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A survey of the prevalence of fatigue, its precursors and individual coping mechanisms among U.S. manufacturing workers

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ABSTRACT

Advanced manufacturing has resulted in significant changes on the shop-floor, influencing work demands and the working environment. The corresponding safety-related effects, including fatigue, have not been captured on an industry-wide scale. This paper presents results of a survey of U.S. manufacturing workers for the: prevalence of fatigue, its root causes and significant factors, and adopted individual fatigue coping methods. The responses from 451 manufacturing employees were analyzed using descriptive data analysis, bivariate analysis and Market Basket Analysis. 57.9% of respondents indicated that they were somewhat fatigued during the past week. They reported the ankles/feet, lower back and eyes were frequently affected body parts and a lack of sleep, work stress and shift schedule were top selected root causes for fatigue. In order to respond to fatigue when it is present, respondents reported coping by drinking caffeinated drinks, stretching/doing exercises and talking with coworkers. Frequent combinations of fatigue causes and individual coping methods were identified. These results may inform the design of fatigue monitoring and mitigation strategies and future research related to fatigue development.

1. Introduction and motivation

The manufacturing sector is an important contributor to the U.S. economy, accounting for 14% of the Gross Domestic Product (GDP) and 11% of total employment (Economic Development Partnership of Alabama, 2012). Since 2011, the U.S. government has made significant investments in *advanced manufacturing*, which is a subset of manufacturing activities that relies on the use of automation, computation and sensing technologies. The President's Council of Advisors on Science and Technology (2011, p. i) describes advanced manufacturing activities to "… (involve) both new ways to manufacture existing products, and the manufacture of new products emerging from new advanced technologies". According to The White House (2016), the transition to advanced manufacturing has commenced in the United States, and it has started to impact many manufacturing industries.

With this transition, it is important to understand how the role of labor is changing based on advanced manufacturing. First, advanced manufacturing, which is also related to Industry 4.0 (Lee et al., 2015; Spöttl, 2017), is different from the computer-integrated manufacturing approach of the 1980s and early 1990s. Specifically, the end goal of computer-integrated manufacturing was a workless manufacturing environment (i.e. lights out manufacturing facilities); however, advanced manufacturing aims to integrate workers into the cyber-physical infrastructure to maximize the impact of their skills (Gorecky et al., 2014). Second, it is well documented that automation can lead to: (a) reducing repetitive, mundane and dangerous work (see e.g., Kelly, 2012; Thompson, 2014; Yakowicz, 2016); (b) increasing the dependency on multi-skilled workers who can simultaneously work multiple workstations, which originated with the creation of U-shaped cells in lean manufacturing (Black and Phillips, 2013) and became more prominent with automation (Ferjani et al., 2017); and (c) broadening the workers' autonomy and responsibility as well as requiring new job duties (Waldeck, 2014). Third, the advancements in computation and sensing technologies is leading to smart factories, where workers will respond to mass-customized products (Hu, 2013) and have to

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be able to process and act upon large amounts of information.

Based on the above discussion, the transition to advanced manufacturing can potentially increase the physical and mental workload on workers. There is an increasing amount of literature suggesting that the increased workloads, which result in a higher prevalence of fatigue, continue to be a factor in advanced manufacturing settings. For examples, we refer the reader to: Brocal and Sebastián (2015), Romero et al. (2016), Ferjani et al. (2017), and Gust et al. (2017). In our estimation, these examples and the changing nature of jobs require a holistic analysis of the workers' states, from an occupational health and safety perspective and in the emerging era of advanced manufacturing.

Therefore, in this paper, we examine the impact of these changes on U.S. manufacturing workers in an attempt to answer the following research questions:

- What is the prevalence of (primarily physical) fatigue among U.S. advanced manufacturing workers?
- What are the main drivers for fatigue (if it is prevalent)?
- What are the coping measures of workers in combating fatigue (if it exists)?

These questions aim to understand fatigue prevalence from a macro-level among manufacturing workers, i.e., we are not interested in whether a worker is fatigued at this moment but rather over the span of their typical work week. To answer these questions, we created an online questionnaire that targeted U.S.-based manufacturing employees. To our knowledge, this survey represents the first nationwide study that aimed to evaluate and assess the prevalence of fatigue, its drivers and how workers attempt to manage it within U.S. manufacturing companies. Understanding these three aspects are important in designing (advanced) manufacturing workplaces that are centered around human workers. In Section 2, we provide a definition for fatigue, highlight its impacts and present how our survey addresses an important gap in the occupational safety literature.

2. Background

The term "fatigue" is used to describe a number of different, sometimes interrelated, phenomena. Specifically, it may be used in referring to: (a) lack of sleep, where it is utilized to capture "tiredness" (Shen et al., 2006), (b) whole body physical fatigue that includes cardiovascular fatigue (Davila et al., 2010), (c) localized muscle fatigue, see Chaffin (1973) for a detailed description, (d) mental fatigue/exhaustion, defined by van der Linden et al. (2003) "as a change in psycho-physiological state due to sustained performance," and (e) symptoms associated with a number of medical ailments that include cancer, Parkinson's disease, depression and multiple sclerosis (Dittner et al., 2004; Shen et al., 2006). Based on the multidimensional nature of fatigue, there are no universal definitions for it (Shen et al., 2006; Cavuoto and Megahed, 2016). From a workplace perspective, fatigue is linked to an impaired/reduced performance (e.g., see the discussion in Brown, 1994; Dittner et al., 2004; Barker and Nussbaum, 2011; Yung, 2016; Yildiz et al., 2017, and Filtness and Naweed, 2017). Thus, in this paper, we use "fatigue" to denote "a lower level of strength, physical capacity, or performance as a result of work activities." We include "strength" and "physical capacity" in our definition since they are important to manufacturing tasks. Note that both "capacity" and "performance" were included in the definition of fatigue that came from the CRE-MSD Workshop, Toronto (see Yung, 2016).

Fatigue is a known precursor to a number of negative outcomes. From a health perspective, fatigue has significant short-term and long-term implications. Some of the short-term implications include (Björklund et al., 2000; Côté et al., 2005; Huysmans et al., 2010): discomfort, lowered strength, and reduced motor control. In a workplace setting, these short-term symptoms result in "reduced performance, productivity, quality of work and increased incidence of labour accidents and human errors" (Yung et al., 2014, p. 1562). Perhaps, more importantly, fatigue has been hypothesized to result in several long-term health outcomes, including: (a) the occurrence of musculoskeletal disorders (Iridiastadi and Nussbaum, 2006; Naranjo-Flores and Ramírez-Cárdenas, 2014), (b) the development of chronic-fatigue syndrome (Fukuda et al., 1994), and (c) a diminished immune function (Kajimoto, 2008). From a workplace point of view, Ricci et al. (2007) reported that fatigued workers report health-related lost productive time more than twice as often as those without fatigue. It is estimated that these short-term and long-term fatigue outcomes cost U.S. employers $136 billion annually (Ricci et al., 2007).

Due to the negative consequences of fatigue, there has been a large number of studies that attempted to measure the prevalence of fatigue in the workplace (often focusing on specific industries). In a population of 28,902 working adults (all occupations), Ricci et al. (2007) conducted a survey of U.S. workplaces and reported that 37.9% of the respondents have suffered from fatigue in the past 2-weeks. A high prevalence of fatigue has also been reported in Canada (Yung, 2016), the EU (Loriol, 2017), Japan (Kajimoto, 2008) and Sweden (Evengård, 2008). Based on a meta-analysis of the fatigue research pertaining to shift workers (all countries), Richter et al. (2016, p. 1) estimated that "90% of shift workers reported regular fatigue and sleepiness at the workplace." For estimates in specific industries, see Barker and Nussbaum (2011), Mehta et al. (2016), Yildiz et al. (2017) and Yoo et al. (2017). In our estimation, understanding the prevalence of fatigue in a given industry is an important first step towards identifying systematic interventions, policies and/or guidelines. Thus, in this paper, we survey U.S. manufacturing companies to assess the prevalence of fatigue, its drivers and how workers attempt to manage it.

Based on the discussion above, there are potentially two main differentiators across industries: (a) how fatigue affects public interests (i.e., consider the number of people who witness or get impacted by an instance of a fatigued employee in each of these domains), and (b) to some extent, the degree of uniformity of the tasks within an industry (e.g., consider the difference between manufacturing and truck operators, where manufacturing presents a diverse set of jobs from welding, CNC operators, assembly line workers, manual material handlers, etc.). Based on the discussion in Section 1, there are several indicators that these two differentiators are changing (at least in the US). First, the federal investments using taxpayer dollars reflect a significant shift in the public's interest in manufacturing operations (see Zients and Holdren, 2016). Second, the literature suggests that job duties, workload and task repetition have been altered by advanced manufacturing technologies (see Section 1); however, we have limited information of the corresponding state of worker fatigue in advanced manufacturing environments. This is an important gap that needs to be addressed.

The remainder of this paper is organized as follows. Section 3 presents a detailed discussion of the survey design and data collection/analysis approaches. In Section 4, the results are provided and discussed. Some concluding remarks and future research ideas are provided in Section 5.

3. Methods

3.1. Participants

In order to survey the prevalence of fatigue, its drivers, and individual coping mechanisms among U.S. manufacturing workers,