A PORTFOLIO FOR OPTIMAL COLLABORATION OF HUMAN AND CYBER PHYSICAL PRODUCTION SYSTEMS IN PROBLEM-SOLVING

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ABSTRACT

This paper discusses the complementarity of human and cyber physical production systems (CPPS). The discourse of complementarity is elaborated by defining five criteria for comparing the characteristics of human and CPPS. Finally, a management portfolio matrix is proposed for examining the feasibility of optimal collaboration between them. The optimal collaboration refers to the exchange of knowledge, reciprocal learning, and interaction of human and CPPS in smart factories. The proposed portfolio matrix provides feasibility check rules to trigger the transition towards ideal state of human and CPPS collaboration in Industry 4.0.

KEYWORDS

Human, CPPS, Complementarity, Problem-solving, Portfolio Matrix, Industry 4.0

1. INTRODUCTION

Industry 4.0 revolution and evolution of industrial internet is going to become a mega-trend, connecting various disciplines. Technological enhancement involves changes in human-technology interactions, whether technology guides human or human guide technology (Jäger et al., 2014). In addition, the emergence of cyber physical production systems (CPPS) raises several challenges for industries with regard to potential changes in processes, systems, human-based skills and organizational competencies (Acatech, 2013). CPPS are new types of production systems which are characterized as Feedback Systems that are ideally intelligent, real time, adaptive and predictive, networked and/or distributed, possibly with wireless sensing and actuation, and also possibly in loop with human (Lee & Seshia, 2015). Anticipating the trends of the 4^{th} industrial revolution and evolution of CPPS, there will likely be a shift from a need for “data workers” to a need for “decision-makers”. For instance, an operator in the future will not only run and monitor the performance of an industrial machine; rather he/she will customize machine performance under various requirements such as energy consumption. The transition is, therefore, assumed from low level operation to (high level) decision endeavors. The operator should check the output of the machine, interact with the system and make evidence based decisions considering quality, time and cost factors. This raises some questions: Which skills and competences should workers hold for problem-solving? How can we employ artificial intelligence (AI) solutions to facilitate human-machine interactions? What will be the Industry 4.0’s conditions and requirements of human learning and didactical conceptions?

This paper exploits the previous studies of the authors on investigating two perspectives of human approaches of problem-solving, first synoptic and incremental, and second heuristics and meta-heuristics (Ansari et al., 2016a) and (Ansari et al., 2016b). In particular, we firstly examine and compare the characteristics of human and intelligent machines and/or production systems (i.e. CPPS) from the perspective of complementarity (Cf. Section 2). Secondly, we go beyond of the state-of-the-art by providing a portfolio matrix for characterizing the optimal collaboration between human and CPPS depending on the qualification level and degree of autonomy, respectively (Cf. Section 3). Finally, we emphasize on complementarity of human and CPPS whereby not only CPPS learn from human behavior and decision-making instances via advanced machine learning approaches, but also human can learn from CPPS behavior through communication.

2. COMPLEMENTARITY OF HUMAN AND CPPS

The human-machine interaction is an integral part of today's industrial operations. The tendency to proliferate CPPS in research laboratories and smart factories (Acatech, 2013), depending on the technology readiness level (TRL) (EC, 2016), raises uncertainty about the role of human in a CPPS environment (Jäger et al., 2014). Despite societal challenges and philosophical accounts on human substitutability, we approach the discourse of complementarity of strengths and weaknesses of human and CPPS from the perspective of knowledge exchange, reciprocal learning, and synergistic problem-solving. Hence, we have identified five criteria which may influence on complementarity of human and CPPS in smart factories, namely C1. Cost, C2. Flexibility with regard to fulfillment of various tasks and temporal availability, C3. Capacity with regard to mechanical (physical) job, information processing and problem-solving, C4. Performance variation, and C5. Quality variation with regard to mechanical job and decision-making. Table 1 compares the characteristics of human and CPPS with respect to the aforementioned criteria. It has been inspired and partially adopted from (Blohm et al., 2016) in which the characteristics of human and conventional production systems were compared with regard to mutual substitutability.

Table 1. Comparison of Human and CPPS in the context of Industry 4.0

Comparison Criterion (C)	**Human**	**CPPS**
1. Cost	**High cash expenses and mostly fixed cost,** depending on the number and the qualification of employees (within certain limits variable cost is applied due to compensation of wages for the involvement of manpower in a different operation area).	**High fixed cost** which tends upward especially due to increasing investments and service costs within the life time because of complexity of the computational and embedded controlling components.
2. Flexibility with regard to		
2.1 Fulfillment of various tasks	**High flexibility** which can be advanced through further (vocational) education and training.	**Medium to high** flexibility which depends on the advancement of the algorithms, adaptiveness e.g. to changes of processes, information and work orders, and degree of learnability.
2.2. Temporal availability	**Relatively low** (can be increased in case of readiness to flexible working hours and shifts).	**High** (24-hour operation is feasible).
3. Capacity with regard to		
3.1. Mechanical job	**High inter-individual differences and diversities**, efficiency limited through physiological conditions and mental ability, while both can be influenced by training.	**No technological limit.**
3.2. Information Processing	**Time-intensive** in access (mental and physical) databases. **Unreliability** in information storage and retrieval. **Ability** in error detection and correction routines.	**Moderate to high time-effectiveness** in processing algorithms, storage and retrieval. **Reliable in large scale** information storage. **Moderate to high ability** in error detection and (auto-)correction.
3.3. Problem-solving	**Advantages** … in solving ill-structured problems. … in managing exceptions. … in problem-modeling and -solving on the first occurrence (depending on the complexity of the problem and individual mental ability). … in collaborative and heuristic problem-solving.	**(Medium to High degree of) Advantages** … in learning and formalization of trouble-shooting process (depending on the advancement of the machine learning algorithms). … detection and correction of repeated problems (depending on the repeating rate). … prediction of standard problems based on continuous monitoring of functional and environmental parameters.
4. Performance	**Relatively high** (depending on individual capacity,	**Very low** (depending on lifetime, associated

Comparison Criterion (C)	Human	CPPS
variation	motivation and commitment). **High possibility** of work fatigue and job dissatisfaction.	degradation rate and service quality).
5. Quality variation with regard to		
5.1. Mechanical job	**High inter-individual differences and diversities** which can be improved by training and job satisfaction.	**Very low.**
5.2. Decision-making	**High inter-individual differences and diversities** depending on problem-solving abilities, competences, experiences and qualification level. The complexity and sensitivity (risk) of the decision may affect it.	**Low to moderate** depending on the quality of data (affected by disturbances and noises), preciseness of algorithms, degree of preparation by human, and complexity of the problem field. The quality can be improved after training the system with (relatively large) data-sets.

3. PORTFOLIO MATRIX FOR OPTIMAL COLLABORATION BETWEEN HUMAN AND CPPS

Taking into account the discourse of complementarity of human and CPPS (Cf. Table I), it is vital to identify the areas in which human and CPPS may collaborate to exchange knowledge, interact and learn. For this purpose, we have established a management portfolio matrix (Cf. Figure 1). The portfolio matrix identifies four zones and the transition rules between them, depending on the human qualification levels (Low or High) and autonomy degree of CPPS (Low or High).

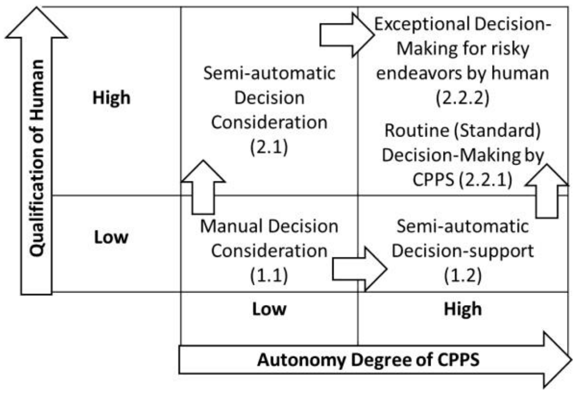

Figure 1. Portfolio matrix for optimal collaboration of Human and CPPS

The collaboration of human and CPPS is, therefore, identified according to the combination of qualification level and autonomy degree as follows:

- Low-Low (Zone 1.1) which addresses manual decision consideration through analysis of a problem space and identification of decision alternatives.
- Low-High (Zone 1.2) which refers to semi-automatic decision support by deployment of advanced assistance and recommendation systems.
- High-Low (Zone 2.1) which concentrates on semi-automatic decision consideration by highly qualified personnel through analysis of information and notifications provided by information systems.
- High-High (Zone 2.2) which is divided into two sub-areas as:
    - Routine (standard) decision-making by CPPS, i.e. autonomous decision-making with regard to low risk and non-sensitive endeavors such as shifting maintenance milestones (Zone 2.2.1)

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- o Exceptional decision-making by human, i.e. supervised decision-making with regard to risky endeavors such as purchasing a new machine (Zone 2.2.2).

The feasibility of incremental transition is examined by applying certain rules which are summarized below:

- Rule I - If the advancement of the TRL and utilization of AI is achieved, then transition from 1.1 to 1.2 is feasible.
- Rule II - If the Industry 4.0's requirements for goal-oriented and effective personnel training, assessment and selection are fulfilled, then transition from 1.1 to 2.1 is feasible.
- Rule III - If the Industry 4.0's requirements for effective personnel training, organizational change and reduction of risks for employing intelligent systems are fulfilled, then transition from 1.2 to 2.2 is feasible.
- Rule IV- If the technology maturity and reliability is highly improved through technology enhancement via in-house development or outsourcing, then transition from 2.1 to 2.2 is feasible.

4. CONCLUSION AND OUTLOOK

This paper discusses the complementarity of human and CPPS and provided a portfolio matrix for characterizing the optimal collaboration between them. While we emphasize on the fact that the transition to Industry 4.0 will result in substantial changes in the human work place, we stress that the interaction of human and CPPS during problem-solving processes promotes knowledge exchange and reciprocal learning. In the context of Industry 4.0, the tendency is to substitute human with CPPS in standard and routine decision situations. CPPS, also, generate information that has to be understood, interpreted, evaluated, verified and used by employees. Thus, the proposed portfolio matrix lays the ground for identifying the strategies for supporting the transition to the ideal state of smart factory model which is distinguished by collaboration of highly qualified personnel and highly autonomous CPPS.

Moreover, the portfolio matrix not only identifies the need to create artificial algorithms and software solutions for digitalization of human kind of problem-solving, but also indicates the demand to establish an Industry 4.0's work-based learning mechanism for training human resources towards holding new job roles which may involve multiple levels of problem-solving.

With the intent of promoting interdisciplinary research in Industry 4.0, the future work is aimed at identification of the semantic linkage between problem, solution and problem-solver characteristics through consideration of the organizational factors (e.g. enterprise size, human resource capacity, branch specificity, organizational culture), learning concepts, and machine learning approaches.

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