WHITE PAPER

Man vs Machine: The Evolution of Human Operators in Process Safety

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Originally, industrial plants and processes were controlled entirely by human operators. With the rapid development of automated control systems, operators seem to have been laid aside. However, even in the most automated plant, humans still have a role to play in operations. In fact, if the working environment is designed ergonomically, to suit both human bodies and human brains, the synergy between machines and their human counterparts can lead to minimal vulnerability in plants and processes.

On the Origin of Human Operators

Nitroglycerin, a compound invented in 1847, has both medicinal and manufacturing applications. In manufacturing, it is a component in explosives used in the construction, demolition and mining industries as well as by the military. It is produced industrially by the acid-catalyzed nitration of glycerin. Typically, glycerin reacts with a mixture of concentrated nitric and sulfuric acids. The reaction is exothermal, and when the temperature is too high, toxic nitrous vapors are released. The significant process safety risks associated with its production have been acknowledged for decades. As early as 1870, Alfred Nobel chose Ardeer (now incorporated into Steventston, Ayrshire, Scotland), a notably remote location, as the site of what was at the time the largest explosives factory in the world.

In Nobel's day, the production process involved spraying glycerin inside a reactor previously loaded with the acid mixture, and cooled with cold water.[1] A human operator would control the spraying rate by continuously checking the temperature on a five foot long thermometer whose bulb was dipped in the acid mixture and whose marked section protruded from the reactor. If the thermometer rose above twenty-two degrees centigrade, the man would shut off the inflow of glycerin. If it continued to rise, he

1 The description of the process that follows has been adapted from "Lateral Science" (http://lateralscience.blogspot.com/2014/10/scottish-nitroglycerin-one-legged-stools.html), based on an account from 1897, of a visit to Ardeer by H. J. W. Dam.

would give a warning shout, "Stand by," to a man watching below. If it continued, he would then shout, "Let her go," and the man standing by would open a valve; this would sweep the whole charge down to the "drowning-tank," which would extinguish the imminent explosion in an excess of water.

There is both a basic process control system and an interlock in this description. However, both relied on the operator's attention to the temperature of the reactor. Nobel knew perfectly well that long working hours and the tedium of the job would eventually induce drowsiness in human operators. To prevent it, he provided the operators with one-legged stools as shown in figure 1.

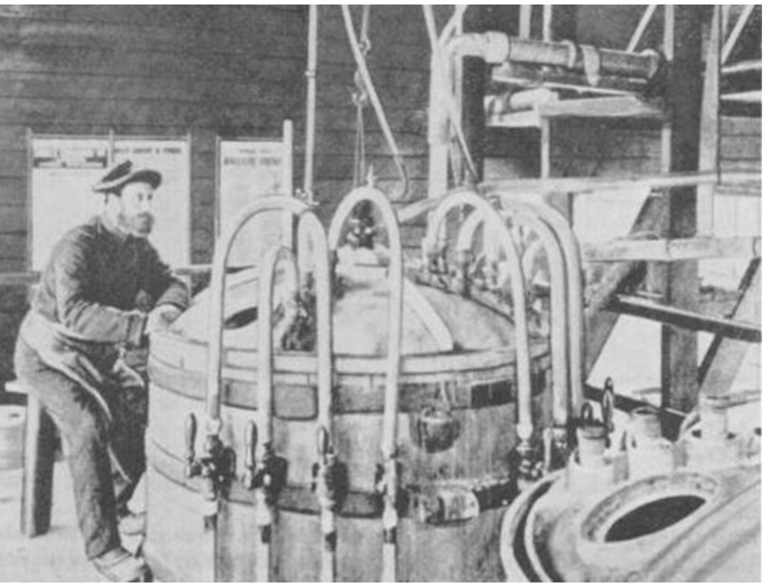

Figure 1. One-legged stool as a safeguard in the manufacturing of nitroglycerin ca. 1870.[2]

In comparison with today's automated systems this solution seems somewhat primitive. Yet even now it is not unusual for operators to play a significant role in sectors such as fine chemicals, where plants need to be extremely versatile, and continuous production changes are the rule rather than the exception. Even in the late 1990s I witnessed a biomass-fueled boiler generating 20 t/h of steam at 40 bar / 400ºC, whose two main controls (fuel and water feed) were handled by a human being instead of the now-usual Automated Control System (ACS).

In our passion for technology and automation, it is important to remember that human operators still offer great advantages over automated controls.

The versatility of the human mind is yet unsurpassed by automation, despite what we have all heard about Deep Blue badly beating the human chess world champion. After all, shape recognition-based CAPTCHAs[3] are still quite effective in distinguishing human from machine input. In addition, there have been important developments over the last few years in understanding how our minds work, and the new research does not necessarily reflect conventional wisdom. An entirely new discipline that we could call neuroergonomics is emerging and is already starting to help us make our workplaces more brain-centric and, therefore, safer.

At the same time, humans are at a clear disadvantage in some regards:

- Humans are prone to distraction, especially during routine work. Much has been written about our "fast" and "slow" brains:[4] the human mind tends to linger in fast mode, as it is energy efficient. If the stimulus is not big enough, the "slow" brain, that is adept at recognizing anomalous conditions, will not fire up. For instance, temperatures creeping up above 22ºC might not be detected by an operator who has been sitting in front of a nitroglycerin reactor for several dull hours.
- Humans become fatigued: we need to eat, sleep and visit the toilet. We also may be heavily influenced by emotions.
- Last, but not least, the corona crisis has shown dramatically how disease can seriously impede human activity. Workforce shortages and disruptions also occur in other contexts; for instance, in some regions turnover is too high to allow for the appropriate induction of recruits, and there are situations in which recruiting isn't possible at all.

Enter the Machine

Moore's law states that the number of transistors in an integrated circuit doubles every two years. This is not, of course, a law of physics, but rather an empirical observation that has been valid since the 1970s. This growth in capacity, unprecedented in any other technology, has touched every single aspect of humankind's activities. Specifically, in industry, the rapid development of increasingly reliable and powerful automated control systems (ACS) has relegated human beings from direct operation positions to a supervisory role.

2 Source: "Alfred Nobel in Scotland", https://www.nobelprize.org/alfred-nobel/alfred-nobel-in-scotland/

3 CAPTCHA is the acronym of "Completely Automated Public Turing test to tell Computers and Humans Apart"

4 See, for instance, a very good summary in Daniel Kahneman's "Thinking, Fast and Slow." Farrar, Straus and Giroux, 2011.

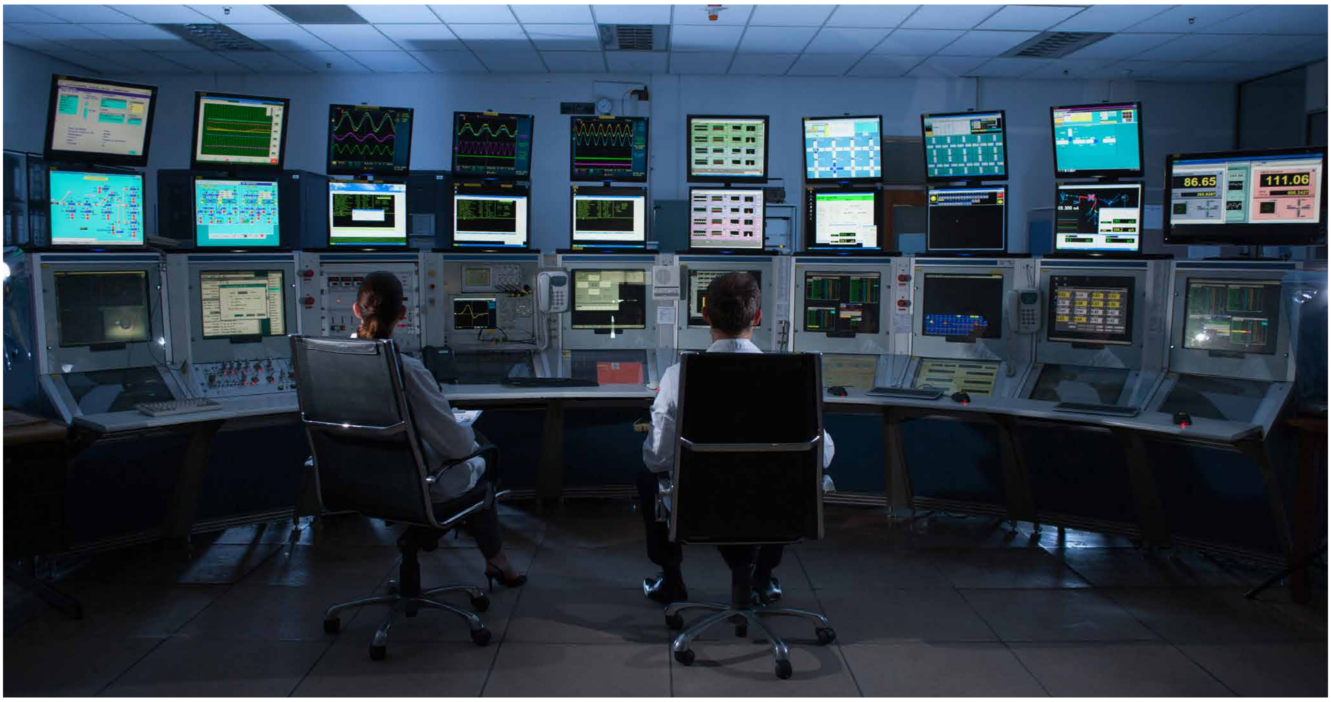

Figure 2. Contemporary control room.

Where we once saw operators sitting on one-legged stools, we now observe state-of-the-art control rooms like the one shown in Figure 2.

Clearly, ACSs do have some advantages over human operators:

- Machines never get distracted; actually, they are very good at handling routine work. For instance, an ACS operating properly would detect every time the temperature exceeded 22ºC in a nitroglycerin reactor, no matter how long the ACS had been in operation.
- ACSs never become fatigued, nor do they eat, sleep or visit the toilet. They only need to be fed with electricity, and this can normally be assured. Machines are not influenced by emotions or stress, which is a critical advantage during process upsets and emergencies.
- Under normal conditions, there is no supply shortage of ACSs anywhere in the world.

An important similarity between ACSs and human beings is vulnerability to viruses. An ACS is obviously immune to biological agents such as the corona virus, but computer viruses, which have multiplied during the pandemic, are another story. ACSs need to be protected against cyberattacks just as humans need to be protected against disease.

Much has been written regarding the respective capabilities of ACSs and human beings.[5] It is very clear that ACSs are more resilient than our "fast brains." Indeed, the fast brain is often referred to as the "automated mind." But the flexibility of the human slow brain in tackling complex issues is as yet unsurpassed. Most of the time the problem lies in making sure that the slow brain is in charge.

A Winning Combination: ACS and the Human Brain

Given the respective advantages and disadvantages of human beings and ACSs as operators in industrial plants, it makes sense to attempt to get the best of both worlds. Let's have a look at Figure 3 (on page 4).

The visual shows the vulnerability of a plant or industrial process as a function of its degree of automation. Assuming that in every plant there is a certain mix of human and automated control, the overall vulnerability is the sum of both. On the extreme left of the chart are plants with little automation and controlled almost exclusively by human operators. The Ardeer nitroglycerin plant mentioned at the outset would be an example. On the other extreme, are heavily automated plants, with very little human interventions.

5 See, for instance Kletz, T. An engineer's view of human error. CRC Press, 2001.

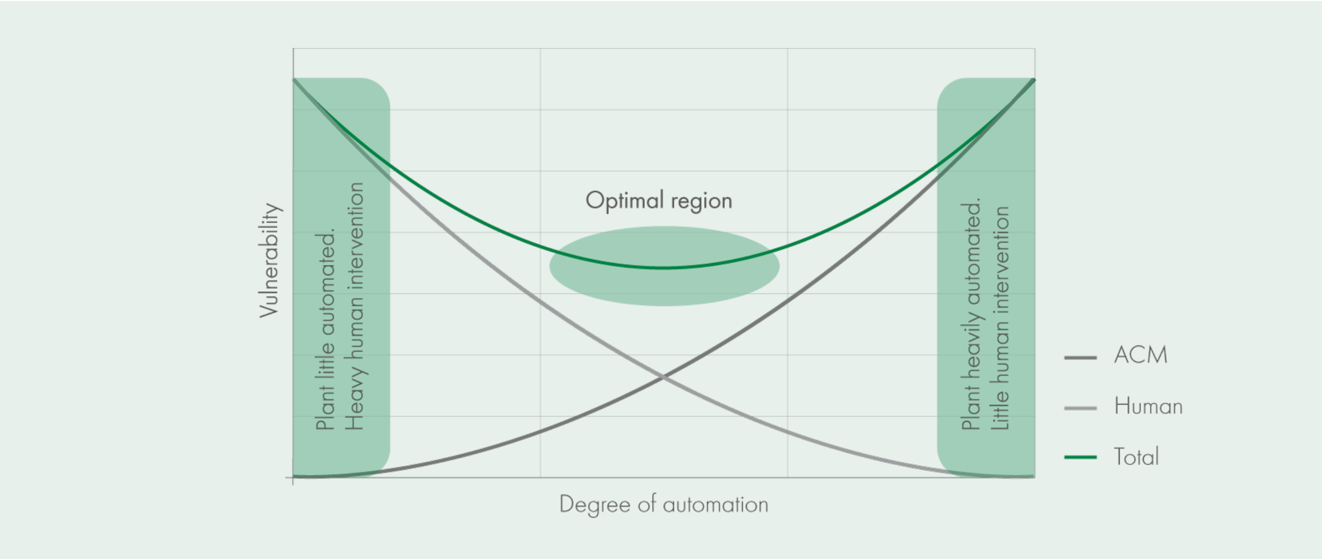

Figure 3. Human vs machine reliability.

The refinery whose control room is shown in Figure 2 would most likely lie in this area.

As we can see, the vulnerability resulting from automation grows from right to left, whereas the vulnerability linked to humans decreases in parallel. When we add both vulnerabilities, we find an optimal region, the one representing the best of both worlds. To achieve this ideal balance:

> Use ACSs for those tasks where they surpass human ability: processes that require distraction-free, constant supervision for long, uninterrupted periods of time; situations where a fast and reliable response is necessary according to previously analyzed plant disruptions.
> Use humans where their capabilities are still superior to ACSs: supervision of the ACSs, troubleshooting, analyzing complex situations, dispatches
> Understand and communicate clearly the roles of the ACS and those of human operators at every step of the process: this prevents incidents that arise from misunderstandings, for example, human operators assuming the ACS performs a given task.
> Create brain-centric workplaces for human operators and supervisors: both the physical space should be ergonomically optimized as well as the procedures, so that, for instance, the ‘slow brains’ of human operators are able to perceive alerts.

A Path Forward for Optimized Process Safety

The promises of technology and automation are often dazzling, and we continue to invite their advances into all facets of our lives. As process safety professionals, however, we need to maintain a rigorously rational perspective supported by data and analysis in order to protect lives, the environment and assets. What data and analysis show, is that our best defense is a joint effort between the human mind and machines in the form of ACSs, where the strengths of each are deployed in a targeted manner. As progress continues in the fields of brain research, neuroergonomics and automated technology, we will continue to learn and adjust, optimizing industrial operations for the safety of ourselves and our planet.

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Dr. Arturo Trujillo is Global Director of Process Safety Consulting. His main areas of expertise are diverse types of process hazard analysis (HAZOP, What-if, HAZID), consequence analysis and quantitative risk analysis. He has been involved in many projects over the last 25 years, especially in the oil & gas, energy, chemicals and pharmaceutical industries.

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