COGNITIVE SYSTEM DESIGN AND BUSINESS PROCESS MANAGEMENT

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Abstract — *The aim in this paper is to explore some of the important issues involved in the design of business process management (BPM) systems from a cognitive systems perspective. BPM is viewed as a socio-technical construct where Cognitive Systems Engineering (CSE) serves as a guiding framework for design. The design process is centered on Joint Cognitive Systems (JCS) paradigm, which is relatively new, compared to the classical Information Processing Systems (IPS) paradigm. The potential benefits offered by the JCS in the design of human-machine systems will be elaborated, and design for simplicity and design for complexity will be contrasted as alternative approaches. Design for complexity is suggested as a more promising approach for designing BPM systems.*

Index Terms — cognitive system design, business process management, information processing systems, human-machine system design

INTRODUCTION

Business process management (BPM) has become quite an important aspect of modern management recently. The number of publications in the area and applications in industry seem to be increasing rapidly. In literature, the treatment of business processes can be categorized roughly into three groups. The first and probably the most popular one is to view business processes as structured processes, similar to production processes, with inputs and outputs. This linear view tends to oversimplify the social realities and the complexity involved in business processes. This approach is usually associated with the information processing (IPS) paradigm. The second view may be summarized as seeing the whole exercise as methodologies for achieving specified business goals. These solutions appear to be fragmented and isolated. The third view is the socio-technical perspective where the processes involved are seen as complex socio-technical constructs.

There are quite a number of studies based on the classical IPS paradigm. As Vergidis, Turner, and Tiwari report, some researchers define objective of business process modeling as a tool for capturing, structuring and formalizing the knowledge about business processes [1]. According to them, there are an abundance of modeling techniques, such as flowcharts, IDEF models, and Petri-nets. They conducted a survey study in service industry and reported some of the difficulties faced by practitioners in BPM design. In this study, it is claimed that software that provides a holistic solution to BPM does not exist. Hence, they think that 'a software suit is needed for a complete and a comprehensive approach embracing all aspects of human processes (definition, modeling, enactment, analysis, optimization, conformance) demonstrating and measurable benefits'. It is doubtful whether it will ever be possible to produce such a software suit. Lee and Ahn asses the results of process improvement from an organizational change point of view; the variables and their relations are defined to perform task activity analysis, bottleneck analysis, cycle cost analysis, and resource utilization analysis [2]. Umar and Zordan present a decision model for SOA (service oriented architecture) reengineering projects that combines strategic and technical factors with cost–benefit analysis for integration versus migration decisions [3]. They identify the key issues that need to be addressed in enterprise application reengineering projects for SOA, examine how alternatives can be evaluated based on architectural and cost-benefit considerations. Goepp, Kifer, and Avial propose to analyze how an information system (IS) designs approach, based on a key-problem framework, enabling both to involve users efficiently and improve the design of a model of an integrated enterprise [4]. The proposal links the IS design to enterprise modeling in order to improve the design of the conceptual model of an integrated enterprise, therefore process integration and improvement. The work published by Kock, Verville, et. al. is on communication flow orientation in business process modeling and its effect on redesign success [5]. Their main conclusion is that a focus on communication flows in business processes is an important ingredient in successful business process redesign projects. The work reported by Armistead, Pritcard, and Machin may be classified into the second category; the category where some methodologies are used to achieve specified business goals [6]. In this work, BPM issues at the strategic level are seen from an organizational effectiveness perspective. It is argued that many large organizations tend to adopt general quality management methodologies, such as European Foundation of Quality Management (EFQM) and Malcolm Balridge Quality Management Award (MBNQA). Also, they say that some companies adopt business process re-engineering (BPR), lean manufacturing, concurrent engineering, and just-in-time (JIT) as a part of materials supply chain system in dealing with the problems of BPM.

There are also some studies in which business processes are seen as socio-technical constructs. One of the early works in this respect was reported by Rousseau [7]. He notes that studies in job design and socio-technical systems theory emphasize the importance of job characteristics to employee satisfaction and motivation, hence help designers develop successful systems. Similar views are expressed by Martin, Kivinen, et.al., who note that 'automation that is appropriate for application in realistically complex socio-technical domains should be based on an integrated understanding of the technical, human, organizational, economic and cultural attributes of the application' [8]. Gregoriadas and Sutcliffe describe a socio-technical approach to business process redesign through the investigation of complex interactions and dependencies

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among humans and IT systems of organizations [9]. Their method is based on human performance quantification and is supported by a tool that enables scenario-based evaluation of prospective organizational processes through simulation. Human performance model is based on human performance shaping factors (PSF) and assessed using Bayesian belief networks.

According to Vergidis, Turner and Tiwari, BPM is viewed with some caution in industry [1]. It appears that practitioners in industry would like to see a fairly clear demonstration of the tangible benefits of BPM; solutions found in industry seem to be fragmented and isolated. Hollnagel and Woods claim that the old IPS paradigm has serious limitations and needs to be Replaced by the joint cognitive systems (JCS) Paradigm [10]. They view JCS as the foundation of cognitive systems engineering (CSE) where human-machine relationship is seen as a joint entity rather than as separate interfaced entities like in IPS. In their interesting book, they describe how socio-technical systems (STS) can be designed effectively through the JCS paradigm.

The theme of the present paper is based on this new paradigm. Firstly, an overview of the CSE framework, the IPS paradigm, and the JCS paradigm is given. This section also includes a comparative view of the two paradigms. Following the overview, the important issues involved in the design of BPM as an STS through the CSE framework and the JCS paradigm are discussed. Here, *design for simplicity* and *design for complexity* approaches are contrasted, and the reasons for recommending the latter approach are explained. The conclusions section summarizes the major points of the study.

COGNITIVE SYSTEMS ENGINEERING, INFORMATION PROCESSING SYSTEM PARADIGM, AND JOINT COGNITIVE SYSTEM PARADIGM: AN OVERVIEW

Human-made systems are designed, constructed, tested, and operated by humans. It is also humans who maintain, repair and provide support to these systems. Therefore, it is the humans, together with technology and organizations, who determine system's level of success. Human-machine systems are always embedded in a socio-technical context. As systems become more complex with the passage of time, the socio-technical constructs involved are becoming more difficult to understand and design successful systems. In this regard, Rasmussen, Pejtersen, and Goodstein report that some significant changes have been taking place in socio-economic and industrial systems [11]. Their observations can be summarized as follows: (1) changes in products and services required are rapid and this pace is steadily increasing; (2) modern work systems are being integrated through advanced communication systems; (3) structural changes in the nature of work done and its contents are taking place; (4) tools used at the work place are changing continuously; (5) new forms of cooperative patterns of work and social organizations are emerging in response to the challenges coming from a highly dynamic environment; (6) systems, markets, plants, work domains, etc. are becoming strongly interdependent on each other; (7) the rate of mechanization and automation is increasing steadily; (8) computer-based interface between humans and their work are becoming more sophisticated everyday; (9) work is becoming more diversified and new skills are required at higher and more conceptual levels; (10) a change has been taking place in the way production planning and the actual production is done, from long term planning for stable markets to flexible manufacturing for dynamic markets; serial and slow operation is no longer feasible; high tempo, simultaneous activity (concurrent engineering) seems to be inevitable; (11) there are an increasing complexity of rules and regulations imposed on companies by governments, international institutions, environmentalists, etc. Hollnagel and Woods note that the industrialized societies have experienced serious accidents with some regularity in the last 50 years or so – notably, it is commonly accepted fact that the contribution of human factors to accidents is between 70%-90% [10]. In addition, they state that there has been a decrease in the number of accidents due to technological failures - partly due to increasing reliability of technological systems. Also, they observe a trend in the increase in the number of accidents due to human failures. According to these researchers, a third trend in the cause of accidents is seen, which is related to organizational factors. This trend seems to be significant since it is directly related to design and performance of the corresponding STS. Hence, they conclude, human-related error is seen as an important cause to be investigated within the CSE framework.

CSE emerged as an interdisciplinary field, concerned with the study of work and design of human-machine systems in a socio-technical context. It requires a multidisciplinary approach, and is related to engineering, psychology, information sciences, management sciences, and computer sciences. Its components are cognitive tasks (thinking, problem solving and decision making), engineering, and systems. It is based on General Systems Theory. In CSE, the emphasis is on the overall system performance rather than on the functions involved. According to Hollnagel and Woods, CSE was formulated in the 1980s as a proposal to overcome the limitations of the information processing systems (IPS) paradigm [10]. They note that this paradigm has been very popular in industry for a long time, in particular the S-O-R (Stimulus-Organism-Response) model. The JCS paradigm *focuses not on how parts communicate,* but on *how the joint system performs as a whole.* Humans and machine are seen as a joint cognitive system rather than as distinct but inter-connected components. Here, the human-machine relationship is viewed as *coagency* rather than interacting subsystems. One of the important consequences of this view is that system designers may have different 'models of the world', hence may develop different system designs. This very significant aspect of the JCS makes it a *pluralistic* rather than a monolithic paradigm. Pluralism is considered to be the major philosophical aspect that separates modern system approaches from the traditional ones [12, 13, 14, and 15]. This is particularly important in socio-technical systems such as BPM where pluralism creates 'richness' in modeling and help people design relatively more successful systems. The major properties of the *JCS* paradigm are as follows: (1) actions are seen together; cycle emphasizes that actions build on previous actions and anticipate future actions; (2) focus is on anticipation as well as response; combines feedforward and feedback actions; (3) users are seen as parts of the whole; users and environments are dynamically coupled –this is what is meant by *coagency*; (4) influence of situation or context is direct; (5) models are functional rather than structural. This model represents how the JCS maintains control of what it does. In the model, the steps taken to control the system may be performed by a human being, an artifact, a JCS, or an organization. Hollnagel and Woods describe JCS as follows: 'any JCS can be described on a lower level of aggregation in terms of parts that together constitute the system, as well as higher level of aggregation where the JCS in itself becomes part of a subordinate

system. The decomposition or disaggregation ends with the simplest JCS, which consists either of two cognitive systems, such as two people working together, or a cognitive system and an artifact, such as someone using a tool. The aggregation, on the other hand, has no natural upper limit but can go on as long as experience and imagination support it. Thus any JCS can be seen as constituting a part of a system on a higher level of aggregation. Whereas HMI (MI stands for human-machine interface) usually has focused on the disaggregation, CSE considers aggregation and disaggregation to be equally important.' The interested reader should consult Hollanagel and Woods' work for a lengthy and an *excellent* description [10].

DESIGN CONSIDERATIONS

1. GENERAL COMMENTS

There is no doubt that complexity in human-machine systems are on the increase, whether it is in manufacturing industries, process industries, or in services The reasons behind this complexity are not simple enough to explain in such a short paper. Hollnagel and Woods provide quite a thought -provoking analysis of the reasons behind this increasing Complexity [10]. In order to understand the complexities involved, let us assume that new technologies are introduced into a system; introducing new technologies means introducing new functions. This inevitably increases the complexity involved in the tasks, and consequently increases the problems related to automation. Even though some benefits of introducing new technologies will be seen (such as reduction in production costs, or increase in efficiency product/service quality), the complexities involved in the system design process will certainly increase. Furthermore, more complexity will be added into the system through higher performance demands, such as expectations for higher efficiency from the new technologies. It is also important to acknowledge the fact that increasing system complexity will also increase the chances of system malfunctioning. To remedy these problems, people introduce more automation into the system, probably making matters even worse. Also, more complexity may be injected into the system by operating it at a narrow margin of stability to achieve higher efficiency - such operations can be seen in electric power generation and distribution industry. This certainly increases the risks associated with system malfunctions, therefore the complexity. Hence, in summary, some benefits of introducing new technologies may be seen at various places in the system, but some other problems may appear at other places where business processes are involved. It goes without saying that all sorts of such problems can be observed in various branches of industry, including robotics technology, numerically controlled machines, computer-aided design and engineering, flexible manufacturing, office automation, electronic, exchange of data and funds, decision support systems [10].

Designing complex systems such as BPM is particularly challenging since they involve significant degree of human factors. The limitations of the conventional or 'hard' systems engineering in dealing with ill-structured socio-economic and socio-technical systems are well known. Several new methodologies or approaches have been developed in the last decades to overcome these limitations. In this regard, Jackson gives an interesting classification and a critical view of various system methodologies or approaches in systems management [12]. In his critical analysis, Beer's Viable System Model and Checkland's Soft Systems Methodology (SSM) stand out as important methodologies to be considered in social and organizational system design. The interested reader should also see Jackson [13], Checkland and Scholes [14], Checkland [15], Skyttner [16], Maani and Cavana [17], Flood and Carson [18], Pidd [19], Hitchins [20], Parnell, Driscoll, and Henderson [21], Sage [22], Sage [23], Stevens, Brook, et. al. [24], Kossiakoff and Sweet [25], Sage and Armstrong [26], and Blanchard [27] for quite diverse discussions on system design. Skyttner gives a superb coverage of General Systems Theory and its applications, including human-systems-technology related issues [16]. Jackson's work on systems management is highly recommended [12] and [13]. Hitchins emphasizes the following ideas in relation to design of complex systems: (1) conceiving solutions to problems is creative, requiring perception, imagination, understanding, and judgment; (2) one solution may be more aesthetically appealing than another, although both may be equally justifiable and effective in other respects; (3) in the practice of system design, choices may be made in the absence solid information about the future in which the designed system will exist and function; (4) system design is based on open systems, and reductionism is avoided as much as possible to maintain the principles of synthesis, holism, and organismic construction [20].

2. DESIGN BASICS IN JOINT COGNITIVE SYSTEMS PARADIGM

Design of human-machine systems fall primarily within the domain of CSE. Rasmussen, Pejtersen, and Goodstein [11], and Hollnagel and Woods [10] give comprehensive coverage of the subject matter in their books. The JCS, as a relatively new paradigm, appears to have significant potential for STS design. It is holistic in nature, and provides a top-down approach to studying and designing human work with complex technology. It emphasizes a proactive (coping) perspective, as opposed to the reactive view of the structural human information processing approach. The JCS is based on a conceptual framework with theories and methods that are consistent with General Systems Theory. Furthermore, the conceptual framework provided is applicable across a wide variety of systems, including single human-machine systems, socio-technical systems, and organizations.

Following Hollnagel and Woods' thoughts [10], the sources of complexity can be summarized as follows: (1) insufficient training and experience of operators; (2) insufficient time and knowledge to handle the task; (3) deficient interface design. In order to increase the chances of the human operator coping with complexity without losing control, or helping her/him to regain control if somehow control is lost, the sources of complexity should be analyzed with some depth. It seems that problems related to control are primarily related to the following reasons: unexpected events taking place; operator not having sufficient time to perform the task; lack or insufficient knowledge of processes and the system; insufficient or lack of readiness or preparedness; insufficient resources. The issues stated above should receive a comprehensive treatment in the JCS design. In addition, designers need to assess the impact of changes on the roles of people in the system throughout the design process. It is also important to recall the fact that that system description is given in terms of goals and functions required rather than system components and capabilities in STS's such as BPM. Design involves assigning tasks and functions to humans and machines in the system in a top-down manner. In 'conventional' systems

engineering, this is achieved by developing a functional architecture. This approach may be employed in CSE design as well, but the goals-means approach, as an alternative, may be preferred. The reader should note that this latter approach is known as means-ends analysis in GPS (General Problem Solver). The goals-means decomposition can be performed recursively; that is the means at one level becomes the goals at the next level down, etc. The reader will find detailed treatment of this topic in Sage and Armstrong [26].

The designer has choices in modeling the task-controller relationship in the design process. These choices can be classified as *Designing for Simplicity,* and *Designing for Complexity.* A summary of these approaches will be given here; the interested reader can find a detailed treatment of the subject matter in Hollnagel and Woods [10]. *Designing for Simplicity* is based on reducing the demands on tasks or increasing the controller capacity, or doing both. In this approach, although it seems possible to handle the growing system complexity by reducing the mismatch between the demand and capacity, the resulting system will have a built-in limitation. This is due to what is known as *the n+1 fallacy*: the system is designed to handle *n* number of possible states, but there is always the state *n+1* that has not been accounted for. *Designing for Complexity,* on the other hand, is based on the premises that complexity cannot be reduced to an arbitrary low level. In other words, the *Law of Requisite Variety* should be satisfied; that is the controller or operator should have at least as much variety as the system to be controlled. Since the designer cannot reduce the requisite variety through interface design, she/he has no choice but to increase the variety of the controller. The resulting system is very likely to perform better since complexity of the reality is acknowledged rather than simplified. In fact, experiences seem to indicate that designing for simplicity is possible if one can transform the complexity involved according to a set of well defined rules, which is hardly the case in the real world. Hollnagel and Woods conclude their assessment of these approaches as follows: '*rather than designing for a simple world that does not exist, the goal should be to design for the complex world that does.'* [10]

STS design within the CSE framework requires some other changes. Firstly, a major shift in modeling philosophy is needed. Models of human-machine relationship should primarily be based on field study-based techniques rather than operations research (OR) and system science-based techniques. Secondly, optimization of system design should be based on the actual work content rather than on some misconceived hypothesis about the users. However, the use of OR and system science–based techniques should not be ruled out. Instead, they should be complemented by some CSE design tools [10] and [11]. Secondly, both vertical and horizontal communication lines should be established in the system, and the control structure should be decentralized. Thirdly, the system should have self-organizing features (where the system structure is updated as conditions change), or at least should have adaptive control features (where some of the system parameters are changed as the conditions change). Adaptation is essential since preplanned activities and procedures may not work well due to various reasons. Fourthly, like all human designed systems, the system must be goal-oriented, and the goals or objectives need to be propagated throughout the system effectively. It is also important to note that systems evolve over time, meaning that the objectives, the structure and the means of propagating these objectives have to be updated continuously. Furthermore, system capabilities and resources, in particular saturation of resources should be taken into account in the design process; system performance at the boundary conditions should receive careful consideration. All these features must be included in BPM design since human factors play a crucial role in system performance. The reader is reminded here that JCS forms the core of the design process. It is should also be noted that design should be performed through the use of *Systems Engineering Life-Cycle Model;* implementation, operation, maintenance and retirement phases should also be included in the design process.

BPM or STS design can certainly be improved through the use of decision support procedures, particularly the intelligent ones. This topic is obviously too long to be handled in such a short paper. Here only some brief observations from the literature will be given, leaving a detailed treatment of the subject matter to another study. The advances seen recently in computer and communication technologies certainly increase the importance of decision making and decision support in STS design. In the JCS, decision support is viewed differently. The classical view is based on normative decision making process within the framework of information processing paradigm, whereas in the JCS 'a more descriptive or naturalistic approach' is suggested [10]. The summary of implications of this view for STS and JCS design are as follows: (1) decision making is a continuous process, not a one-time activity; (2) the important issue is to support monitoring, detection, and recovery rather than decision making; (3) decisions should not be automated; (4) if the environment is regular and predictable, there is no need for decision support; (5) decision support is needed when humans can not accomplish a task; (6) decision making is an overall function- intelligence must be viewed as a continuous process, not as a discrete one; (7) decision cannot be separated from task intelligence, hence it must be present in the controller and in the implementation; (8) design of decision support needs to be based on an analysis of the control issues, particularly how control is lost and how it can be regained and maintained. It is fair to say that even the most sophisticated AI-based intelligent systems or expert systems cannot cope with complex reality; they reduce the complexity to their level. Hence, they can provide *only* partial answers to ill-defined problems [8] and [16]. The reader here is reminded of Gödel's Incompleteness Theorem which states 'for any formal system, there exists no decidable propositions which cannot be proven by the formal system itself'. In decision support systems, the meaning of symbols are context dependent, hence cannot be formally described in principle - for instance, a system cannot recognize an object for certain in computer-aided vision and pattern recognition. Also, fully automated systems based on heuristic processes are known to be problematic [8]. In short, caution must be exercised in automating and in building decision support systems for STS's. This caution is particularly important in handling high level and complex tasks; only human operators can handle certain complexities. This caution should certainly be emphasized more in service systems such as BPM where human factors play a more significant role.

CONCLUSIONS

In this paper, business process management (BPM) is viewed from a cognitive systems engineering (CSE) perspective. It is argued that complex systems such as BPM should be modeled as socio-technical constructs, and should be designed within the framework

of CSE. It is also argued that design should be based on joint cognitive systems (JCS) paradigm rather than the conventional and constraining information processing paradigm. In the JCS, humans and machines are viewed as *coagents* rather than separate-interfaced entities. Finally, it is suggested that controller design should be based on *design for complexity* approach rather than *design for simplicity* approach. This means that the *Law of Requisite Variety* should be satisfied; that is the controller or operator should have at least as much variety as the system to be controlled.

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