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"State of the art" human factors innovations in operator measurement

Summary

Forest operations have many similarities to the mining and military sectors. All three sectors have an extensive history of technology development aligned with human factors research and implementation. Like mining and military, the forestry sector is hazardous and physical tasks are demanding, resulting in the potential for greater use of machinery and automation to remove people from hazards while maintaining productivity. Examples of mining and military innovations drawing on human factors research are presented in this report and relevant human measurement and data collection methods are outlined.

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Introduction

The purpose of this report is to summarise human factors innovations from the mining industry and military that have relevance to forestry particularly with the introduction of new automated technologies in operations across New Zealand. This review is part of the Human Factors programme of the "Forestry Work in the Modern Age" Primary Growth Partnership (FGR, 2018). One of the drivers of the programme is to make harvesting and log logistics operations safer.

Human Factors Research

Human factors is also referred to as "ergonomics" and is defined by the International Ergonomics Association as: "…the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimise human well-being and overall system performance."

In practical terms, this means modifying the work environment and designing the way people work, and the tools they use, so they can stay safe and work efficiently. Examples of human factors innovations include:

- design of machine cabins so that the operator has a better field of view (Aromaa *et al.,* 2020; Gilad and Byran, 2015)
- lighting for night operations (Reyes *et al.,* 2013)
- location of levers and controls so that the operator can work comfortably for long periods of time (Hansson, 1990)

Human factors also includes the design of the work system (work organisation) to maintain human safety and productivity, including factors such as the length of the workday (Lilley *et al.,* 2002), the management structure and the level of autonomy of the worker.

The forest industry in New Zealand has a history of supporting human factors research in forest operations because of the high hazard environment that results in deaths and injuries to workers. Since 1976 there has been an active forestry human factors research programme undertaken in New Zealand by the Logging Industry Research Association (LIRA), which was heavily influenced by the Swedish forest industry (Gaskin, 1986).

Forestry human factors research in New Zealand up to about 2000 often focussed on the physical aspects of forest work. These projects are summarised by Parker *et al.,* (2002). Research topics included:

- Use and analysis of an Accident Reporting Scheme (Sullman *et al*., 1999)
- Protective clothing for chainsaw operators (Prebble 1981)
- High visibility clothing (Isler *et al*., 1997)
- Assessment of spiked soled boots (Kirk and Parker, 1994)
- Hazards during chainsaw tree felling and perception of risk (Parker 1991)
- Factors influencing log making ability (Cossens 1991, Cummins 1998)
- Fluid intake of forest workers (Paterson 1997, Bates *et al*., 2001)
- Size of chainsaws for delimbing (Parker *et al.,* 1999).

Other projects investigated workforce retention, skills requirements, and job satisfaction (Byers, 1995). From

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2000, this work was continued by the New Zealand Forest Research Institute (Scion) in a group called the Centre for Human Factors and Ergonomics (COHFE). This human factors research in forestry investigated causes of injury to forest workers (Ashby *et al.,* 2002, and Bentley *et al.,* 2004), health and wellbeing of forest workers (Thomas, Bentley, & Ashby, 2001), heart rate strain in cable hauler choker setters (Kirk & Sullman, 2001) and development of a strategic ergonomics, safety and health research programme (Bentley *et al*., 2002).

More recent work has investigated systems failures and contributory factors in logging injuries (Hide, 2015 and Hide *et al.,* 2009), human behaviour in accident causation (Hooper, Parker, & O'Connor, 2017) and implicit learning to strengthen intuitive decision-making (Hooper, 2016). This work has led into the area of enhanced immersive environments such as virtual reality and augmented reality as ways to create opportunities for implicit learning (Thompson *et al*., 2020).

Forestry is moving to introduce more automation, to attract a broader range of staff, and provide their workforce with less exposure to hazards (FGR, 2018). With the Primary Growth Partnership Steepland Harvesting programme, research started to focus on robotics technology (Meaclem *et al.,* 2016) and robotics systems (Parker, Clinton, *et al*., 2018). This move will also reduce the occurrence of chronic occupational illness due to exposure to vibration, noise, and emissions from chainsaw exhaust gases (Hooper, Parker, & Todoroki, 2017).

Both the mining and the military sectors are relevant to the forest industry. Historically, mining and military operations were manual with miners and soldiers using hand-held tools and operating predominantly on foot (apart from cavalry operations). Then mechanisation occurred and both occupational groups developed machines to perform the work. More recently, sophisticated machines controlled by human and computers and linked by data networks have been introduced to both mining and military operations. Forestry has followed this same developmental path (although at a slower rate, conferring some advantages in terms of learnings). Forestry can draw on the massive research and development effort of both mining and military human factors specialists. Outlined below are a few of the relevant interventions which have been developed for mining and military systems.

Mining

High hazard industries of relevance to forestry include mining (Dempsey *et al.,* 2018). Mining operations can be underground or surface and, like forest operations, the tasks can be physically demanding and hazardous. Like forestry, the work environment is changing as the mine advances and environmental challenges present. In surface mines, the workers are exposed to changing weather, whereas underground miners are exposed to changes in air quality, air and rock temperature and the ingress of water. In both mining and forestry, workers often operate or interact in close proximity to large and essential mobile machinery (Figure 1).

Figure 1: Human factors research has been critical in the design of sophisticated mining machinery

The mining sector has an active human factors research and development programme (Rogers *et al.*, 2019). For example, in the US the Pittsburgh Mining Research Division (PMRD) is part of the US National Institute for Occupational Safety and Health. The UK has the Health & Safety Executive to undertake mining human factors.

A few of the many significant ergonomics interventions in mining are summarised in Sanders and Peay (1988). These include:

- Hearing protection
- Controls, seating and operator field of vision in mining machines
- Design of machines to improve maintenance access, safety and speed
- Hand tool design to reduce injury such as repetitive strain or vibration
- Recommended energy expenditure in tasks
- Heat and cold stress limits.

More recently, teleoperation and automation of machinery in mines has become more common to reduce the exposure of people to hazards (Rogers *et al*., 2019). Other researchers describe the issues of bigger machines, aging workforce, remote control and teleoperation and the associated design and organisation challenges to run a modern and profitable mine (Horberry *et al.,* 2016). Valuable insights to dealing with these issues can be found from the mining literature (for example, Rogers *et al.,* (2019) and Gruenhagen and Parker (2020)).

Military

The other high hazard sector of relevance to forestry is the military (Savage-Knepshield *et al.,* 2012). Military operations require people to work in often uncontrolled hazardous natural environments, for long hours, with a high level of autonomy, where situations can change rapidly. Military operations can be undertaken anywhere, but generally, they are outside

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in the environment. Soldiers are exposed to weather, difficult terrain, and night operations etc.

Soldiers may operate alone or in small groups and rely on communications often by radio or hand signals only. Many of the tasks are manual, on foot and require load carrying. The workers tend to be predominately male. Like forestry and mining, there are specialist vehicles which operators must train to learn and these machine traverse difficult terrain with significant hazards (Savage-Knepshield *et al.*, 2012).

There are numerous parallels between forestry and military operations and the forest industry can gain considerable insights from military human factors research.

The military has an active human factors research and development programme. Military human factors are undertaken by many countries, including New Zealand's Defence Technology Agency (DTA), Australia's Defence Science & Technology Agency (DSTO) and numerous organisations in the US, Canada, and UK.

Recent military human factors investigations of relevance to forestry automation include:

- Control panel design (Lim *et al*., 2018)
- Head mounted vs flat screen displays for visual search (Brooks *et al*., 2017)
- Humans working with intelligent machines (Chen, 2018)
- Enhance training through capturing experts' knowledge in a way to support novices (Clewley *et al.*, 2019)
- Communication by touch (tactile) in noisy military vehicles (Katzman & Oron-Gilad, 2020).

Human factors innovators and developers need data to identify whether there is a problem in the work environment and once a solution is found, to determine if that solution has solved the original problem. Data is needed to understand and characterise the work environment. The collection of data is discussed in the next section.

Background to operator measurement, data collection and analysis

Data is valuable to the human factors specialist to understand what tasks a person undertakes while they are working, and the effects of the work and environment on that person. Data collection methods include video of the worker and immediate environment to understand tasks, processes, and what events in the environment trigger particular actions, tracking of worker eye movements, transcripts of radio traffic, heart rate and variability, blood pressure and geographical location. Data is collected with a range of sensors worn on the body of the worker, on the machinery they are using or near the place of work.

Sensors

It is important to understand the historical background to the measurement of work because there has always been an interest in making work safer and more efficient. Initially, work was measured by observation and subjective judgment rather than electronic technologies. Later, efficiency experts, Frank and Lillian Gilbreth pioneered the use of ciné and still photography for the study of work and the use of micro-motion (slow-motion) cinematography (Whitmore, 1987).

Physiological monitoring

In the 1960s, Socially Acceptable Monitoring Instruments (SAMIs) were introduced. Baker, Humphrey, and Wolff (1967) reported that data (for example, number of heart beats over the recording period) were stored in a sealed miniature cell in which silver was plated on to a gold electrode in proportion to the charge passed through it. SAMIs were the first self-contained 'wearable' physiological recording devices and have since been superseded by a stream of ever-improving devices.

The Dutch physiologist, Willem Einthoven, developed the first electrocardiograph (ECG) in 1903 and subsequently was recognised with the Nobel Prize in Medicine in 1924 (Kligfield, 2002). The first self-contained, wearable and recording heart rate monitor was developed in 1978 by the Polar Electro Company in Finland (Laukkanen & Virtanen, 1998). Over subsequent years, refinements in electronics and software have resulted in a vast range of wearable heart rate recording devices by numerous manufacturers.

Now investigators can purchase heart rate monitors that can record heart rate variability, record full EMG profiles and continuously record heart rate for up to one month storing the data within the heart rate monitors memory. More recent developments in heart rate monitor technology have seen devices incorporated in clothing (e.g. Vivometrics 'LifeShirt') and the development of technology where the pulse can be detected by light passing through the skin (Allen, 2007).

Heart rate in isolation tells the investigator little about what work is being done. A visual recording of work by video has helped to address this deficit and is the most common method used today to understand the context of work.

Video

Ciné cameras and film for the study of work were superseded by video in the 1970s when video cameras and recorders became available to the consumer. The greatest technical developments, which have been pivotal in workplace research, are the wearable miniature video camera (Mann, 1997) and recording video to solid state memory (Parker,

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Vitalis, *et al.,* 2017), and Hooper *et al.,* (2017). These developments have allowed people to wear a video camera and recorder during their normal work (Figure 2). The latest embodiment of this technology is the GoPro type sports camera.

Figure 2: Tree faller wearing helmet- and shoulder-mounted video cameras during a human factors study (Parker, 2010)

The Global Positioning System (GPS)

Another technological development that has proven useful in human factors applications is the Global Positioning System (GPS). GPS data can be integrated with Google Earth maps so the path of a subject can be viewed with a three dimensionally rendered terrain model. This offers the capacity to overlay high resolution aerial photography over the Google Earth terrain model to create an almost photo-realistic image of the terrain which can be viewed from the operator's angle of view (Parker *et al*., 2017).

Integration of data streams

Modern technology allows the capture of vast quantities of information. For example, one hour of video recorded at 25 frames/second at a sampling rate of 2000 Hz and a resolution of 720 by 480 pixels, occupies one gigabyte of memory. Software is needed to interpret this data and create useful information.

Advances in this field come from the military. Sensor ensembles are being developed for military use where the outputs from sensors can be used as an aide-to-memory for reviewing when writing intelligence reports and to understand events during high pressure situations and intense operations (Minnen *et al*., 2007). The technology used in the Soldier Assist System (SAS) of sensors mounted on a soldier's body to record aspects of the ambient environment and his movements has been described. The soldier has the following equipment:

- accelerometers attached to clothing at various sites to measure body position
- a commercial GPS unit
- an altimeter
- a digital compass
- a still digital camera is mounted on the soldier's helmet and takes a photograph every five seconds
- a digital movie camera records to an internal SD card.
- a microphone to record conversation; and
- a second microphone to record ambient sounds.

Images and sounds can then be reviewed in context because corresponding location information is available. The complex software developments which have allowed the automation of physical activity recognition are also described.

A similar system was constructed to record the activities of New Zealand tree fallers and rural fire fighters (Parker, 2010). Video data and sensor data can be bought together for analysis with specialised software such as the Noldus Observer (Ice, 2004) (Figure 3).

Figure 3: Output from two video cameras showing tree faller's view and chainsaw

Other specialised software has been developed for the integration of video, operator heart rate, and other measures in sports and biomedical applications (Mendes Jr. *et al*., 2016).

Occupational health investigators have embraced video technology since the mid-1980s. A prominent use of video technology is video exposure monitoring which involves the combination of real-time monitoring instruments, usually for gases/vapours and dust, with video of the worker's activities (Rosén *et al*., 2005).

Real-time occupational health monitoring equipment became widely available in the 1980s. The National Institute for Working Life in Sweden linked a real-time paint fume monitoring instrument with a concurrent video recording of the spray painters in a woodwork factory (Rosén & Lundström, 1987). Having a video record of the workers activity, while simultaneously viewing the concentration of paint fumes (Figure 4), enabled the researcher and the worker to see the effects of different work activities on paint fume exposure (Rosén *et al.*, 2005).

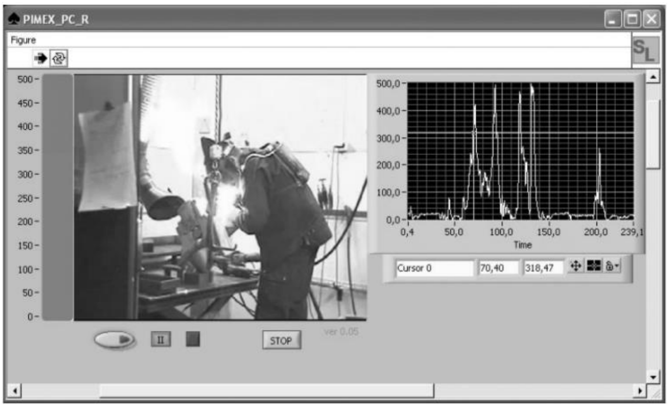

Figure 4: Example of a PIMEX-PC recording shows a worker carrying a monitoring instrument for fume in a backpack while welding. The graph on the right shows how the welder's exposure to smoke has varied during the period (Rosén *et al.*, 2005).

Video exposure monitoring (VEM) supplies solutions, and a way to test those solutions, to occupational exposure problems. This technology is being used today in mining to determine exposure to dust (Patts *et al.,* 2020) and in New Zealand forestry to investigate exposure to carbon monoxide (Hooper *et al.*, 2017).

Conclusion

High hazard industries of relevance to the forest industry include mining and the military. This report has summarised examples of mining and military innovations drawing on human factors research. Human measurement and data collection methods have been described that will be useful in the ongoing Human Factors programme in the Automation and Robotics Primary Growth Partnership.

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