Early Warning Systems in Industry 4.0: A Bibliometric and Topic Analysis

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ABSTRACT

This article is based on a literature search, using the keywords: Industry 4.0, smart manufacturing, smart factory, early warning systems and decision making in the Web-of-Science (WoS) database. The authors conducted a bibliometric and topic analysis that covered the year of publication, country of publication and the frequency with which authors, institutions/organizations, journals and phrases appeared in the literature. Based on the research, it was found that research on EWS in Industry 4.0 mainly focused on predictive maintenance. Security threats, workplace safety and managerial early warning systems (MEWS) were also present in the literature on EWS, however to a much lesser degree. The article concludes by discussing the importance of this bibliometric study within the context of MEWS in Industry 4.0 and Industry 4.0 in general.

KEYWORDS

Artificial Intelligence, Artificial Neural Networks, Cloud Computing, Early Warning Systems, Industry 4.0, Managerial Early Warning Systems, Predictive Maintenance, Smart Manufacturing

INTRODUCTION

Bibliometric research began gaining popularity from the 1970s onward as a method of quantitative analysis of literature (Patra et al., 2005; Bilas and Moutusi, 2013; Mallig, 2010; Belter, 2015; Ellegaard and Wallin, 2015). Bibliometric analysis can be conducted by searching online databases, such as Web of Science and Scopus, after which the found literature is analyzed with the help of software specifically designed for bibliometric analysis (Ellegaard and Wallin, 2015). Bibliometric studies initially began as a result of the advent of communication technologies and the internet, which in turn contributed to the development of bibliographic databases. In bibliographic databases different kinds of information can be found, such as information on the authors of a study, country of origin, institution involved in the publication of certain articles, impact factors and other relevant information (Patra et al., 2005; Belter, 2015; Ellegaard and Wallin, 2015).

Bibliometric studies present knowledge-based organizations with a useful tool, whereby knowledge-workers, who use their skills, experience and abilities to gather information, can look at what a bibliometric analysis has to say about the current situation of research being done, in regard to their specific industry (Leon, 2013; Patra et al., 2005; Belter, 2015; Ellegaard and Wallin, 2015). Bibliometric analysis can also be complemented with database tomography (DT), which was initially proposed by Kostoff (2000). DT uses data from scientific articles to look for phrase frequencies, which gives information on how often phrases occur, as well as information on the pervasiveness of themes. Secondly, DT also helps determine how close together these phrases occur, giving information on the relationship between various phrases and words (Kostoff, 2000).

DOI: 10.4018/IJESMA.2019040104

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BACKGROUND

Early warning systems (EWS)

As opposed to traditional business environments, today’s business environments are changing at an increasing rate. In the context of smart factories, these changes can be technological (Craig and Douglas, 1996; Day and Shoemaker, 2006; Dobbs et al., 2015; Greenberg et al., 2017). Urbanization, accelerating technological change, an aging society and greater global connections in trade, people, finance and data, are the major forces that are creating change in the global economy (Dobbs et al., 2015). According to estimates by Dobbs et al. (2015, p. 1), these four forces are creating change in the global economy at a rate that is “happening ten times faster and at 300 times the scale, or roughly 3,000 times the impact” compared to the first industrial revolution.

There are also other changes that can take place in the political, social and economic environment of an organization that are not among the four major forces shaping the world economy, but can nonetheless negatively impact an organizations health (Day and Shoemaker, 2016; Dobbs et al., 2015; Greenberg et al., 2017). If an organization is not well prepared to adapt and respond to these changes in a timely manner, it can lose its competitive advantage (Ansoff, 1975; Day and Shoemaker, 2006). Ignoring these changes can lead to strategic surprises, which is according to Ansoff (1975), defined as “urgent, unfamiliar changes in the firm’s perspective, which can result from a loss of profit or a loss of a major opportunity”. This strategic surprise is the result of an organization not detecting early warning signs (also known as weak signals) in a timely manner. These subtle signals of impending impactful events might at first be ignored as unimportant, but end up being very important for the survival of an organization (Day and Shoemaker, 2006; Leon, 2018). These early warning signs can be defined, according to Nikander (2002, p. 49), as “an observation, a signal, a message or some other item that is or can be seen as an expression, an indication, a proof, or a sign of the existence of some future or incipient positive or negative issue. It is a signal, omen, or indication of future developments.” Ansoff was the first to propose that managers use EWS as a strategic tool to detect weak signals and prepare ahead of time to avoid negative events in the future (Ansoff, 1975; Leon, 2018).

In an organizational context, EWS can come in three different forms; those that use computational methods, such as artificial neural networks, those that use statistics and those that use cognitive-behavioral strategies (Day and Shoemaker, 2006; Leon, 2018). EWS can provide a means for detecting negative events of all kinds. Studies done on the topic of EWS were typically case studies and mostly researched impending natural disasters, dangers of meteors and military threats, however EWS have also been studied as a form of preventing negative events within the context of business, economics and finance (Trzeciak and Rivers, 2003; Day and Shoemaker, 2006; Abon et al., 2012; Assilizadeh and Gao, 2010; Collins and Kapucu, 2008; Davis and Izadkhah, 2008; Xie and Lia, 2014; Chaves et al., 2016; Klopotan et al., 2018). Data used for prevention of such negative events can be both of a qualitative or a quantitative nature. With the help of this data and by being aware of potential risks beforehand, monitoring systems can warn an organization by effectively communicating these early warning signals on time, however this process also entails that the organization is capable of reacting to the early warning signals in a way that prevents the negative event from occurring (Klopotan et al., 2018).

Industry 4.0

Digital technologies are becoming increasingly prevalent in the manufacturing industry and in turn it is said that this will usher in the new industrial revolution, Industry 4.0. There are many potential benefits that Industry 4.0 can bring. Some examples are increased efficiency, quality, flexibility and adaptability of manufacturing and lower costs associated with it, due to, among other things, lower energy consumption, as well as increased sustainability of manufacturing through decreased damage to the environment, faster time to market and mass customization (Wang et al., 2017; Prause and