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A Qualitative Systems Dynamic Model of Human Monitoring of Automated systems

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Abstract

This paper describes the problem of human monitoring or supervision of automation. It includes a review of current research describing how automation monitoring increases the chances of error if the operator is not involved in the control process.
A qualitative systems model is developed because of the lack of sufficient data to completely describe the causal pathways and provide a numerical simulation. This leads to a number of research strands for which data is not available or needs to be improved.

Keywords: Automation, supervisory control, qualitative system dynamics model, human monitoring

1. Background

Over the last 60 years automation has played an increasing role in our society. With the reduction of prime human control of systems has come the situation whereby supervision of automated systems is now common. The role of the computer has made this almost inevitable. Computer controlled systems are more reliable than operator controlled situations. However when the certain failure of the computer system happens our society demands that some backup human control, or at least monitoring exists. There is some discussion amongst aircraft designers and pilots about the degree of pilot authority that should exist on the flight deck. The majority of the flight of an intercontinental aircraft is undertaken on autopilot without direct action by the pilots. If there were an incident we would expect that the pilots could rapidly regain control and save the aircraft. This has not proved to be possible in every case.

In 1973 an Eastern Airlines flight 401 was landing and the pilot was trying to sort out a problem with the undercarriage when the autopilot disengaged. Neither officer noticed a problem due to their preoccupation with the landing procedures. The report said that the crew had become complacent and had not monitored the instruments effectively (NSTB 1973).

This crash and many other examples of similar events exhibit pilot overreliance on automation (Lee & Moray, 1992; Mosier, Skitka & Korte, 1994; Riley, 1994). On June 30th 1994 an Airbus A330 crashed while on a test flight. The aircraft was being tested to ascertain how well the autopilot could control an engine out situation with different loading conditions. A later investigation concluded that the crew were overconfident and did not intervene early enough to prevent an accident. It was alleged that if they had responded 4 seconds earlier then the accident could have been avoided.

The accident at Three Mile Island Nuclear plant in is another example of a critically complex system where the monitoring process failed. Bignell and Fortune (1984) give a critical evaluation of the whole episode. Their conclusions show that the failure of one valve and the way the information was presented to the operators was the overwhelming cause of the disaster. The confusion in the data and the amount of signals to be monitored by the operators was too great for effective intervention.

In many of these examples the number of alarms set off in a typical incident is in the hundreds (866 in the Lockheed L –1011!), surely too many for any operator to cope with.

Parasuraman et al (1996) give a pertinent example of a system where the staff are poorly trained, paid little and have a small opportunity for advancement. This case is that of the staff who monitor x-ray apparatus at airports for detecting weapons and hazardous or explosive materials. They have an excellent detection record exceeding 90%, despite long hours and poorly presented information.

When humans were displaced from their prime controller role it was expected that the supervisory role that they were given would be a much lighter load. This has not proved to be the case, in fact the supervisor or monitor may have to experience a much greater workload than before. Present systems have increased complexity such that it may require many monitors or supervisors. The degree of complexity is made worse by the tightly coupled sub-systems often inherent in the design. Aircraft and nuclear power plants are two such obvious examples. Electricity supply and communications are two similarly complex examples. The degree of automation now contributes to the case where we have failures, which are low probability but are of such serious consequences that we must consider the whole system including the human monitor (Koshland, 1989).

Sheridan (1997) gives the whole process by which human interaction with control systems can be categorised.
His descriptions of the stages of supervisory control are reproduced here for clarity. There are five components in Sheridan's description: a sensor, actuator, display, controller and computer (figure 1).

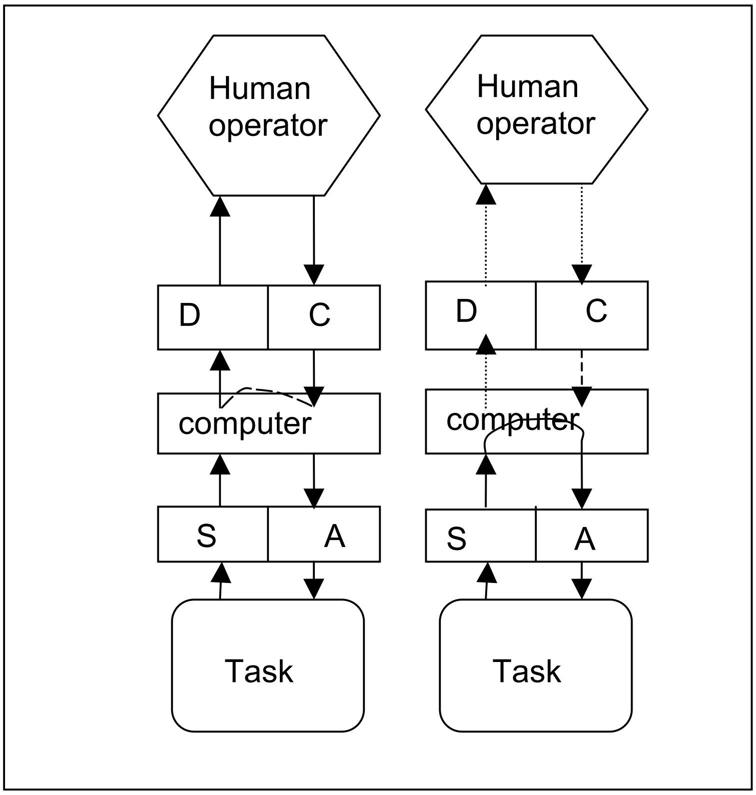

Figure 1 Sheridan's Model of Supervisory Control

He details the five stages required for supervisory control:

1. *Planning* off-line what tasks to do
2. *teaching* or programming the computer
3. *monitoring* the automatic action on-line to detect failures
4. *intervening* i.e. taking over control in emergencies
5. *learning* from experience to do better in future.

The rest of this paper has the aim to produce a qualitative systems model to help analyse the monitoring process. Stages 1 & 5 are also included since they cannot be divorced from the others completely.

2. Critical Factors

We know from many investigations that the human operator has a good record of managing very complex situations right from the start of the industrial revolution where people were expected to manage the operation of steam engines in dangerous circumstances. However the human operator unlike the machine suffers from fatigue, distraction and fallibility. We need to put these on a rational basis.

Hopkin & Wise (1996) give a taxonomy of Human-Machine relationships:

- The human adapts to the machine
- The human and the machine compete for functions
- The human is replaced by the machine
- The human and the machine complement each other
- The human supports a failed machine
- The human is adapted to by the machine
- The human and the machine are symbiotic or hybrid
- The human and the machine duplicate functions in parallel
- The human and the machine are mutually adaptable
- The human and the machine are interchangeable
- The human and the machine have a fluid and unfixed relationship to each other
- The human and the machine together form a virtual world
- The machine takes over in the event of human incapacitation.

All of these, except the last, require considerable human capacity in monitoring the system performance hence the rest of this paper discusses a model of this problem.

2.1 *Human Attention Processes*

Generally we are interested in the human ability to process information in parallel or in a time-sharing manner. Moray (1984) suggests that human attention depends on the operators' model of the external environment and its' statistical properties.

The prime consideration for the overall system performance is the mental workload experienced by the operator (Wickens 1987).

Effects on the mental workload come from many sources. Audley et al (1979) gives perhaps the most complete picture. They maintain that these sources include:

1. External disturbances
2. Varying parameters of the system structure external to the human operator
3. Human-produced noise in observing the task stimuli
4. Lack of a good internal model of the external system
5. Human-produced distortions in interpreting the external stipulated criterion of performance
6. Human-produced motor noise.

Wickens (1984) describes mental workload in terms of primary-task resource demand, resources supplied and performance. The concept of the effect of secondary tasks is well illustrated.

The work of Garvey &Taylor (1959), Enstrom & Rouse (1977) and the work of Jex & Clement (1979) support the Audley model.

It has often been thought that automation would reduce mental workload but the work of Edwards (1976) and Weiner (1988) have shown this to be untrue. The work of Sheridan (1970) has shown that in some cases the workload with automation is greater than with manual control.

Wickens (1992) drew attention to the increasing number of tasks when monitoring automation, for example for the automatic monitoring of aircraft doors. Here in the event of an indication of failure the cabin crew must decide whether the situation is dangerous, a failure of the indicator or a failure of the automatic system. The paradox of using automation to reduce workload that can actually increase workload. Traditionally monitoring has been considered to be a low stimulus task leading to the problem of 'vigilance deficit' (Duffy 1957). This problem of arousal is dependent on monotony and boredom.

Although there is considerable evidence in the literature (Davies & Parasuraman 1982) that human monitoring performance deteriorates over long periods of time most is the result of tests on systems which are too simple to be compared with current complex systems (Parasuraman 1986).

Idaszak and Hulin (1989) completed one set of experiments where the effects of monitoring automation with decision making tasks. They used subjects to simulate process control tasks, one set were active where the subjects were in control of the process and monitored it at the same time and the other where they were passive observers only. The active group were faster at detecting out-of-limit conditions and alarms than the passive monitors. In contrast Wickens and Kessel (1979) found that error detection was better in automated rather than manual assignment conditions. Hilburn, Jorna & Parasuraman (1995) examined Air Traffic Control simulation in Netherlands airspace and found benefit for automation on monitoring performance. Overall studies indicate that when operators are not in active control they perform worse than when they are actively engaged in both control and monitoring.

Parasuraman (1993) investigated the effect of multiple tasks. He used subjects to perform tracking and fuel-management tasks manually over four separate sessions of 30 minutes. They were required at the same time to detect automated engine failures. The result was that they detected 70% of the, malfunctions when they were manually controlling the tasks but under automation the detection rate reduced substantially. In another test when only monitoring the engine status task the subjects were substantially better at detecting failures. Parasuraman (1996) showed that for a system with variable reliability the detection rather was poor. This supports item 4 that the operators' internal model cannot cope with a variable system.

Sarter (1991) has commented that current flight deck automation fails to take account of the pilots' internal model of the flight management system. Kantowitz & Campbell (1996) discuss the effects of interface design on the feedback to the pilot, arguing for better information cues to the pilot and crew.

Dekker and Woods (2002) point out that we still have not developed procedures for deciding which part of the overall automation process is to be allocated to machines and which to humans. They discuss the recent introduction of new technology and the way that people have changed their operating procedures to suit the new automation.

3. Model

A qualitative model was used to inform a research programme in rehabilitation robotics. Some progress has been made in the direction of obtaining quantitative data.

The main requirement is overall system reliability. This has main contributions from the machine reliability, which can be designed into the system and human supervisory capability (HSC). Both of these contribute positively to the overall system capability. HSC is itself a function of mental workload, stress and, as we have seen above, on the length of time since the last machine failure. As this time increases the HSC deteriorates.

The mental workload depends on external inputs (EI); the lack of a good model (LGM); human produced noise (HPN); lack of interpretation of criteria (LIC); human motor noise (HMN) and variable system properties (VSP). All of these contribute positively to mental workload.

Stress contributes to the increase of motor noise as does fatigue. Fatigue also increases human produced noise. Training can reduce the effects of a poor mental model of the system. Fatigue is increased by time on the job and by an excessive previous work pattern.

Good design is improved by good requirements while good design reduces the effects of poor display and reduces conflicting tasks. In turn these increase LIC and HPN respectively.

Good design reduces variable system properties and is informed by human supervisory capabilities.

This model provides a series of pathways to enable system designers to see how parts of the system interact with one another.

4. Future work

How could this model be developed further? Some of the pathways have no data as yet that could be used to provide a numerical model.

The effect of excessive work and of cumulative time on the job on fatigue is fairly well studied and could be represented.

The higher level elements of this model have considerable work already produced as detailed in section 2. (Parasuraman et al 1996)

Training can alter mental models and some dynamic data is available (Lee and Sanquist 1996)

4.1 *Experimental data required*

1. These include the effect of design on workload parameters and the effect of good design on variable system properties.

2. The effect of poor displays is well known for static cases but not well studied for dynamic cases.

3. The effects of a combination of fatigue and conflicting tasks on human produced noise are not known in the dynamic case.

4. Conclusions

- A qualitative systems dynamic model of the process of human monitoring automation systems has been developed.
- This incorporates most of the recent research into the problems of supervisory control and human interaction with machines.
- Three strands for further human factors research are identified which will utilise both the effects of design on operators and the effects of psychological pressures on the operator in a dynamic sense.

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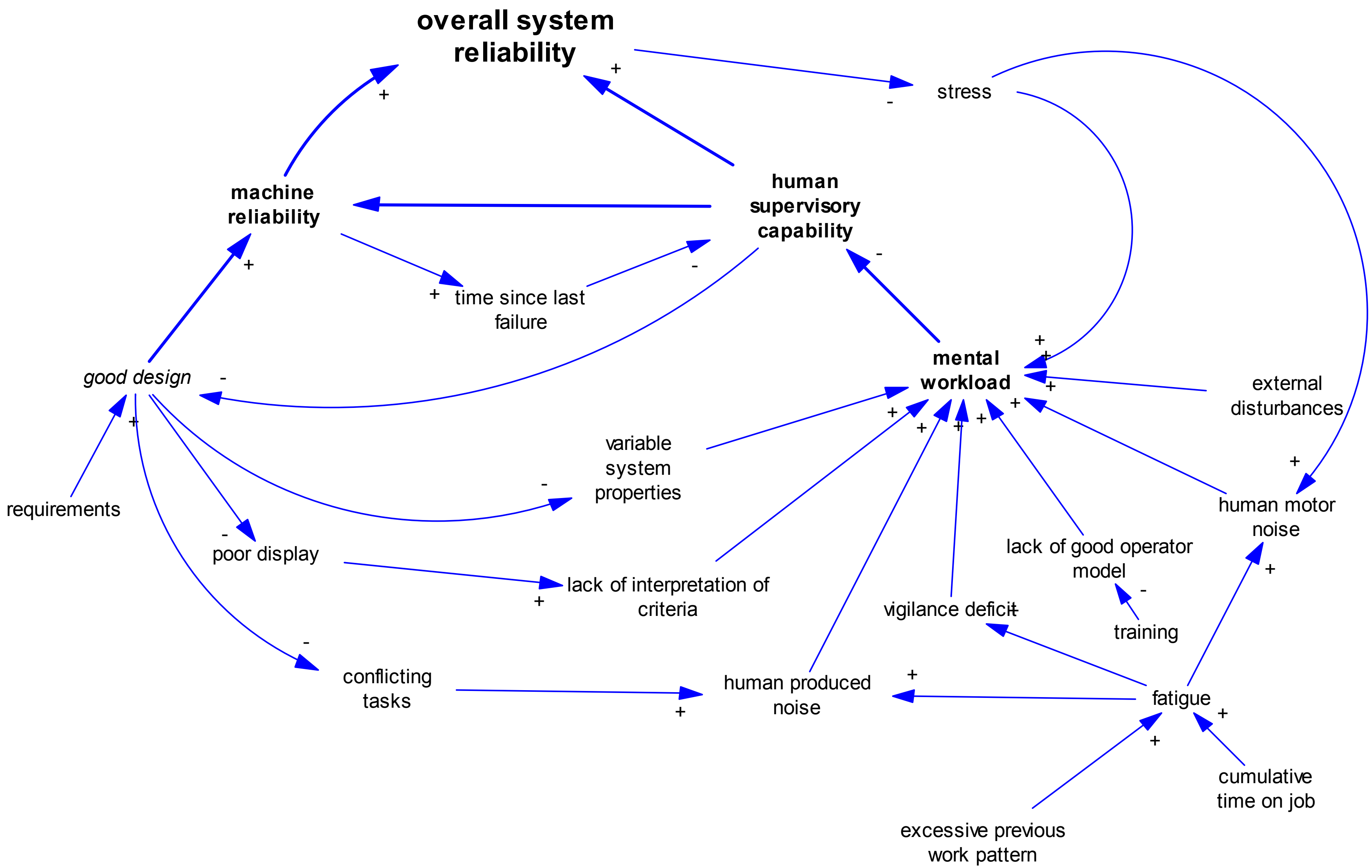

Figure 2 Qualitative Systems Model of Automation Monitoring

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