Research note: Machinery, manumission, and economic machinations☆

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ABSTRACT

This research note reports upon advancements in computerization and big data creation within the off-highway plant and machinery sector. A thematic literature review synthesizes a disparate range of research initiatives and industrial developments and highlights specific examples of technological developments. A discussion regarding impact upon future employment concludes that rather than creating mass unemployment, computerization will change the employment horizon and continue to shape the global economic community. Education is quintessentially important to humanity which must master the machine and not become a slave to technology. Future proofing of educational provisions will therefore feature heavily in tomorrow's employment market. This provocative research note advances new ideas and theoretical perspectives that are specifically designed to stimulate academic debate in this novel and rapidly developing area of scientific endeavor.

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1. Introduction

"*Homo sapiens* have outgrown their use…" Bowie (1971)

The rapid pace of computerization has created a digital economy to challenge the modern capitalist economy; societal, political and economic ramifications of this change are profound, not least upon employment, education and prosperity (Parayil, 2005). The digital economy manifests from two key sources: i) the transformation effects of general purpose technologies (hardware) in the field of information and communication; and ii) the overwhelmingly vast inter-connectivity afforded by the internet. Unlike the Industrial Revolution, the digital age is maturing at an exponential pace. In 2010, the internet contained an estimated five hundred billion gigabytes of digital content but increasingly, experts refer to digital content in yottabytes (i.e. a trillion terabytes) (Bollier, 2010). This growth trend is fueled by the rise in internet traffic which is doubling every two to three years, with mobile internet traffic doubling every year (EU, 2014). Ross (2016) reports that the currently estimated 16 billion internet connected devices will increase to 40 billion by 2020. The voluminous data generated (and knowledge contained within such) signifies that whilst iron represented the Industrial Revolution's raw material, data constitutes the raw material of the information age. As well as fueling prosperity, the information age has also created opportunities for cybercrime and terrorists. The number, cost and sophistication of these attacks is increasing at an alarming rate and the value of crime is estimated to cost the global economy billions of pounds (UK Sterling) each year (Ablon, Libicki, & Golay, 2014).

The digital revolution far exceeds the confines of the information and communication technology sector, and ubiquitous mobile computing provides a menagerie of mobile digital devices that generate vast quantities of data, information and knowledge for businesses and government – so called big data. Big data has the inherent potential to uncover patterns, trends and associations related to machinery, human behavior and the interactions between the two. Industries that increasingly use mobile machinery are no exception. Frey and Osborne (2013) report that this observed growth is founded upon advances in machine learning (ML) and mobile robotics (MR). The term robot has its etymological roots in the word serf and the unlimited productive capacity afforded by computers and robotic self-regulated machines will shape economies and alter employment markets (Levy & Murnane, 2012).

Automation of mobile machinery within the off-highway plant and equipment sector has similarly proliferated. Off-highway plant and machinery (which is often erroneously referred to as construction plant and equipment) consists of largely mobile self-propelled machines that are operated in a range of heavy industries including construction, civil engineering, quarrying, warehouse and distribution and mining. Typical machines include road rollers, articulated or rigid dump trucks, cranes and excavators. This research note reviews developments in the field of automated off-highway plant and equipment and discusses the social and economic ramifications of such technological advancements,

where the discussion is based upon a synthesis of literature and the authors' twenty years of experience working within this field of science. The purpose is to generate new ideas and provide polemic clarity geared to intellectually challenge readers from across a range of academic and industrial disciplines.

2. Manumission and technological transformation

Early off-highway plant and machinery shared a symbiotic linkage with the operator, and represented a mechanical extension of human physicality, where human senses were transferred through machinery to complete physical work effort without exerting load upon the operator's musculoskeletal frame. This pseudo-cybernetic organism (i.e. man and machine inextricably linked) led to manumission but remained dependent upon operator cognitive ability (i.e. skill, knowledge and competence) to guide the machinery to complete predefined tasks. The advent of globalization intensified competition within world economies by eroding regional monopolies, increasing competition and consequently stimulating a drive to increase productivity performance. Reacting to customers' demands, original equipment manufacturers (OEMs) acknowledged that human intervention impacted upon machinery productivity performance in various ways and sought to better understand these through work study. For example, consider a tracked face-shovel excavator used at the blast face in quarries where the machine's performance is dependent upon factors such as: a bucket fill factor, slew times and break-out forces. Modelling of work study data revealed the extent to which operator performance, and other environmental conditions (such as soil type and meteorological conditions), impacted upon machine performance. A renewed focus upon operator training and competence development followed but new knowledge acquired on human behavior (primarily limitations to machine utilization, i.e. hours operated) revealed that maximizing machinery productivity efficiency was a persistent issue. The natural extension was to design-out human error, omissions or inactivity via the development of automation and robotics.

Robotics now effectively challenge the manual operation and maintenance of off-highway plant and machinery. Recent developments in belief space (i.e. the ability of a robot to make intelligent decisions based upon complex algorithmic computations) have enabled tasks that were previously too complex for robots to undertake, to be achieved with considerable aplomb (e.g. deceptively simple tasks that require an assessment of weight, fragility and density or the gravitational forces exerted upon an object). Belief space has transformed robots from a two-dimensional to a three-dimensional life via cloud robotics. The robot (Robot B-9) in the 1960's television series Lost in Space would be hugely expensive and require a multi-million pound investment in standalone hardware and software technology to operate. Mobile communications via cloud technology have removed this financial barrier (and increased computational power) by allowing internet connected devices to communicate algorithmically via the cloud, providing the machines with information and instruction. Robots have become a servant class that can replace not only hard labor but also work that requires more cognitive skills and ability. Aviation was one of the first industries to embrace the incredible sophistication and versatility offered by mobile computerization, in the areas of civilian aircraft and remote controlled drones (Holland et al., 2001). Indeed, most aircraft today have very limited human interaction. Whilst computerization is being increasingly adopted within the realm of off-highway plant and machinery, several limitations are apparent, the most prominent being related to the value of the machinery purchased and not necessarily the technological costs. Smaller machines under circa 10 tons in weight (e.g. the micro or mini excavator) are often treated as disposable white goods and liberally used and abused until written-off over a predefined depreciation term (often three-five years) (Edwards, Harris, & McCaffer, 2003). For this reason, the majority of automation and robotic research in the off-highway plant and machinery

sector has predominantly focused upon larger and more expensive machines (>30 tons and ≤200 tons in weight).

3. Technological developments in the off-highway plant and machinery sector

A peculiarity of the off-highway plant and machinery sector is that advancements in computerization, automation and robotics sometimes co-exist in a parallel universe. Academic institutions typically pursue knowledge via research grants won, PhD completions and research papers published. OEMs, whose research and development departments employ vast resources, ruthlessly pursue profitability and market share. When the two converge onto a common research project, the outcomes are remarkable but too often academic outputs stagnate in a self-referential cycle where the self-serving principal objective is publish or peril (Neill, 2008). Despite this concern, extraordinary advancements in the sector have been made. A brief review follows to provide a contextual backdrop by which to measure current progress; of particular note, many of these innovations are based upon advanced sensor technology.

3.1. On-board condition based maintenance monitoring

Maintenance is a necessity for sustaining machinery availability and reliability, which in turn ensures productivity, product quality, timely product delivery and a safe working environment (Tran & Yanga, 2012). Simultaneously, maintenance preserves a machine's working life and extends its residual value (Edwards et al., 2003; Edwards & Holt, 2009). On-board condition monitoring techniques have capitalized upon sensor technology to provide direct, on-line, big data streaming to record the health (or otherwise) of critical components, including most rotating and reciprocating parts (Heng, Zhang, Tan, & Mathew, 2009). Noise and temperature signatures of healthy components or compartments are then compared to these actual values to determine the presence and extent of wear (Turner & Huff, 2003; Choy, Mugler, & Zhou, 2003). A component is a single mechanical item, such as a piston ring within an engine; the engine itself represents the compartment, which contains numerous components. The major beneficial ramification of on-board condition monitoring is that parts and components are no longer replaced on a time-usage basis, a particularly wasteful strategy as parts that could have extended useful life are simply replaced regardless (Komatsu, 2016). Rather, intelligent management decisions, founded upon algorithmic calculations, are used to determine the most economical time to conduct maintenance in order to prevent breakdown and machinery downtime.

3.2. Health and safety

Research into preserving health and safety focuses upon protection of persons who may be affected by machinery usage. Some sectors, for example the construction industry, have an unfortunate record of injuries and fatalities (Edwards & Nicholas, 2002) and two common root causes are inadequate operator competence (Edwards, 2003) and/or deficient on-site maintenance (Edwards & Love, 2016). To counter the causation of these incidents, a number of research studies have been completed on a broad range of topics – notably, each study has attempted to augment machine performance by bypassing limitations in an operator's cognitive ability. For example, Pizarro, Price, and Beliveau (1997) experiments with auditory collision warning signals for a crane/overhead power line collision simulated scenario whilst Chae and Yoshida (2010) and Riaz, Edwards, and Thorpe (2006) utilize radio frequency identification tags to prevent machine and/or pedestrian collision. Chen, Chao, and Kim (2002) focus upon recent hardware and software developments in machine vision systems for multispectral and hyperspectral inspection of food, whilst Trivedi, Gandhi, and McCall (2003) use computer vision technology to develop safer vehicles. Future