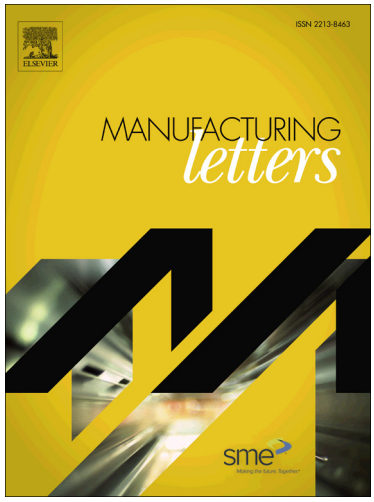

Modeling Agents as Joint Cognitive Systems in Smart Manufacturing Systems

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Modeling Agents as Joint Cognitive Systems in Smart Manufacturing Systems

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Abstract. Latest innovations and developments in Information and Communication Technologies (ICTs) as well as Operational Technologies (OTs) are changing manufacturing forever. Ideas such as Industry 4.0 and the Industrial Internet of Things (IIoT) are attempting to impact, even dictate those changes. In this paper, we focus on the changes to the role of humans in their interactions with those innovations, known as Cyber-Physical Systems (CPSs) and Industry 4.0 technologies. We review the current interaction model based on Human-Machine Interfaces (HMI), and we propose a new model based on the engineering of Joint Cognitive Systems (JCS). Then, we discuss some of the implications of this new model for the modelling and control of smart manufacturing systems.

Keywords. *Human-Machine Interfaces, Joint Cognitive Systems, Smart Manufacturing Systems, Control, Collaborative Agents.*

I. INTRODUCTION

It is a widely held belief that we are entering the Fourth Industrial Revolution, sometimes called *Industry 4.0* or Smart Manufacturing [1]. The goal of Industry 4.0 is the information-intensive cyber-physical transformation of the manufacturing sector, resulting in a network of data warehouses, people, processes, services, systems and production assets [2]. Each of these network components can generate, leverage and utilize actionable-information to make real-time, cooperative decisions. We refer to the result of this "cyber-physical transformation" as *Smart Manufacturing Systems (SMS)*, however, what exactly do we mean by this term.

If *Industry 4.0* is successful in achieving its objectives, then an SMS will be able to (a) self-optimize performance across that network of heterogeneous components, (b) learn from the past and adapt that knowledge to new conditions in real or near-real time and (c) jointly control automated, manufacturing functions and production assets [3-5]. In this context, the most important feature that makes these "smart capabilities" possible of an SMS is its *connected* and *interoperable nature.* This nature enables the generation, communication, and analysis of the sensor and other digital data necessary to realize these *smart capabilities.* We classify these capabilities, and the functions associated with them, into two groups:

i. *Cognitive capabilities*, which refer to the human brain or Artificial Intelligence (AI) capacity and ability to undertake the mental tasks (i.e., awareness, perception, reasoning, and judgment) needed for accomplishing a certain goal under certain operational settings, and

ii. *Physical capabilities*, which refer to the human skeletal muscle or mechanical/mechatronic mechanisms capacity and ability to undertake a physical function (e.g., ability to lift, manipulate or assemble).

Throughout most of history, only humans have had the capabilities to perform both cognitive and physical functions. Beginning with the First Industrial Revolution (end of 18th century), however, and continuing with accelerated pace to this day, humans have been working collaboratively with automated machines, and today 'co-bots'. Initially, the term *automated* suggested the performance of a single, discrete, physical task and/or process. Overtime, hardware technologies have continued to improve, thereby, increasing the *automation of physical tasks.* In fact, today, many machines can execute those physical functions automatically with little or no-human intervention. Some machines can even make simple decisions (i.e., actuators). Even so, until recently, humans have remained the sole executor of all *cognitive functions* to this day.

However, there is consensus that some cognitive tasks are similarly strenuous, stressful and ultimately harmful to humans as repetitive, dangerous and strenuous physical tasks. These types of physical tasks are the first to be automated, therefore, it can be assumed that some of the comparably problematic cognitive tasks should be *automated* as well – to ultimately free up the human workers to do what (for the foreseeable future) cannot be automated: Use their human ingenuity for creative and innovative problem solving. A simplified vision for technologies and/or techniques that can enable automating cognitive and physical tasks is presented in Table 1.

Table 1. Vision for Cognitive and Physical Automation

	Physical	**Cognitive**
Routine	Traditional Automation	Machine Learning Techniques
Non-routine	Collaborative Robots	Artificial Intelligence (Intelligent Assistants)

Cyber-technologies, which first emerged in the latter part of last century, have exploded since the dawn of the 21st Century. As these digital technologies have grown in functionality, sophistication, quality, and quantity, engineers began to realize that they could be used to automate *cognitive functions* as well. This realization is at the heart of Industry 4.0 or SMS. The implications are: (a) cognitive functions are the critical ones and (b) these functions can be implemented by humans, by hardware, and by software – individually and collectively.