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Prepared for work in Industry 4.0? Modelling the target activity system and five dimensions of worker readiness

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ABSTRACT

Within Industry 4.0 research, the spotlight shines on technological and organisational challenges. This study shifts the focus to worker readiness, beginning with an analysis of twenty-three models to establish the state of research. Findings demonstrate that existing models are mostly early-stage proposals addressing competences featured in mainstream 21st-century and digital-competence frameworks. Worker-level factors explicitly aligned with emerging cyber-physical systems receive little attention. To construct a worker-readiness model calibrated to the needs of Industry 4.0, the authors devised a research procedure based on a two-phase integrative review of 135 publications. Firstly, they deployed an activity-system apparatus to produce a structured description of the target environment. Secondly, major worker competence groupings, aligned with this target, were extracted, tagged and reduced to five dimensions. The resulting model consolidates prior research and introduces two original competence groupings addressing human-machine partnering and decision-making in Industry 4.0. This study is a foundational step by the Educational Informatics Lab, Ontario Tech University, Canada, toward deploying a global online profile tool for generating, analysing and aggregating worker readiness profiles. This cross-disciplinary project will help researchers, educators, corporate trainers, human resource managers, policymakers, and systems designers more effectively diagnose the readiness of workers for Industry 4.0.

ARTICLE HISTORY

Received 10 June 2019
Accepted 11 October 2020

KEYWORDS

Industry 4.0; work environment; worker readiness; worker competences; readiness model; digitalised work

1. Introduction

The digitalisation of industry is advancing steadily. Catalysed by international programs like Industry 4.0, academics, governments, and private companies are collaborating to reinvent manufacturing. Industry 4.0 is an established global innovation program aimed at making manufacturing facilities more intelligent, efficient and flexible (Orellana and Torres 2019). However, there are different views of Industry 4.0 among small- and medium-sized enterprises (Da Silva et al. 2019) and ongoing challenges producing a roadmap for its full realisation (Liao et al. 2017). Indeed, leading German companies are still working toward advanced stages of maturity (Bittighofer et al. 2018). Given the complexity and scope of industrial digitalisation, much of the academic research focuses on technological and organisational problems. Addressing ‘human factors,’ and in particular, conceptualising and measuring human readiness for digitalised work receives less attention, and remains an early-stage project (Shahlaei, Rangraz, and Stenmark 2017; Peruzzini, Grandi, and Pellicciari 2020).

Nevertheless, this project is crucial to the success of Industry 4.0 because aside from a few ‘dark factory’ scenarios (Oztemel and Gursev 2018), humans are considered more adaptive than machine entities and vital to future production (Leineweber et al. 2018; Ghobakhloo 2018).

To date, researchers have studied work transformations in digitalised industries from several perspectives. For example, economists have assessed the impact of automation on jobs (Frey and Osborne 2017; Autor 2015), and industrial management specialists have proposed strategies for realigning organisational resources, including personnel, with digitalised manufacturing models (Mittal et al. 2018; Pessl, Sabrina Romina, and Mayer 2017). At the worker level of analysis, the literature offers seminal case studies (Johansson 2017), industry reports (Canadian Apprenticeship Forum 2018), conceptual explorations (Karacay 2018; Romero et al. 2016a) and empirical analyses (Richert 2018). Most importantly, researchers have begun producing new competence models as foundations for Industry 4.0 worker development (Erol et al. 2016; Galaske et al. 2017). With few

exceptions (van Deursen and Mossberger 2018; Blayone et al. 2020), however, specialised digital-competence researchers have not explored the ability requirements of digitalised industrial work. Instead, they have investigated mainstream digital competences of students and citizens from operator-tool perspectives misaligned with intelligent systems and new forms of human-machine partnering (van Deursen, Helsper, and Eynon 2016; Ferrari 2013; Eshet 2012; Blayone et al. 2018c).

This study bridges this divide and contributes to the advancement of Industry 4.0 readiness research at the worker level. It begins by establishing the state of research through a systematic review of 23 prior readiness models. Then, a new model is constructed from the literature via a two-stage research synthesis to consolidate previous efforts and address significant research gaps. In stage one, the salient characteristics of Industry 4.0 work environments are modelled as an activity-system. In stage two, major competence groupings aligned with these systems are synthesised, and an original five-dimensional model of worker readiness for Industry 4.0 is proposed. This model is a necessary *first step* by the Educational Informatics Lab (EILAB), Ontario Tech University, Canada toward implementing an online application for generating and aggregating Industry 4.0 readiness profiles of individuals around the globe, supporting self-diagnosis and ongoing research to inform higher education, employee (re)training, human resource management and policymaking. Having already implemented a global readiness application for measuring the digital competences of students, teachers and knowledge professionals (Blayone 2018; Blayone et al. 2018a, 2018b, 2018c), this project pivots to the development needs of industrial workers and the requirements of digitalised manufacturing.

2. Establishing the state of research

At the individual and group level, readiness research has roots in learning psychology and technology-systems development (Thorndike 1932; Sullivan 1970). The common goal is to identify and measure *factors* enabling successful human functioning within a *target* context. Factors of interest most often include knowledge, skills, attitudes (KSAs) and related dispositions, which may be grouped as competences (Hoffmann 1999). These are ability complexes that individuals can develop through experience and

learning. Situational, cultural and personality factors, though less widely studied, may also be considered, particularly as mediating and moderating variables.

Twenty-three readiness models addressing the needs of workers in Industry 4.0 were selected and reviewed to establish the state of research. They are presented in two groups, featuring thirteen models developed from an organisational perspective, which address workers as a collective entity (e.g. 'workforce' or 'human resources'), and ten from a worker-level perspective. Each model was reduced to a tabular data set to identify common foci, key differences and research gaps. This data set included specified model type, derivation methodology, conceptual readiness structures, human readiness factors, and available instrumentation. The availability of instrumentation was used as a general indicator of a model's maturity because successful operationalisation via the development and validation of a self-report or expert-based assessment tool requires several stages of research beyond initial theorisation.

2.1. Organisation-level readiness models

Key findings from thirteen organisation-level models, shown in Table 1, are as follows. Firstly, these models use 'readiness' and 'maturity' interchangeably as descriptors, even though some studies distinguish between preparation for an initial implementation (readiness) and subsequent development (maturity) (Akdil, Ustundag, and Cevikcan 2018; Botha 2018). Secondly, about half of the models were based on small-scale literature reviews and first-hand theorisations. Others incorporated organisational surveys, interviews with managers, expert processes and assessment frameworks adapted from software development and IT. Thirdly, conceptual structures are diverse, but they position the performance capacities of workers as a critical facet or sub-facet of organisational preparedness. Fourthly, although most models address human readiness generally (1, 3–8 and 13), the rest mention specific worker-level factors, including technology/IT skills (9 and 10), social competences (11 and 12) and intrapersonal dispositions (2). Finally, six studies (1, 3, 9, 11,12 and 13) have produced instrumentation in the form of a survey instrument, checklist or interview guide, but reliability and validity testing is either not reported or planned as next-stage research.