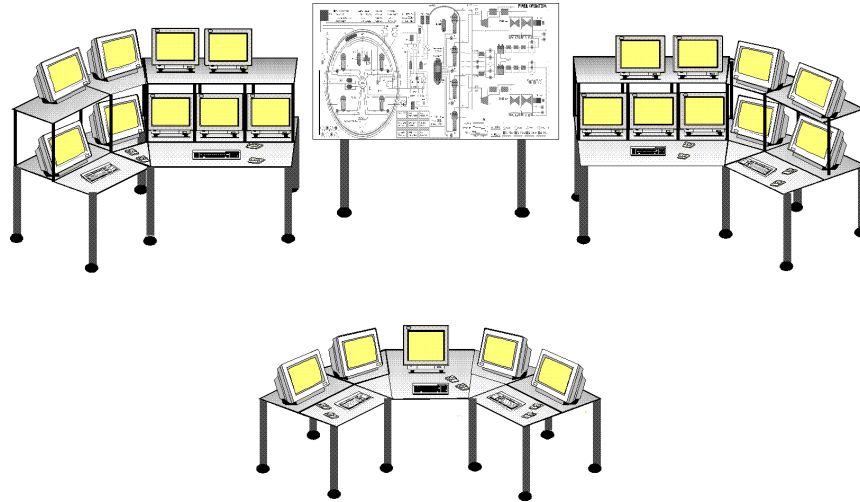


Fig. 1 The HAMMLAB Experimental Control Room

To carry out a large human factors experiment requires careful preparation prior to the actual execution of the experiment, and a large period for data analysis after the experimental execution. The data collection phase, i.e. the actual execution of the experiment, requires the availability of advanced data recording equipment. Audio and video recorders, eye movement trackers, computerised data logs of various kinds, are heavily used in addition to questionnaires and on-line expert commenting. HAMMLAB of today provides the experimenters with advanced data recording equipment and everything is configured and operated from a specially designed experimenters' gallery. Fig. 2 shows a picture of the experimenters' gallery where the human factors experts carefully follow what is going on in the HAMMLAB control room, while Fig. 4 shows a block diagram indicating the various parts, functions and systems involved in the experiments in HAMMLAB.

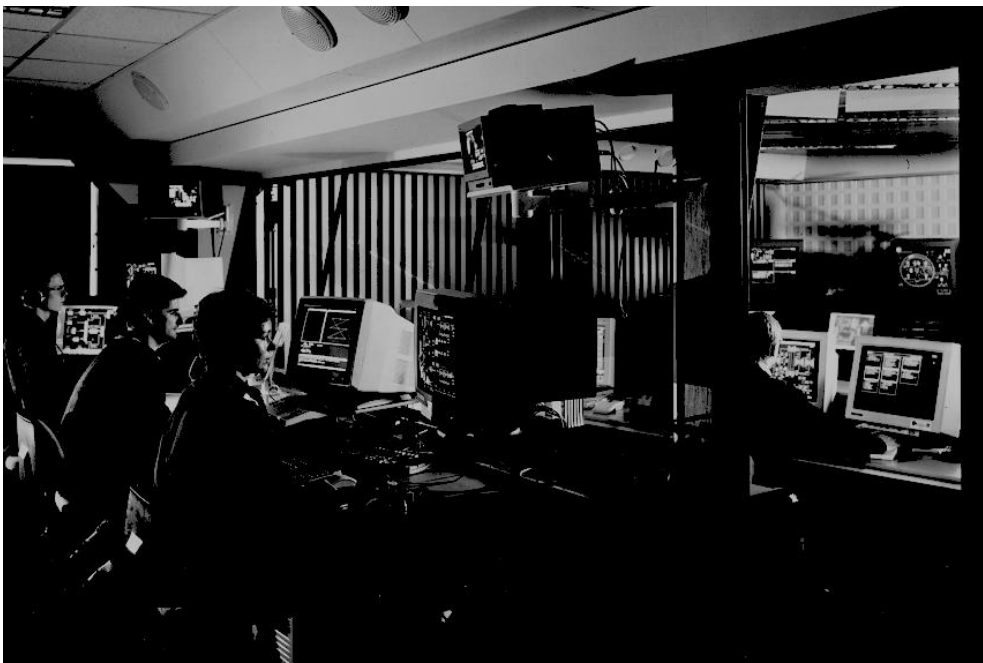


Fig. 2 The Experimenter's Gallery of HAMMLAB

3. THE RESEARCH AGENDA

When discussing advances in human-machine systems research, the technological development is fast and to some extent unpredictable. On the other hand, the main characteristics of the human being does not change in the time scale of interest. The human capacity for perceiving, thinking, and acting develops so slowly that it for all practical purposes may be considered constant. This makes the prediction of future research needs for controlling complex processes a little bit easier, because it must concentrate on development and adaptation of new technology, starting out from the characteristics of the human being.

In order to make any predictions, it is necessary to make some basic assumptions, and the following assumptions are considered pertinent (4):

- People (humans) will remain an essential part of the control of complex dynamic processes. In other words, there will not be full automation. Sub-systems may become fully automated, but they will always be embedded in a larger system.
- The scope of control will increase in terms of the system boundaries and the time horizon. The system boundaries will grow and technology will enable processes to be coupled over significant distances. The control will be of the coupled process rather than of the local process which may be highly automated and control need no longer be confined to a central control room. The time horizon must be extended to ensure a sufficient economy. It is necessary to plan not only for the current situation, but also for the future, e.g. after a change of process parameters. Down-time must be reduced and availability increased, involving aspects of preventive and state-based maintenance. Safety will, however, still be in focus both on the short-term and the long-term scale.
- There will be a greater need for predictions as part of control, hence a need for modelling and simulation. This follows partly from the extension of the system boundaries and time horizon, but also from the increased speed and complexity of processes. Prediction is an essential function both for the process control operator and for managers, and for operation as well as e.g. maintenance (outages), procurement, decommissioning, design, safety assessment, etc.
- The design of MMI has on the whole been driven by technological innovation rather than by sound human factors principles or user needs. Despite a growing awareness of the importance of human factors, it is probably safe to assume that the development of MMI will to a large extent continue to be driven by technology. Since people will be the same with their recognised strengths and weaknesses, this will perpetuate the known problems and probably even create some new ones.

3.1 Research Themes for the Future

Based on the issues and trends discussed in various organisations, one can argue for a human-machine systems research agenda which includes at least the following items.

- *Developing A Joint Situation Understanding*

Developing a joint situation understanding among people who are in the same room is not straightforward. This has led to considerable research for e.g. training and large overview displays. When the scope of the system grows larger, particularly when the boundaries of the system extend to other locations, the problem of establishing, supporting, and maintaining a common situation understanding becomes very much larger.

- *Information Integration*

There will be a significant need to be able to integrate information from various sources, regardless of the original formats or protocols. As the system boundaries expand in space and time, it is necessary to include data within the new boundaries. For the operator, there will be a requirement or a need to look at a particular combination of data in order to assess the situation. The system technology should be able to provide this within a reasonable time limit and with a minimal effort from the operators' side.

- *High-Level Automation*

The effects of high-level automation in the system design should be studied in an experimental environment. The software of the high level automation will use input from the process, the normal automatic systems, the protection systems, the computerised operator support systems and the operators. The automation can either execute the resulting high-level control commands directly on the process and the normal automatic circuits, or present them as suggestions/ recommendations to the operator, who will then take the final decision whether to execute the control commands or not.

- *Accident/Emergency Management*

There is an increased interest for research in the field of Accident or Emergency Management. This work aims at utilising the capabilities of computerised tools to support various users such as the control room staff, people in the technical support centre, and safety bodies providing advice to national authorities. The use of experimentation in a simulator environment should be very interesting in order to improve the management of emergencies (5).

- *Integration Of Maintenance Activities And Process Surveillance*

There is a strong trend towards increased integration of maintenance tasks and process operation tasks. This obviously has consequences for several aspects such as:

- integration of maintenance staff and operation staff
- the ability to prepare, train and even perform several maintenance tasks during power operation
- integration of computerised tools for maintenance with systems used during normal operation.

4. THE HAMMLAB 2000 PROJECT

The predictions of future areas of research, some of them mentioned in the previous chapter, imposed requirements to the experimental environment. In addition, direct transferability of results, i.e. to make studies with the use of a process similar to an organisation's real process, whether it is a nuclear power plant of BWR, PWR or VVER or the petroleum industry's oil & gas production process, is given more emphasis from member organisations of the Halden Project. Some studies are, however, generic in nature and the results are likewise applicable across industries, therefore synergy is also an interesting aspect being focused upon by several organisations.

This discussions led to the start-up of the HAMMLAB 2000 project in 1997 with the goal of establishing a new HAMMLAB meeting tomorrow's demands. The HAMMLAB 2000 project had the goal of establishing a flexible infrastructure regarding the physical laboratories and the hardware and software, as well as making sure tomorrow's HAMMLAB has a broad pool of simulators. The latter will be described somewhat in more detail below.

4.1 The HAMMLAB 2000 Simulators

As part of the HAMMLAB 2000 pre-project, requirements to process simulators to be included in the new HAMMLAB was identified. The requirements are briefly summarised below. In addition, this section gives an overview of the simulators for HAMMLAB 2000, see Fig. 3.

4.1.1 Simulator Requirements

The process models are the heart of the simulator facility, and its quality determines to a large extent the applicability of the results obtained in human factors and systems research. In this context quality refers to various properties of the plant model. The main items of importance for determining the quality and applicability of a process simulator are listed below.

- *Scope*

The simulator shall be full-scope, i.e. all systems in the process relevant for control room operators shall be simulated.

- *Simulation Range*

The simulator must be able to simulate the process realistically for a large set of normal, disturbance and accidental states.

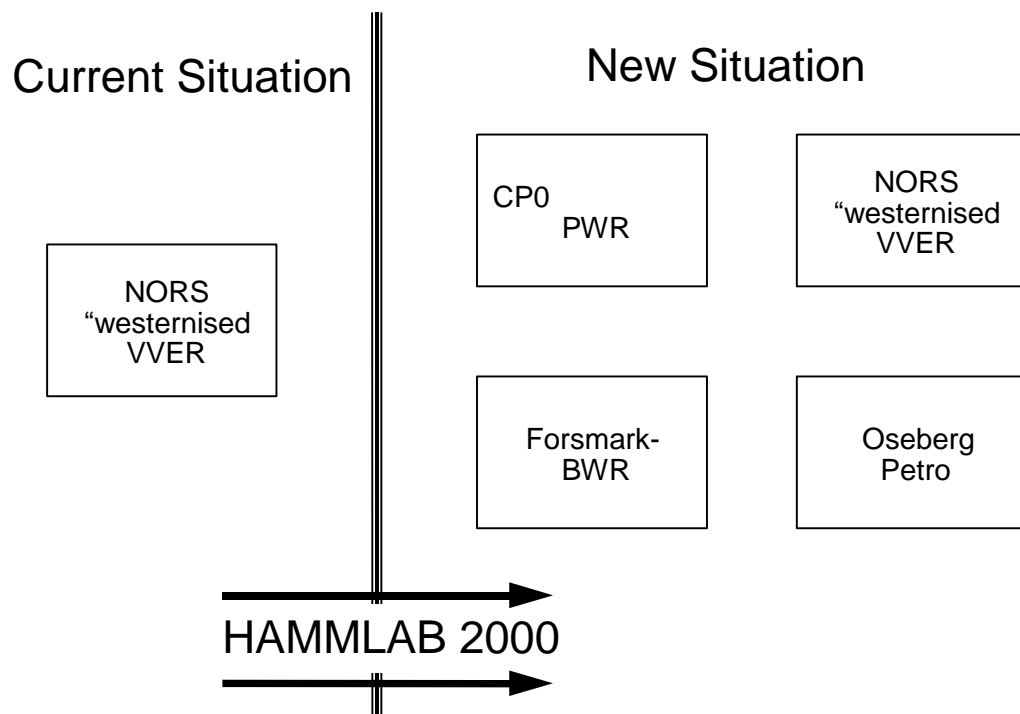


Fig. 3 The HAMMLAB 2000 Simulators

- *Process Realism*

The simulator shall simulate in detail a given process. This is very important with respect to: documentation, verification and validation of process behaviour, and training/ use of experienced operators in human-machine interaction experiments.

- *Malfunctions*

A wide range of malfunctions shall be available for use in experiments and tests. This includes malfunctions for all types of components and systems. In addition, it must be easy to make new malfunctions. It is also required that the simulator and its environment shall be able to handle instrumentation errors and inaccuracies.

- *Process Control System*

The overall process surveillance and control system shall be designed to or somewhat beyond the state-of-the-art for modern industrial plants. The implementation solution shall resemble modern plants as much as possible, with potential for significant improvements.

- *Automation Systems*

It must be possible to include all types of automation systems in use in industry today and planned for the next 5-10 years. This includes modern distributed control through utilisation of PLCs. In the simulator, the process and automatics shall be clearly separated, making it easy to implement independent changes in process and automatics.

- *Real Time Performance*

The simulator shall be able to run in real time over the whole simulation range with realistic process behaviour.

- *Integration Of Operation And Maintenance*

The plant simulator shall be prepared for being coupled to something like a maintenance planning simulator. The latter will be used to plan the maintenance work in detail, in order to minimise shutdown time and costs. Furthermore, a version of the plant simulator may in the future be extended to become a life cycle simulator for preventive maintenance. This tracking simulator will run in parallel with the real process and generate automatically on-line updated maintenance parameters.

4.1.2 The NORS Simulator

The NORS simulator is a “westernised” VVER simulator of the Loviisa nuclear power plant in Finland. NORS was manufactured in 1983 by Nokia Electronics, and has since then been the nucleus of HAMMLAB. Several modifications and additions have taken place of the NORS simulator models, and NORS is now considered to be a very good simulator for the purpose of being “the process” when performing experimental studies.

4.1.3 The CP0 Fessenheim Simulator

The CP0 Fessenheim simulator is a full-scope simulator of the French Fessenheim-1 PWR plant. Fessenheim-1 is a Westinghouse-like 900 MW 3-loop plant built by Framatome. The simulator was manufactured by Thomson, Training and Simulation, and installed in HAMMLAB in 1998. Currently, development of a new mimics-based operator interface and an advanced alarm system is taking place, in order to turn the CP0 Fessenheim simulator into a full experimental simulator.

4.1.4 The Forsmark-3 BWR Simulator

The HAMMLAB facility is also equipped with a full-scope modern BWR simulator of the Swedish Forsmark 3 plant. Forsmark 3 is an ABB-constructed 1160 MW BWR located close to Stockholm in

Sweden. The development of the BWR simulator was made jointly by VTT Energy in Finland and The Halden Project, and the simulator was installed in Halden in the summer of 2000.

4.1.5 The Oseberg Simulator

The Oseberg training simulator is a full-scope simulator of the Oseberg A oil production platform located in the North Sea (6). The simulator was originally manufactured for Norsk Hydro in the middle 80's by Norcontrol Simulation and Institute for Energy Technology, to play a central role in the training programme for the operators of the Oseberg A platform. The Oseberg simulator is currently used as "the process" when performing human factors studies related to the oil and gas industry.

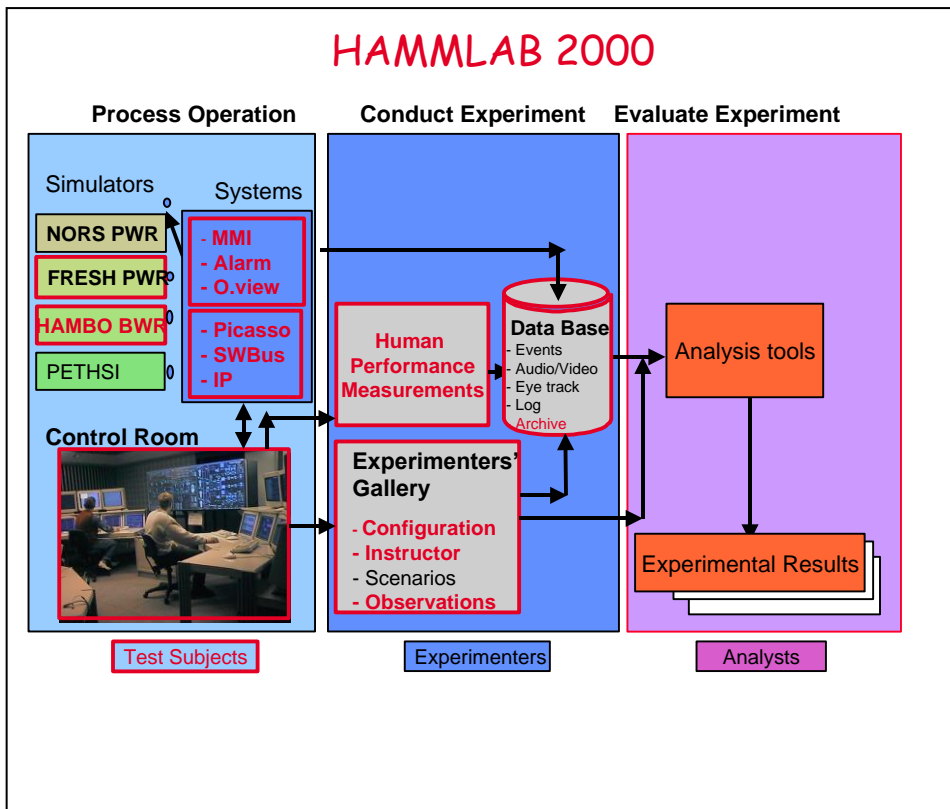


Fig. 4 Block diagram of Hammlab functioning

5. THE HALDEN PROJECT APPROACH TO CONTROL ROOM STUDIES

Improvement of control rooms requires expertise in a wide spectrum of disciplines. In the control room, the human meets with the technology (computerised) to control a complex process. To reach the goal of improved operator performance in both normal and disturbance situations, deep insight in to human behaviour and control room experience must be combined with process expertise and knowledge of computer technology. This integrated approach is considered necessary to reach reliable results, and is reflected in the multitude of disciplines represented in the Halden organisation. As an example, 16 human factors experts are presently working in this field at Institute for Energy Technology which operates the Halden Project.

Another aspect of the human-machine research connected to control room development, is the emphasis put on an experimental approach. Only through realistic experimental evaluation of the whole control room, or its individual elements can concrete conclusions be drawn on the quality of the system. In order to improve the knowledge of the human behaviour in the control room environment, extensive

experimental research is required to support development of models of operator behaviour. Due to the need for an experimental approach, HAMMLAB has come increasingly into focus in the research programme at Halden.

The emphasis put on research products for practical use, motivates a strong coupling between the research programme and potential user organisations. The trend in Halden is to combine the work on the research

programme with bilateral projects with individual organisations. This results in an efficient synergy between research and industry use: research products are taken into practical use; and experience from industry project helps identifying essential research issues.

Finally, human factors studies motivated by needs in the nuclear community give results that are also applicable in other industries. This has resulted in extensive activity, especially towards the petroleum production industry in Norway.

6. CURRENT RESEARCH TOPICS

The aim of the human factors research programme is to provide knowledge about the capabilities and limitations of the human operator in a control room environment. Understanding the impact of new technology on the roles of performance of operating personnel, is crucial in decision making concerning safety and efficiency of nuclear power plants. Halden has a wide ranging research programme covering many aspects of human performance, the main elements of this programme are briefly described below.

6.1 Human Error

The aim of the activities on the human error analysis project (HEAP), is to provide improved understanding of how operators diagnose disturbances and to identify potential errors or inefficiencies which may occur in the diagnostic process. The long term goals are to produce practical knowledge for system and human interface design and to achieve better modelling of cognitive errors for representation in probabilistic safety analysis.

A series of pilot studies and one major experiment have been performed to find a reliable and valid methodology to investigate human error in a control room setting. The practical insights from these studies can be found in Green (7).

6.2 Complexity Profiling

The main goal is to identify dimensions of complexity and to study the relation between complexity and operator behaviour. The analysis of data from previous experiments indicated that the four main areas that influence the complexity of the work situation in a control room are: the process; the interface; the operator / team; and the operator's tasks. The preliminary results also indicate that further developments of the measures have potential for enhancing the understanding of complexity and how it is related to operator performance.

6.3 Error Recovery

One of the issues addressed by the current set of experiments is the question of detection and recovery of erroneous actions in the situation where they actually take place. Since detection clearly is a prerequisite for recovery, the experiments will, in the first instance, consider how well people are able to detect the erroneous actions they make and how the level of detection depends on the circumstances or

conditions, such as, interface, team, workload, etc. This also suggests that a possible objective for the next experiment is to study the conditions for recovery, as well as in more detail, the specific circumstances that can facilitate detection.

6.4 Error Mode Prediction

The main purpose of the first main HEAP experiment (autumn 1996) was to develop a method for predicting performance failures, specifically the error modes that can be expected for a specific task. This used CREAM (Cognitive Reliability and Error Analysis Method) developed by Hollnagel (8).

6.5 Human-Centred Automation

At Halden it is acknowledged that the role of the operating crew is either intentionally or unintentionally created by the system design process. However, there is very little empirical data about the effects of different trade-offs of function and task allocation on the performance of control room crews. In 1998 Halden has studied the effect of different task allocation methods in particular with respect to analysing and presenting plant automatics. In autumn 2000 a major new experiment will be performed on the effect of automation system failure on operator performance.

6.6 Methodological Development

An important area, central to both the use of HAMMLAB and the research programme, is the development and use of methods to allow the investigation of sophisticated aspects of operator behaviour and performance. Halden has developed a wide range of measures and methods which have been applied both within HAMMLAB and within existing industrial control centres. Examples of the methods developed include:

- Eye-movement Tracking Measurements
- Situation Awareness
- Workload
- Operator Performance Assessment System (OPAS)
- Plant Performance Assessment System (PPAS).

7. CONCLUSIONS

Institute for Energy technology is currently performing advanced experimental human factors studies in the Halden Man-Machine Laboratory, mainly within the Halden Project research programme. With the HAMMLAB 2000 project the goal is to broaden the scope and domain of studies, by introducing non-nuclear process simulators, first within the petroleum area, and different kinds of nuclear process simulators. In addition, studies related to severe accidents will be possible to perform, due to the extended operational domain of the new simulators.

HAMMLAB will be expanded with new laboratory areas making it possible to perform experiments in parallel, without interfering each other. The laboratories will be flexible with regards to physical size, in order to adapt to small and large studies. A software and hardware infrastructure is being developed, allowing for integration of software systems developed at the Halden Project or in member organisations. Such systems can then be tested in a realistic environment, prior to installation in real-life plants. Based

on the above, the Halden Project aims to further develop the new HAMMLAB into a global centre of excellence for performing human-machine interaction studies for the management and control of industrial processes.

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