Automation and automation surprises: lessons from aviation. Should health care brace itself?

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The immense growth in computing power and software tools has virtually eliminated 'steam gauges' in the cockpits of modern aircraft and it is rapidly encroaching upon health care. This means that controls, dials and levers are no longer connected to mechanical components of medical devices, but are just control inputs for software that controls the device. This is immediately apparent in the last generation of ventilators that have discarded traditional rotameters to indicate gas flows in favour of software controlled flow control valves and on-screen graphical representations of gas flow, often using bar graphs to mimick the familiar mental model of a rotameter. Rather than setting flow rates individually, modern ventilators allow the user to set inspired oxygen concentrations or an 'economically optimized' gas flow, while the software calculates and controls actual gas flows.

In contrast, computerized drug delivery and closed-loop control solutions have lagged behind, mainly as a result of fear for adverse events and possible litigation. There is also more debate as to whether such closed-loop control systems are solutions for actual clinical problems or just 'gadgets' for technically talented anaesthesiologists. Closed-loop control of neuromuscular blockade is certainly feasible [1,2] and relatively safe, although accidental overdosing will necessitate postoperative mechanical ventilation. In contrast, errors with closed-loop administration of vasoactive drugs could kill a patient. Potential sources of error are unreliable blood pressure data or undetected software errors. Interestingly, even relatively simple model-based 'target- controlled' infusion of hypnotics that has long been available to anaesthesiologists in Europe, is still not approved in the US by the Food and Drug Administration. Much to the chagrin of TCI enthusiasts, FDA employees have expressed vaguely defined fears such as "important health implications", "significant incremental risk" of anaesthetic controllers, "combining high level languages, general purpose computers, and complex operating systems that might result in products that are too elaborate for the developer to verify entirely," [3]. The logical result is that manufacturers have been discouraged from developing improved systems and entering this market and closed-loop control of hypnotics remains in the experimental domain.

Automation versus the experienced human operator: who is in charge?

Several notorious aircraft disasters were clearly related to problems at the interface between the human operators and their automated flight management systems. American Airlines flight 965 crashed into a mountain near Cali, Colombia because the crew had first entered the wrong waypoint code for the non directional beacon 'Rozo' in the FMS ('R' – as indicated on their charts - instead of 'ROZO'- the most current identifier) which took them into the direction of Bogotá. When the crew discovered the error, they entered the coordinates of the Cali airport in the FMS; the aircraft changed course to Cali, but the aircraft was now to the east of mountain ridge and the plane crashed into a mountain with the loss of 189 lives.

Gol Transportes Aéreos Flight 1907, a Boeing 737 collided in mid-air with a business jet over the Brazilian rainforest. All 154 passengers and crew were killed. Investigation of this crash revealed that the crew of the brand new Embraer business jet had failed to notice a tiny text message announcing that the automatic Traffic Collision Avoidance System was inoperative. Both planes had difficulty communicating with air traffic control. As a result, both planes - although flying in opposite directions - were on the same altitude, which should not have happened. As a result of 'perfect' flight guidance by GPS and FMS automation, both planes were flying exact opposite headings at exactly the same altitude.

More recently, a Boeing 737 from Turkish Airlines crashed 1.5 km north of runway 18R at Schiphol airport, the Netherlands, because a defective radio altimeter - registering minus 8 feet altitude and thus assuming that the aircraft had landed on the runway - repeatedly closed the autothrottle causing the aircraft to sink below the glideslope. The crew reacted too late to this automation surprise, the aircraft stalled and crashed into a field north of the runway threshold killing 9 people including the captain and first officer. The accident investigation also blamed the crew for reacting too late to the failing automation.

Automation: who is in charge? Who is responsible?

There seems to be a dividing line between Europe and the US regarding the amount of control we are willing to hand over to automation. The Americans seem to be more distrustful of computers taking control than Europeans. Nonetheless, it is impossible today to make any scheduled flight in a modern jet aircraft without entrusting one's life to the proper functioning of a large amount of computer systems, both in the plane and on the ground. The two major aircraft manufacturers, Boeing and Airbus, have opposing views as to the degree to which the flight data management computers should be able to overrule a pilot when he is about to subject the aircraft to dangerous extreme attitudes and control movements. While each aircraft will generate alerts and voice alarms ("pull up!", "too low, terrain!"), the automation of a Boeing will never take control away from the pilot and will grant him the power to decide how to steer the plane. In contrast, Airbus has decided that the safety of the flight is best guaranteed if the automation can overrule a pilot who is about to perform a very dangerous manoeuvre. These differences in 'control philosophy' will soon become important in health care. Designers of anaesthesia machines and delivery systems are already confronted with such decisions. Similar design issues also confront software developers who build hospital-wide electronic patient record systems. Should a doctor be blocked from prescribing penicillin to a patient when the 'allergy' data field contains: 'allergic to penicillin', or should she only be warned and required to electronically sign a motivated waiver?

Taken together these issues constitute the field of *Human Factors*. It is remarkable how many industries have embraced the science of Human Factors to help them improve man-machine interaction, the design of user interfaces and team interaction. Health care has been slow in adopting Human Factors knowledge into the design of its processes and equipment. The rapid rise in complexity of care, new technology and increasing pressures to produce both efficient and safe care, make it necessary to better reflect on the design of interfaces to ICT systems and medical devices.

Unintended consequences of technology: problems and pitfalls of automation

As we rapidly move towards hospital wide electronic patient records (EPR) and Computerized Physician Order entry (CPOE), new types of errors can occur. Several studies have shown that

CPOE reduces the number of medication error, but it is unclear to what extent serious new errors resulting from working with a computer interface might counterbalance the benefits of CPOE. To select a drug, so-called 'pick lists' are used in pull-down menu's. It is relatively easy to accidentally select the item below or above the correct item in an alphabetic pick list, especially in the case of 'sound alike, look alike' drugs. A similar problem might occur with preformatted order sets.

Will automation promote *complacency*? When automated blood pressure monitors appeared, taking a blood pressure was no longer an act that involved feeling the patient's pulse. Some experienced anaesthesiologists expressed fear that automated blood pressure monitoring would reduce vigilance and lead to anaesthesia practice that is less 'hands-on'. Similar objections have been voiced against automated anaesthesia record keeping systems or closed-loop control of anesthesia administration: they might discourage systematic scanning of the monitors and promote complacency. Few studies have addressed this issue. Loeb et al. found no evidence for reduced vigilance when anaesthesia residents were relieved of the task of charting the anaesthesia record.[4]. Weinger et al. also were unable to document a reduction in vigilance when an ARK was used during anaesthesia for cardiac surgery[5]

What if the system fails: are we ready?

The more hospitals start to rely on ICT solutions for their clinical processes, the more critical such systems become for safe patient care. Beth Israel Hospital in Boston, MA was an early adopter of electronic patient records and its residents had never used paper-based records or ordering. In November 2002 the network was down for 4 days, forcing doctors and nurses to revert back to pen and paper. The cause of the problem was later discovered. A researcher had started to upload several gigabytes of data and the process was stuck in an endless loop blocking the network. Separating databases for research and clinical use clearly is mandatory, using 'mirror' databases for all clinical research queries.
The issue of how to balance the need for redundancy with the additional costs is also unresolved. Pagers and analog telephone lines are on the brink becoming extinct and new technologies such as voice over IP (VoIP) are ready to take over. The risks of entrusting all communications (data and voice) to a single hospital network are immense. If today a part of the hospital information system fails, doctors and nurses can still use the telephone to communicate with colleagues, the emergency room, ICU or the laboratory. If the network is also used for voice communication and the network is down, all communication except talking face to face becomes impossible.

Conclusions

Computers and automation are now an integral part of anaesthesia and intensive care technology. Computer control is already built into many new anaesthesia devices, but closed-loop control of critical anaesthesia processes such infusion of vaso-active drugs or hypnotics remains in the experimental domain. Computerized patient data management systems are rapidly becoming standard of care and will increasingly incorporate decision support algorithms in the form of reminders and alerts. Such systems offer a promise of considerable clinical benefit, but we do not know yet the risk-benefit ratio of allowing ICT to overrule the doctor. This wave of ICT also creates new challenges, as we discover the unintended consequences of this technology. Unique new types of error such as selecting the wrong drug from an alphabetic pick list, will require new solutions. Finally, as hospitals become dependent on the correct functioning of their network and tightly coupled ICT subsystems, sufficient redundancy needs to built into the system.

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