Preparing Production Systems for the Internet of Things The Potential of Socio-Technical Approaches in Dealing with Complexity

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Abstract
The Internet of Things will influence how production systems of the future will work. An expected change is the increase in complexity when production system will start communicating with each other. This complexity can be managed by applying socio-technical approaches. This includes analyzing a production system regarding the domains: tasks, actors, technology, and structure. We identified three topics per domain that we think need further investigation, as they may influence complexity to a strong degree. For tasks we suggest looking into urgency, habituation, and strategies; for actors we suggest looking into skills, human factors, and user diversity. In the field of technology we find visualization, decision support, and interactions to be most pressing, while in the field of structure we see responsibility, delegation, and communication.

Keywords
Socio-Technical Systems, Human Factors, Complexity, Digitalization, Cyber-physical Systems

1 INTRODUCTION

The address space of the protocol IPV6 allows addressing 3.4×10^{38} unique identities [1]. This allows giving every device on the planet a unique identifier and alongside the possibility to communicate with its peers. This will also allow production systems to communicate their state, their task, and their capabilities. Production systems in the future will we be intricately connected, allowing never before seen individualized and automatized production [2]. Machines will be able to adapt the production process automatically to highly individual products in accordance with their capabilities, capacity utilization, and cost-effectiveness. These cyber-physical systems or the Internet of Things [3] will influence working environments heavily, but will also spur new innovation [4].

Increasing the individualization of products causes on-the-fly restructuring in shop floor logistics [5,6] and increases the repertoire of skills needed by workers at each individual workplace to handle individual operations for each product. Increasing the level of automation increases the dependency of manufacturing machinery from the manufacturing set-up on the shop floor as a whole and its communicative capabilities. Both changes increase the amount of complexity of the shop floor in general. This increase of complexity within a factory is matched by an increase of the complexity in supply chain logistics. In order to fully leverage digitalization of production systems, all operators, planners, engineers & managers must be enabled to handle the complexity inherent in these systems [7].

But not all complexity is created equal [8]. Complexity is often misused as the sheer difficulty or size of a problem, but essentially it refers to the intricateness of problems alongside its difficulty and size. Some forms of complexity are easily solved by computers (e.g. large divisible problems) while others are more easily solved by humans (e.g. object recognition). Most relevant complexity will require both humans and computers to address problems collaboratively. To make things worse, this collaboration produces further complexity to be managed.

So what is necessary to cope with the increasing pervasiveness of digitalization in production systems? Certainly investing in improving the skill-set of workers and engineers is necessary to enable them in dealing with the challenges of complexity. But complexity takes different forms (e.g. perceptive, cognitive, task-related, etc.) and modes (e.g. incidental, continuous, expertise resistant, etc.), and therefore different tolls on different users [8]. Designing socio-technical systems with the diversity of users in mind and context adaptive to both user and task has the potential to lift the burden of complexity off the user. Still little is known what human factors determine how well different forms of complexity are managed. We propose a research outline to investigate the influence of human factors on complexity in production systems in order to develop methods, tools and social practices to deal with new forms of complexity in socio-technical systems.

2 SOCIO-TECHNICAL SYSTEMS

A socio-technical system is an organized system of humans and technology that is structured in certain fashion to solve specific tasks. A typical approach to model such a system was proposed by Leavitt [9], which visualizes the interrelation of the subsystems (see Figure 1).

The technical sub-system on the one hand contains the *task* and the *technology* to solve the task, while the social sub-system contains the *actors* and the *structure* and *roles* that govern the interaction. Both sub-systems are said to benefit from each other. The interactions between the systems are said to determine the success of the whole system. Designed features of the system are said to have linear cause-effect relationships in the interaction and can be planned. The more interesting features are the unplanned, non-linear emergent relationships in such systems, which may be good or bad.

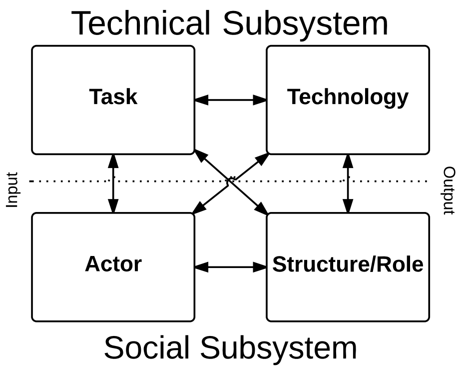

Figure 1 - Adapted Socio-Technical System, cf. [9]

These unplanned relationships are also often the cause of complexity in the system. Trying to manage these relationships (e.g. through organizational rules) can introduce new complexity into an organization, as the amount of additional features (e.g. circumvention strategies) may again increase non-linearly with the amount of managerial effort put into place.

3 COMPLEXITY

Complexity can occur in multiple locations in a production and manufacturing process. In order to understand where complexity matters, we must first understand who will have to deal with the complexity – who, what, where and how. Future production system will incorporate further meshing of human and machine operators in order to fulfill the increasing demand of individualization and mass-customization. The integration of information and communication technology in production processes, will bring new challenges regarding security, usability and trust in interoperability of the systems [10].

3.1 The human operator

Even with drastically improving machine-learning capabilities humans – and for a while so – are champions in the domain of dealing with novel problems. If the question that needs answering is neither clear nor known, human operators are required to deal with a problem. Future production systems though will have a complexity hardly comprehensible with the skill-set of single human operator.

But not only the skill-set of a human operator is unique. Human factors (e.g. perceptual and motor limitations) and diversity (e.g. cognitive capabilities or personality structures) plays a large role in human individuality and influences performance in dealing with tasks in cyber-physical systems [7,11].

Given the demographic changes in most industrialized nations, talents and skillful workers will be a scarce and diverse resource [12]. Thus management of skill-sets and capabilities and the management of the knowledge thereof can become crucial in effectively operating a production system. Mapping available workers to processes in shifts should be managed and planned ahead. Doing this with classical managerial approaches though, might also lead to an increase in complexity in the organization.

3.2 The technology-interface

The ever-increasing complexity that is hidden behind the interface of a technological artifact is unknown to most users. Still most interfaces are complex in their design and do not support the user in completing their tasks. Particularly in professional settings cognitive ergonomics are ignored and "efficient" solutions are produced. But saving time on developing solutions that do not cater to the users' needs is time saved at the wrong place. In the long run more time – and not just time – will be saved, when enough attention is given to optimizing a user-interface for a given task.

The question remains though: What is an optimal user interface? Given the complexity of user diversity, a singular answer will hardly suffice. Giving users the option to customize their interface just begs the question. A serious approach should incorporate human factors and user diversity using adaptive interfaces. But adaptive to what?

3.3 The cost of complexity

Basic interactions with interfaces and their associated costs are quite well understood. Fitt's law for example measures the cost of a pointing interaction as consumption of time from the parameters distance and target size. The influence of user diversity (e.g. age [13]) has also been incorporated into the equation. But even simple interactions of interface, user, and task complexity have only recently been investigated [11]. But what is the cost of delegation of a complex task to a younger user with less experience, under time pressure with high responsibility? Models to understand the interaction of users und technology, when embedded in a given structure for a given task are needed in order to improve the understanding of production systems and to design technology that optimizes complexity costs for any given scenario.

How to achieve this, is still unclear. We propose a research outline to tackle some of the questions, which we deem to be important first steps.

4 RESEARCH OUTLINE

In order to address the above-mentioned challenges we suggest the following research outline.

The core idea of the research outline is to use methods of human-computer interaction (HCI) and iterative user-centered development to optimize the technical systems and task-analysis and job design to improve the social subsystem.

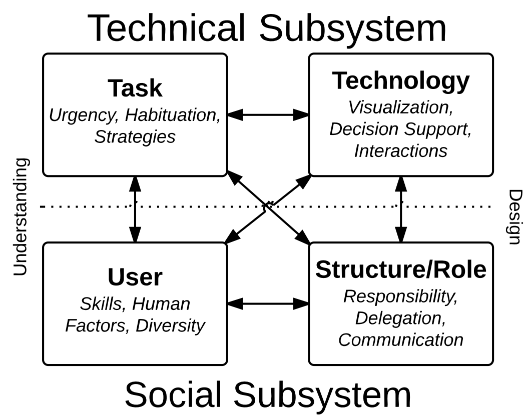

Figure 2 - Four domains of Socio-Technical Systems and suggested research areas

The four domains (i.e. task, technology, worker and structure) are addressed simultaneously and related to each other. We would like to address the following sub-aspects in the four domains individually (see Figure 2).

4.1 Task Domain

Task complexity has been approached in multiple fashions. Its complexity is often imputed from criteria such as time pressure, habituation, multi-variate decision making, task clarity, goal-conflicts, redundancy, and many more [14]. In a production system that needs to quickly adapt to new production procedures we assume that the following criteria are most pressing.

Urgency is the extent to which a task needs quick completion. Not just in planning the task earlier in a schedule but also in completing the task in shorter time frames.

Habituation is the consequence of the reoccurrence of a task. If the task needs to be repeated exactly the same over and over again, habituation may free cognitive resources and improve motivation [15]. If the task often changes habituation may never occur. The uncanny valley is the area where habituation occurs and slight changes in the task are overlooked because of habituation.

Strategies are the mental procedures that workers associate with a task to either put a system to good use or circumvent cumbersome actions to fulfill a simple task. A typical circumvention strategy for the task “sharing a document between co-workers“ is to avoid the haphazardly designed CSCW solution and use a commercial service such as Dropbox, thus enervating the organizations data security by exposing data to a third party [16].

4.2 Technology domain

HCI approaches can be used to understand the interrelation of users and technology and furthermore its usability. A technology that is used in an organization shapes the understanding of tasks, skills, and communication processes in an organization, intricately influencing the success of an organization. Under the changes of the Internet of Things and Big Data we assume the following aspects of technological artifacts will need further investigation.

Visualization of information can be used to instantly access large amounts of data, but only so if the data is properly mapped to the perceptual dimensions. Features such as dimension reduction, entropy detection, and hypothesis generation are important because relevant questions may still be unknown but important for the organizations success.

Decision support can be implemented in monitoring system to aide the operator in finding optimal machine configurations. Here questions of transparency, comprehensibility and trust are of high importance to allow the user trace the decision suggestions, evaluate consequences, and make an informed decision.

Interactions of a system should be designed to facilitate the users skills in solving the task at hand. The famous pinch-to-zoom gesture on a multitouch-tablet, drastically improved the accessibility of an interaction pattern of “locate x on a spatial map”. Nevertheless, an expert mouse user might be faster using a scroll-wheel and a high-dpi mouse. The interactions should adapt to the users needs in regard of the context, bearing in mind the role of the user in the larger context.

4.3 User Domain

Different users cope differently with complexity in different usage contexts. Mapping a task – and thus its complexity – to a user that is both capable and motivated enables an organization to handle fluctuating staff even under individualized production settings. Failing to facilitate user diversity will hamper innovative capability and thus organizational success. Aspects that need to be addressed are the following:

Skills of the users may vary. Some skills may be correlated others may be independent. Often skills are not actively managed or part of organizational knowledge. Human resource management could include skill and competence features, which would allow mapping workers to tasks in context-optimal settings. Often the expert is not available, but an advanced worker may be able to complete a task with a support system. Additionally managing staff fluctuation from a skill-based perspective helps prevent loss of talent [17].

Human factors or *ergonomics* address the limitations and variance in human perception and ability (e.g. spatial perception and cognition), when interacting with a system. Incorporating human limitations is necessary, but optimizing user-task fit can improve work satisfaction and yield.

Similarly *user diversity* addresses the variance in human diversity. For example, users can have different motivations for work, different personality profiles and different values. All of them play a role in matching a user to a task. Giving a user a task that contradicts his values and motivation will yield worse outcomes, than matching them up.

4.4 Structure domain

The structure of an organization (and the roles attached to it) can heavily influence the complexity of the organization. Structure inherently reflects the organizational culture by implying procedures of work. The more levels of hierarchy exist in an organization the more formal procedures will be. Production systems might require changes quickly, even when some consequences are oblique to the person in charge. Having fewer levels of hierarchy may lead to faster decision making in urgency scenarios. We think the following aspects of structure need further investigation.

Responsibility in future production system must be handled differently. A user that makes a decision using a decision support system or a visualization may not be solely responsible for the outcome (be it either good or bad). When algorithms do pre-processing on different levels who is responsible for errors of human-machine interaction? Furthermore how will this possible shift in responsibility affect the users motivation and zest?

Delegation means the outsourcing of tasks to subordinates or colleagues. In high-skilled teams the best suitable worker may not be determined, as all might be suitable, having different benefits. Giving a task to a less qualified worker as a planned procedure can be seen as a means of learning-by-doing, when task-settings can be adjusted to suit the novice. Analyzing the context, finding goal measures, and choosing a goal-setting that improves short- and long-term organizational goals, may be crucial to efficient work delegation.

Communication lies at the heart of all organizational efforts, for without communication no organization is present. Understanding how communication affects intra-organizational development, when changing aspects of an organization (e.g. technology or structure) is crucial for a successful organization. Planned and purposeful communication is particularly important when approaching a change from a socio-technical point of view. Unplanned ad-hoc communication shapes the real structure of an organization [18] and must be understood, if an organization is to succeed.

4.5 Bringing the domains together

All domains have been traditionally address by HCI, ICT, and IS research. Bringing all domains together is the benefit of socio-technical approaches. For example, questions can be asked that address the change of an organization when switching to hybrid-assembly technology. Using both robots and humans in assembly processes has effects on all four domains. As robots now conduct some of the tasks the set of tasks fulfilled by workers will change. This in turn will change the skillset of workers. Acceptance of the robots will also depend on a variety of worker diversity criteria (e.g. trust in technology). Lastly, changes in structure will occur (e.g. creation of a robot programming department) to cater to the change in organizational needs caused by the use of robotics. Designing models to predict or test these changes is necessary. Applying constant change is adequate [19, 20].

5 SUMMARY

The Internet of Things and Industry 4.0 bring along changes for production systems that will increase complexity for workers, organizations and technology. Applying socio-technical approaches to these scenarios are promising as they address both technical and social sub-systems. Therefore, we proposed a research outline to address different aspects of socio-technical-systems that we consider most pressing for each domain.

Understanding both *task* and *user* and designing *technology* and *structure* to optimize organizational success is the goal of applying a socio-technical approach.

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8 BIOGRAPHY

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