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# The effect of working environment-ill health aspects on the carbon emission level of a manufacturing system

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ABSTRACT

Carbon emission has been identified as a major environmental metrics which is threatening earth's ecology and climate. Governments in developed countries usually get the benefits of carbon policies such as carbon cap and carbon tax to limit carbon emission produced by companies. Organizations also have focused on sustainable development initiatives to reduce the total amount of their carbon emission levels. However, none of them have considered the effects of working environment risk factors (ergonomic conditions) on the carbon emission level at the operational level. To this end, a modeling approach is proposed in this paper to investigate the effects of different ergonomic conditions on the carbon emission level of a serial production system. This modeling procedure includes three-health state Markov chains and Logistic functions that connect physical and psychosocial risk factors to an employee's health states and their associated performance levels. The outputs of the Markov chains are integrated in a cost optimization model, which is including the serial system's carbon emission parameters. Carbon cap and carbon tax are the policies which are set in this study to control the system's emission level. The numerical results show that providing incentives to improve the ergonomic conditions of the system helps reduce the amount of carbon emission by the maximum of 13%. It is also concluded that organizations which are focusing on optimizing their financial indexes (e.g., total cost) must get the advantages of combined carbon reduction solutions by including the simultaneous effects of a carbon policy and ergonomic improvements.



## 1. Introduction

The issues of sustainability is often referred as the management of resources that " meets the needs of present without comprising the ability of future generations to meet their own needs" (Brundlandt, 1987). Companies usually consider sustainable development efforts to reduce environmental concerns (e.g., carbon footprint), improve economic objectives (e.g., energy efficiency and profit) and minimize social concerns at work (e.g., employee health and safety hazards), which are raised due to their business and production activities (Slaper & Hall, 2011). Greenhouse gas emissions have been identified as the major environmental indicator (metrics) that is used to assess sustainable development efforts (e.g., Bekkeringa, Broekhuisa, & Van Gemertb, 2010). Growing demand for energy and resource consumption has led to increasing greenhouse gas emissions (e.g., carbon dioxide emissions), which are threatening the earth's ecology (e.g., Elkington, 2002). According to the International Energy Outlook 2010 on world energy, the carbon dioxide emission is estimated to be 43% higher in 2035 than the level in 2007 (e.g., Administration, U.E.I., 2010). If this emission is left uncontrolled, it will pose a greater danger to the environment by increasing air pollution and leading to serious climate change (e.g., Benjaafar, Yanzhi, & Daskin, 2013; Zhou, Ang, & Wang, 2012). Hence, companies in many developed countries have focused on sustainable development initiatives to reduce their carbon footprints (e.g., Shao et al., 2014). There are many studies that have paid attention to carbon footprint, and different policy instruments on carbon emission levels (e.g., Ben-Gal, Katz, & Bukchin, 2008; Benjaafar et al., 2013; Helm & Hepburn, 2010; Hepburn, 2006). The United Nations (UN) and the European Union (EU) have also designed mechanisms to limit the total amount of carbon emissions (Hua, Cheng, & Wang, 2011). Carbon cap, carbon tax rate, and carbon trade systems are the examples of these policies and mechanisms setting to control the carbon emission level in a company (e.g., Dye & Yang, 2015; Zhang, Hua, Xia, & Huo, 2015; Zhang & Xu, 2013). As an indicator of sustainability, carbon emission was usually considered at the supply chain, industry or firm

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(corporate) levels in previous studies (e.g., Benjaafar et al., 2013). Moreover, an economic input-output modeling approach was mostly applied in these studies to account for carbon emission levels, for example, comparing the amount of carbon emissions among different sectors (Huang, Lenzen, Weber, Murray, & Matthews, 2009). However, there is far less attention on sustainability indicators (e.g., carbon emissions) at the operational (process) level (Kim, Leong, & Chen, 2012). As discussed by Kim et al. (2012), previous studies have less focused on the operational (process) level when they consider mechanisms to control carbon emissions, even though this level plays a crucial role in assessing sustainable development initiatives at the higher levels (e.g., corporate level, supply chain level).

There are few recent studies that have investigated gas (carbon) emissions at the operational level when considering recycling, product life cycle assessment, lot sizing problems, and production strategies (Absi, Dauzere-Peres, Kedad-Sidhoum, Penz, & Rapine, 2013; Benjaafar et al., 2013; Bouchery, Ghaffari, Jemai, & Dallery, 2012). For instance, Letmathe and Balakrishnan (2005) present a modeling approach to examine the optimal product mix and production quantities in the presence of different types of environmental constraints. Cao and Li (2014) also investigate production disruption and the dynamic of carbon emissions to reduce the total carbon emission in a manufacturing system. However, the existing studies mostly focus on reducing the carbon emission by redesigning products and packaging, finding less polluting energy resources, or developing energy saving programs (Benjaafar et al., 2013; Dekker, Bloemhof, & Mallidis, 2012; Lee, 2011). Although these are valuable efforts, they usually fail to assess the effects of ergonomic conditions of the Working Environment (WE) in reducing carbon emissions.

According to International Ergonomics Association, ergonomics (human factors) discipline aims to consider the interactions between humans and other elements of the WE in order to optimize both human well-being and operations system performance (IEA-Council, 2000). The WE is complex and is represented by physical and psychosocial aspects of working conditions (e.g., Rose, Orrenius, & Neumann, 2013). These physical and psychosocial aspects are improved by human factor practitioners to reduce the negative effects of Work Environment-related Ill Health (WEIH) risk factors on employee health conditions at work. Examples of these risk factors are cumulative lifting loads, peak handling loads, social support, job control, and job satisfaction (e.g., Kerr, Frank, Norman, Wells, & Neumann, 2001), and they are usually considered as the indicators of a workplace's ergonomic conditions. There are on-going debates about the contribution of ergonomics to sustainability (e.g., Haslam & Waterson, 2013). Helander (1997) encouraged ergonomists to specify the links between ergonomics aspects of the WE and environmental and social problems. Lange-Morales, Thatcher, and Garcia-Acosta (2014) discussed how ergonomics interventions link to the sustainable development of corporations by improving energy efficiency of their systems, and their health and safety indicators at work. Zink (2014) argued that improving environmental, economic, and social concerns (sustainable development objectives) are parts of ergonomics theories. However, there is a huge gap between theory and practice (Zink, 2014). As stated by Haslam and Waterson (2013) "the current contribution of ergonomics to sustainability appears to still be skewed towards recognizing what ergonomics has to offer and calling for its involvement rather than actually being involved in delivering sustainable development solutions". There are few recent studies which have investigated the contribution of ergonomics to sustainable development initiatives in practice (Thatcher, 2013). A review of these studies shows that they usually apply a snap-shot approach by considering the effects of ergonomics tools and techniques in improving sustainability development objectives (e.g., improving health an safety, reducing air pollutions, reducing energy consumption). For instance, Nadadur and Parkinson (2013) examined the role of ergonomics and anthropometry in designing for sustainability. They reported three ways in which techniques from anthropometry (ergonomics) can help to a better sustainable design. However, to the best of our knowledge, existing studies rarely integrate ergonomics aspects (WEIH risk factors). In order to span the existing research gap, it is necessary to develop a practical modeling approach to evaluate the effects of WEIH risk factors (ergonomics aspects) on carbon emissions (sustainability indicator) at the operational level.

To understand the effect of the ergonomics aspects (WEIH risk factors), humans involved in all levels of operation systems should be considered. The negative effects of WEIH risk factors result in increasing the chance of occupational illnesses and injuries of humans involved in a system (Driessen et al., 2010; Heuvel, Geuskens, Hooftman, Koppes, & Bossche, 2010; Rivilis et al., 2008). Furthermore, previous studies demonstrate the effects of WEIH factors on humans' working behavior which are referred to as presenteeism effects (e.g., Driessen et al., 2010; Heuvel et al., 2010). The presenteeism effects disrupt the overall work performance of an employee and create a negative influence on an operation system's behavior (e.g., Erdinc & Yeow, 2011; Goggins, Spielholz, & Nothstein, 2008; Sobhani, Wahab, & Neumann, 2015). This may increase the energy and material consumptions of an operation system and that subsequently leads to a higher level of carbon emission. For example, a healthy worker performing his/her tasks with at the most level of dedication would let the system emit less carbon dioxide than that of an injured worker, who may have a higher level of quality and productivity losses at work. Quality losses usually measured in terms of defective items produced by an injured worker. Producing defective items causes the system to emit more carbon emission by consuming more energy and materials to rework and scrap the defective items. Regarding the productivity, an injured worker usually take a longer time to complete the same task when comparing to a healthy worker (e.g., Sobhani et al., 2015). This also would let the system consume more energy and subsequently emit more carbon dioxide. However, consequences of WEIH risk factors that influence a system's carbon emission level have not been investigated in the existing literature.

The aim of this research is to span the existing research gap between ergonomics and sustainability domains by developing a practical modeling approach that investigates the effects of different ergonomic conditions (WEIH risk factors) on the carbon emission of a serial manufacturing system (operational level analysis). First of all, a three-health state Markov chain and Logistic functions are developed to connect WEIH physical and psychosocial risk factors to each employee's health states and his/her associated performance levels. Then, the output of the Markov chain is integrated in a cost optimization model, including the serial system's carbon emission parameters. Finally, carbon cap and carbon tax policies are (separately) included in the developed optimization model to control the manufacturing system's emission level. The impacts of different ergonomic conditions on carbon emissions are numerically evaluated by changing WEIH risk factor exposures.

The results of this research provide a better understanding about the effects of ergonomic condition changes and humans' health-states at work on a manufacturing system's carbon emissions. This study also supports the sustainability decisions of managers by demonstrating the benefits of combined carbon reduction solutions, which are including the simultaneous effects of a carbon policy and ergonomic interventions. Therefore, managers are able to consider ergonomics in establishing a sustainable, safer, and more efficient operation system with a lower carbon emission.