4.1 Case study: when faulty design creates catastrophes – the case of the nuclear accident at Three Mile Island

Objective

The objective of this case study is to show how the bad design of a control dashboard can induce inappropriate behaviour in the operators. In particular, we will focus on how lack of symmetry can be a severe design fault and lead to catastrophic consequences, as it happened in the first nuclear accident on Three Mile Island.

Background

The first serious accident in the history of nuclear power took place in 1979 in the US at the power plant located on Three Mile Island, Pennsylvania. The accident resulted in the release of large amounts of radioactive emissions following the meltdown of one of the plant's two reactors. Unlike the Chernobyl case, Three Mile Island did not cause direct deaths. It was by any metrics way less catastrophic, but the environmental damage and the risk of much worse catastrophic consequences that might have occurred created huge concerns about the safety of nuclear power, both in public opinion and the US government.

The analysis of the accident was assigned to several committees tasked with understanding the determinants of the nuclear disaster and, more importantly, to come up with lessons learned and knowledge to improve operations and regulations for nuclear plants.

One of the studies investigated the impact of human error through the analysis of the design of the control room of reactor number 2. *Human error* is a label that is often mistakenly used in accidents, based on the prejudice that technical faults are caused by inadequacies of operators, such as incompetence, negligence, substance abuse. While, unfortunately, many accidents are originated by these causes, the history of design is full of examples in which the operator's inappropriate behaviour is actually a *misunderstanding* amplified and even induced by bad design (Reason, 2016).

Research shows that the cause for ineffective or blatantly wrong conduct very often lies in a misalignment between operators' mental models regarding how a design should or could work, and the way the design actually works in practice. Many studies showed that the design was at fault because it did not account for more spontaneous mental models, and forced users to adhere to quite unnatural, counterintuitive, and complicated procedures. In other words, a design can be sufficiently confusing and misleading to induce any qualified operator to make a mistake.

This was the case for the Three Mile Island accident, as detailed in the official report created by the Essex corporation team charged to investigate the role of Human Factors (Malone at al., 1980). The team of analysts identified several pitfalls in the control room design, one of which was: ‘information required by operators was too often non-existent, poorly located, ambiguous, or difficult to read.’

One of the reasons this information was inaccessible and confusing was the lack of symmetry in the design of the control dashboard.

First of all, the control room was complex but unnecessarily so (fig. 4.1a). In the book titled *User Friendly*, Cliff Kuang (2020) likens the room layout to the bridge of a ship, with a massive console in the centre, behind which there was a wall of control panels stretching around for 90 feet, hosting 1100 dials, gauges, switches, and 600 warning lights. This vast number of indicators requires proper organization if it is to be understandable and to be quickly and safely consulted and operated in emergency conditions.

Figure 4.1a: Three Mile Island control room (Malone et al., 1980)

Symmetry is a powerful way of organizing information in a complex interface. In a symmetric interface, locating the right indicator or interpreting what it is saying can be inferred by comparing it with its symmetric counterpart. Another advantage of a symmetric interface is that it mirrors the symmetry of our bodies. Symmetric controls can be reached with the left or the right hand or observed within our right or left visual field. Finally, symmetry can be cognitive and symbolic, e.g., if A means HOT, the symmetric transpose of A, S(A) means COLD.

Unfortunately, the control panels of Three Mile Island control room disregarded these types of symmetries. Here are a few examples:

- The colour code for indicators was not symmetric. A symmetric colour code would associate an identical colour to a state of things and a complementary or very different colour to the opposite (e.g. red for alert, green for business as usual). At Three Mile Island, many different colours were used inconsistently. Blue would not always mean open, yellow did not generally indicate attention, red did not always signal an anomaly, etc.
- Control panels extended vertically from the floor to the ceiling. Vertical symmetry is against the horizontal symmetry of our bodies. While it is easy to inspect controls

that lie horizontally from left to right, it is much more cumbersome to kneel or bend to read something below or beyond our line of sight. At TMI, many gauges were below eyesight when standing behind the control panel, and many other controls required leaning over to inspect or actuate.

- However, while a horizontal display is easier to peruse, operators can get inaccurate readings if the visual arch extends too much due to the phenomenon of parallax. This optical distortion occurs when a gauge is located in the extreme periphery of our visual field. According to Malone et al. (1980), TMI had 115 vertical indicators above the eye level of the fifth percentile male. None had mirrored scales or limit switches.
- The layering created by the central console and the control panels behind it would generate obstructed views for operators sitting at the console if they needed to read indicators on the lower part of the panel or if another operator was standing between the console and the wall.

The investigation task force determined that these and other design pitfalls provided the control room operators with a false representation of what was happening in the reactor at the time of the accident and that consequently, the course of action they undertook ended up steering the reactor towards the meltdown instead of cooling it down.

Instructions

Pick up a control dashboard of your choice. Any non-trivial interface would be a good candidate, such as a complicated control panel for a thermostat, a software interface's graphic menu and buttons, or a rich car dashboard. Then answer the following questions:

1. Describe the extent to which the interface can be considered symmetric by identifying all available symmetric arrangements and configurations, even if symmetry is only limited to specific groups of controls or particular areas of the interface.
2. Identify asymmetric elements and speculate on why the designers have introduced these asymmetries.
3. What kind of actions symmetric and asymmetric arrangements are supposed to suggest or support?
4. Can you find examples of how symmetry (or lack thereof) can get users stuck or push them to make mistakes?

References

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Reason, J. (2016). *Managing the risks of organizational accidents*. Routledge.