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Socio-Technical Systems: Transforming Theory into Practice

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***Abstract*—**This paper critically examines the evolution of socio-technical systems theory, its practices, and challenges in system design and development. It examines concepts put forward by researchers focusing on the application of the theory in software engineering. There are various methods developed that use socio-technical concepts based on systems engineering without remarkable success. The main constraint is the large amount of data and inefficient techniques used in the application of the concepts in system engineering for developing time-bound systems and within a limited/controlled budget. This paper critically examines each of the methods, highlight bottlenecks and suggest the way forward. Since socio-technical systems theory only explains what to do, but not how doing it, hence engineers are not using the concept to save time, costs and reduce risks associated with new frameworks. Hence, a new framework, which can be considered as a practical approach is proposed that borrows concepts from soft systems method, agile systems development and object-oriented analysis and design to bridge the gap between theory and practice. The approach will enable the development of systems using socio-technical systems theory to attract/enable the system engineers/software developers to use socio-technical systems theory in building worthwhile information systems to avoid fragilities and hostilities in the work environment.

***Keywords*—**Socio-technical systems, human centered design, software engineering, cognitive engineering, soft systems, systems engineering.

I. Introduction

SOCIO-technical systems involve a complex interaction between technology and the social subsystems [1], [2]. Its theory aims at optimizing results from these interactions by designing systems that can adapt to human needs and complex social environment requirements instead of humans adapting to the system's needs [3]. The systems are significantly influenced by social components being open-ended and adapting to changing environments such as culture, organization, the context of use, usefulness, policies, and regulations. Hence, people-oriented computers (systems) are needed instead of computer-oriented people. Socio-technical perspective believes that humans are the primary part of any successful system and therefore plays a pivot role in the designing of such system to meet their operational goal [4]-[6].

According to Brian Whitworth [5] a socio technical system design is a holistic approach which considers the system as whole and not side by side, when one side takes prominence over the other performance will be affected. When the two systems are considered, and the social system takes prominence it guides the whole system. A simple example is a plane and a pilot needing each other [5]. Complex context based rational decision are done by a human pilot to help strategic novel plane maneuvers. The trust social aspect is important since different participants use different communication channels to interact with systems. Hence, systems must be trustworthy, reliable, and fostering privacy, ensuring correctness and quality data [7], [8]. Although most system designers and engineers have abandoned socio-technical systems design concepts [9], [10], they have continually been revised and adapted to current practices to realize a more professional and practical outcome [11]. However, there are good socio-technical methods like socio-technical toolbox drawing concepts from other socio-technical disciplines like SSM, OOAD, Cognitive Engineering, Contextual Design, System Thinking, Cognitive Work Analysis, and Human Centered Design using ETHICS format. The methods have overcome some of the traditional socio-technical methods weaknesses like; very long description of requirements, conflicting value system analysis and ambiguity in defining success criteria [11].

There are many disciplines that evolved from socio technical concept, and each try to adapt to an environment, culture, or organization by putting more emphasis on few aspects of socio technical design. Example, user centered approach put more emphasis on usability while cognitive work system analysis put more emphasis on work capabilities and constraints [12]. A Sociotechnical Systems Engineering (STSE) using constructive engagement and sensitization was introduced in 2008 providing design methodologies and tools for software engineers, however, it was extremely manual [7].

Therefore, there is a need for a pragmatic approach that will attract system developers and engineers to use socio-technical concepts over other engineering methods that are technology focused to facilitate acceptance since it democratizes system design and development process where user preferences are taken into consideration during the design [12]. In addition, the approach advocates design flexibility involving users to shape and manage their work [6], [13]. Our approach combines the capabilities of the three known systems design methods (i.e. Agile, SSM and OOAD) simplified to allow system engineers to use and overcome the inherent challenges which earlier methods or frameworks developed did not completely address.

II. The Socio-Technical Studies

A. Overview

Socio-technical concepts were discovered by the Tavistock Institute of Human Relations to democratize work processes to improve user satisfaction, enrich work practices, add value and include humanistic ideas in work processes [2], [13]-[15]. Many researchers have worked to improve socio-technical concepts to adapt current technology trends. This led to invention of Effective Technical and Human Implementation of Computer-supported Systems (ETHICS) design method. ETHICS did not survive for long [1], [15], [16]although it was built on a strong foundation of different disciplines emphasizing on human involvement in design from the start. Other socio-technical disciplines such as a human-centered approach, cognitive engineering, soft systems method, cognitive workplace analysis, human-computer interaction and contextual design are a modification or extension of the social-technical systems concept based on application context [12], [7]. Socio-technical concepts appeared when there was little automation [11]. However, the introduction of personal computers in 1980's and internet later in 1990's moved the technical part closer to the people, which created complex relationships between human and technology in shaping work practices, organizations, and society [3], [5] making the socio-technical theory more relevant.

B. Socio-Technical Systems Design

The aim is to design systems that can adapt to human needs and complex social environment because humans they are crucial to any successful system, hence are essential in designed system meeting operational goal [4], [14], [6]. The software engineers socio-technical perspective is to fulfil technical aspects of efficiency and business interests such as business procedures, rules, and tasks to achieve business excellency [17].

The different socio-technical approaches and methods used by software engineer designers are:

1. Effective Technical and Human Implementation of Computer Systems

Munford [16] found the impact of computers on people, organization, and society and the relationship between them on how worker’s satisfaction could be achieved through work redesign using socio-technical systems with system designers as agents of change [18]. The focus was how technical and social requirements can together lead to job satisfaction and improved organizational performance which is the basis of introducing ETHICS method [1] used to implement several computer projects. The humanistic concepts/principals for a workplace in ETHICS method led to its acceptability in resolving industrial tension on technology adoption and in achieving business efficiency. Thus, ETHICS themes are “an effective & efficient design (technical) and satisfaction (social)” [1]. ETHICS focused on redesigning work processes to achieve satisfaction and stimulate productivity [15].

ETHICS considered development of computer-based systems as a change process where conflicts of interest between the participants or actors in that process was likely. Therefore, participatory approach which considered the context, size and nature of the organization or business setting to ensure successful implementation of new systems was mandatory [1]. Mumford [11] used a top-level employees consultative participation approach to help in formulating overall procurement system strategies, the representative or selective participation approach for tactical or middle-level employees to allow participation of select individuals from different groups/function/department to define system boundaries and represent other users, and lastly, the consensus participation approach for the bottom/operational level employees where everyone is fully involved to obtain finer details [8], [16].

ETHICS shortcomings include inefficiency for large-scale projects, could not map to the changing computer technologies, could not manage complex design process and requirements, rejection of the XSEL expert system by digital corporation, time-consuming, failed when the business focus changed from internal to external, impaired by conflicting interest among interest groups, not focusing on prioritized business short-term goals and failed to provide technical solutions [1], [15], [19].

2. Quality Information from Considered Knowledge ETHICS

Quality Information from Considered Knowledge ETHICS (QuickETHICS) method is a follow up of ETHIC method meant to address weaknesses of the ETHICS method [16]. QuickETHICS used a centralized approach unlike its predecessor, which used a top-down approach where design starts from the central spanning to top and bottom levels using skilled representative/controlled participation approach. QuickETHICS reduced the number of steps from 15 to 5 and used one-to-one interviews, and group discussions. It is based on practical experience and principals of Process Redesign, Organizational Group Relationships, Efficiency, and Social Stability (PROGRESS) [20]. Although the method reduced costs, it did not facilitate system developers or software engineers to work on the technical components of the system.

3. Socio-Technical Toolbox

STT is framework, methods and tools that draw concepts from other socio-technical disciplines like SSM, OOAD, Cognitive Engineering, Contextual Design, System Thinking, Cognitive Work Analysis, Human Centered Design. STT has overcome some of the known weaknesses of the traditional socio-technical system methods like; difficulties in finding proper levels of abstraction, inconsistent terminologies in defining social and technical systems, multidisciplinary requiring a designer to have knowledge outside one’s domain, conflicting value system analysis and ambiguity in defining success criteria [11]. The STT was introduced in 1999 and continued to be improved by scholars until 2015. STT incorporated contemporary contextual inquiry to give a foundation for strategic systemic thinking. However, it is not a standard approach to address problems in a step-to-step fashion, but on contextual and project requirements, is time-consuming and cannot guarantee quality. STT transforms requirements specifications into system design using OOAD tools.

4. Socio-Technical Systems Engineering

Sociotechnical Systems engineering (STSE) provide usable socio-technical systems design methodologies and tools for software engineers [12]. STSE focused on information systems adding social context thus influencing system productivity [17].

STSE bridges system engineering and change management processes, which were separate in earlier systems, using ethnographic and responsibility modelling techniques to allow humanistic ideas to be considered during system design. However, Socio-technical engineering models are too manual using sensitization techniques on stakeholders and constructive engagement during implementation to integrate the change process into the system engineering as illustrated in Fig. 1 [7], [12]. Therefore, a modified approach is required to address the observed shortcomings while building on all strong features of existing methods.

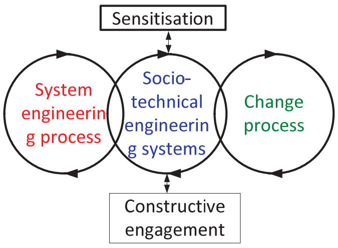

Fig. 1 Socio-technical System Engineering Model

III. Methodology

A qualitative research method is used to collect data from experience, explanations, decisions, cases, opinions, and scholarly research. The method is suitable for investigating the different methods used, their strengths, weaknesses using multiple sources and complex data sets because of its investigative nature and flexibility.

A. Sampling

The research used a deliberate sampling technique where the choice is based on the researcher's judgment on their potential to give worthwhile and comprehensive information. The methods selected for closer evaluation are: ETHICS, QuickETHICS, STT, STSE, Soft Systems Methodology (SSM), Agile Systems development, Object Oriented Analysis, and Design (OOAD), and Socio-technical Systems Design (STSD).

B. Data Collection

The data collection was based on literature and document reviews supported by a limited number of formal interviews.

C. Analysis of Data

Data analysis was done in parallel with its collection since gathered information generated more questions. The analysis of data was cyclical involving Interim Study Analysis, recording was in form of short notes, Deductive and Inductive Coding and Categorizing using Computer-Aided Qualitative Data Analysis Software to improve efficiency and create a better study focus.

D. Quality: Validity and Reliability of Research

Results can be affected by changes in the social, economic, and political environment over time. The challenge for the selected approach is influenced by natural settings hence not easily repeatable, making reliability more difficult than the validity while they are very important factors any qualitative researcher should be concerned about [7].

IV. Findings and Analysis

A. Socio-Technical System Design

The research focuses on using socio-technical concepts in designing and developing system models that are efficient, usable, useful, and embedding in an evolving the society [17], [6]. It is a fact that the quality and engineering efforts of a technical system alone cannot perform well without adapting to organization/institution requirements. Hence, information systems must be redefined, reviewed, and revised to respond to circumstances of usage and other factors that affect system usage or functionality. Socio-technical systems must have interdependent parts, internal and real-world environment, choice/decision-making, separate technical and social subsystems, adapting to changes in the environment, and responsive to joint optimization [7]. Challenges or Drawbacks of socio-technical systems design:

Perceived anachronism: Industrial revolution was marked by mass production where work was divided into simple routines involving small workforce and bureaucracy. However, absenteeism and boycotts were common lowering production. Hence, to raise job satisfaction and hence efficiency and production, social-technical systems concepts were introduced. The work re-design process involving employee to address their concerns had a positive impact on industries. There was no sophisticated technology during 1950's - 1960's. However, during 1970's to 1980's computer science was introduced which enabled production automation. A study of the impact of computers on people, organization, and society was needed using computer systems analysts as agents of change [1]. This lead to the discovery of socio-technical ETHICS works redesign method which creates a balance between social and technical parts to address fragilities and hostilities in the work environment. The top-down participatory method helped Scandinavian countries and America digital corporation XSEL system [20]. However, it could not cope with system complexity of the 1990's, which needed dealing with factors like integration, distributed computing, virtualization, and internationalization of industries. The preference was lean production and business process engineering to cut down costs among other factors. Human-focused methods did not attract industries, focusing on efficiency, short-term profits, process intensive and supporting competitive edge. Socio-technical systems engineering (STSE) was introduced during 1990's and went through different changes until 2011. However, STSE is rarely being used because it is too manual; hence, it needs to be improved

[7].

Analysis without synthesis: Many socio-technical system methods give only an abstract view of socio-technical requirements that lead to many datasets and complex relationships, which were not friendly informative [12]. ETHICS was more of a philosophy than a software engineering method since it did not translate easily into system design. Important boundaries and technical constraints are not usually given due consideration. There can be a conflict between usability or increase flexibility and reliability [14]. The need exists to perfect complex interdependencies between the social and technical parts of the system, which call for sacrifices during design to allow technical implications. However, conflicting requirements need proper synthesis.

Multidisciplinary: Multidisciplinary and application domain are integrated in developing programs for business organizations by system engineers targeting efficiency and effectiveness of business processes [17]. Hence, a system analyst engages domain experts to define requirements and guide the whole process. Socio-technical techniques add disciplines like psychology, sociology, and anthropology to systems engineering. Hence, the multitude of disciplines must understand and follow the process using participatory design.

Inconsistent Terminology: The motivation for introducing socio-technical system theory was to address problems in the British coal mining industry resulting in a poor performance involving simple job routines. The focus was organizational arrangements and its group relationships at all levels and innovative cost-effective work practices to increase productivity. The social and technical organization and workplace environment requirements were studied separately and how to integrate them to improve performance incorporating work redesign and democracy. Socio-technical concepts were introduced into computer science by studying the influence of computers in the organization, people, and work process [1]. Social context and human consequences were key in system design. The system analysts became agents of change to transform information system design, perfecting social and technical subsystems contributions. Employees/users were used to effectively allow humanistic ideas in the change process. The evolution of socio-technical concepts after ETHICS was on developing frameworks to fit defined environment, culture, view and needs. The focus was on understanding the complex interdependencies and coexistence between social and technical subsystems. The researchers differed on the application domain and/or user knowledge/position dependence [4], [15], [16].

Ambiguous success criteria: A limitation of a socio-technical concept is that it does not sufficiently define measurable goals while to measure influence brought by new systems require explicit and specific goals. Socio-technical systems integrate multiple system performance requirements at higher overlapping levels [6]. Things like reliability, availability, and integrity can be measured using quantitative techniques like mean time to failure, mean time to recover, response time, and throughput [12]. The stakeholders differing but overlapping interests on performance make it difficult to evaluate [14], [5]. Therefore, there is need to be more specific and filter unnecessary inputs or draw a boundary of performance fitting the system.

Conflicting values system: The emphasis on user participation during design while a good thing can bring in the conflict of interest between different levels of authority. Management, being more informed and equipped, give direction, make decisions, checks, control and manage the overall operations. Ordinary workers look within their boundaries of control since they do not have complete organization information. Organization interest may contradict those of workers [11]. E.g. employer interest may be cutting down costs, profitability, and competitive edge while those of employees can be on job satisfaction, job security and personal goals. Overcoming contradictions or influences is not trivial since it needs to balance organization goals while attending workers' concerns [13]. Hence, the developed system should be attractive, useful, usable, and perform desired functions while satisfying users to raise morale and performance. The top-down approach and consensus participation ETHICS method failed in this regard, lightweight model Quick ETHICS addressed this partially using a selective/representative approach (management interest) [7]. Soft systems method CATWOE (Customer, Actor, Transition, Worldview, Owner, Environment) framework was also meant to address the contradiction.

Difficulties in finding proper levels of abstraction: System analysts and developers work around project specifications to build the system; any changes can have a big impact on all elements of the project. Hence, the socio-technical system need be considered during definition of requirements specifications to avoid heavy added costs. The socio-technical theory has put more efforts in this area than in any other phase but have failed to define the right level of details needed to support the organization/system goals since it is more of a philosophy than an engineering method [1]. Software engineer or technology expert should not be inclined to focus on technical requirements at the expense of social goals like meeting security specifications while sacrificing usability [14], [21]. Note that defining requirement is hardened because of the complex interdependencies between technical and social systems specifications. A philosophy must be developed to refine or prioritize requirements definition, which is to be implemented, based on the context of use or application domain.

Table I provides a summary of weaknesses or drawbacks where different methods are marked with an x while contribution to systems engineering phases are marked by Double tick (√√) implying remarkable contribution, while single tick (√) implies weaker contribution.

B. The Knowledge Gap

Most of the socio-technical systems have been successful in addressing intended challenges but have been unattractive to software engineers because they use large amounts of data and inefficient techniques in developing systems with limited/controlled budget, which are also time-bound. The methods provide analysis of requirements disregarding its mapping to design steps for software engineer [18]. STT attempted to convert the socio-technical requirement into requirements specification models using OOAD tools for system analyst. However, they were not successful in accommodating overlapping needs and complex dichotomies in the hierarchy of requirements. Barxter and Somerville [12] tried to improve design using engineering concepts to make the socio-technical concepts implementable in the field of engineering. However, it converted socio-technical requirements as an add-in (extraneous factor) into the system engineering using manual sensitization and constructive engagement between the system engineers and the change team during implementation using dirty ethnography [1,12]. Hence, there is a need for a pragmatic approach, which integrates socio-technical concepts into system engineering life-cycle.

TABLE I
WEAKNESS OR DRAWBACK (X) OR DESIGN CONTRIBUTION (√) FOR DIFFERENT SOCIO-TECHNICAL METHODS

Drawback/weakness/methodology	ETHICS	Quick ETHICS	STSE	STT
Perceived anachronism	x	x	x	
Analysis without synthesis	x	x		
Multidisciplinary	x			x
Inconsistent Terminology				
Ambiguous success criteria	x	x		x
Conflicting values system	x			
Difficulties in finding proper levels of abstraction	x	x		x
Expensive/Lengthy	x		x	x
Problem Definition	√√	√√	√	√√
Requirement Analysis	√√	√√	√	√√
System Design	√	√	√√	√√
System Development	√	√	√√	√
Deployment	√	√	√√	√

C. The Way Forward

In this study, a pragmatic approach is introduced which includes the entire system engineering lifecycle which combines concepts from different social and engineering design methods and addresses experienced weaknesses and introduce a more efficient way to design and develop systems using socio-technical concepts [11], [9]. The new approach combines concepts, tools, and methods from agile (scrum), soft systems development method – CATWOE and Object-Oriented Analysis and Design. In this approach, each method acts as input to the other method, starting with the study of the social part during requirements definition as shown in Fig. 2.

This method uses social-technical inquiry to generate requirements to be analyzed and fed into the system design and implementation phases. An engineer or technology expert can thus prepare the right project environment from the start, predict the requirements and select right resources. There is no need for manual sensitization or constructive engagement during design. This approach adopted an agile method for system design and construction. Object-oriented Analysis and Design tools are used to help create useful system models and visualizations that can easily be converted to a modular information system using Object-oriented techniques. Soft System Method can be used for the social inquiry to manage a link between socio-technical inquiry and systems engineering.

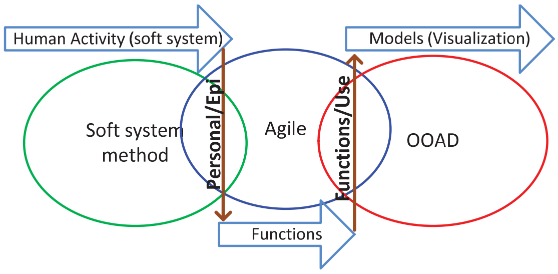

Fig. 2 New socio-technical system design using the concept

The new approach integrates socio-technical concepts into the systems engineering lifecycle to help system engineers' use and implement socio-technical ideas effectively in projects. The system engineering lifecycle has four major phases: Problem Definition and Analysis, System Design, System Deployment/Implementation, and Post-Deployment Reviews.

1. Problem Definition and Analysis

At this stage, problems are investigated with specific goals in mind such as the cost-benefit/ impact of desired changes. The traditional approach is to consider organization metrics like profitability, efficiency, and effectiveness of the existing system. The indicators are technical output like revenue growth, number of faults, redundancy, and average task execution-time [17]. It is here that social factors and their influence on system performance must be considered. However, organizations focus is on other factors like short-term profits, cutting down costs, and market trends, which have little to do with social factors although they influence system effectiveness. Many approaches are goal-directed, driven by technology and the efforts are on minimizing technology constrain and supporting it to meet technical goals. User-centered system force humans to adapt to it, causing system fragilities. It focuses on technology and how humans interact with it and not how it should support human activities [22], [23]. Socio-technical systems are systems that adapt to human needs and complex social environment requirements and not the other way around [18]. Best results can be achieved in an investigation if most proper approach is adopted. Soft system approach in business/management is promising [24], [25]. Hard approach is not adopted since it is not flexible to accommodate context of user variables. The concept is implemented for tax system Fig. 3

The above conceptual model shows the list of actions that can be taken to achieve system goals which can be done by engaging stakeholders to find challenges and desired changes through different means [20], [26]. The approach simplifies work even for a technology unaware person to suggest challenges and desires. It is goal-oriented method rather than technology focused and can be used by computer illiterate to define desirable changes [25].

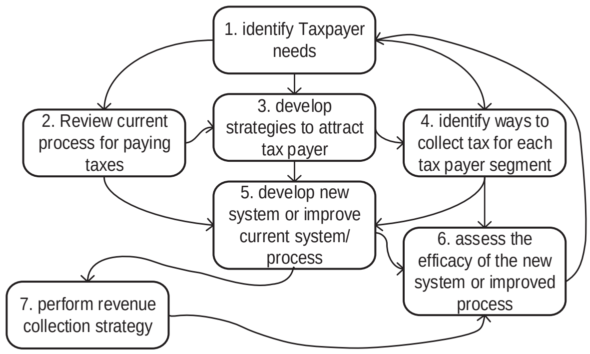

Fig. 3 Conceptual Model Tax Revenue Collection System

2. System Design

Agile methods and object-oriented design techniques is used to inform system construction team. There are three different levels of participation; consensus participation approach involving lower level users to make design decisions and guide the overall direction, selective/representative participation method using deliberately selective product champions to represent other users to contribute to the design team which can be cost-effective, and consultative design method sing top officials or the management selected by a consultant to negotiate end-user requirements who is usually a system analyst [20], [27].

3. System Deployment/Implementation

This approach effectively involves user during the implementation process, which includes retrospective meetings, daily stand-ups, user demonstrations (JAD sessions) which includes acceptance testing. It is both iterative and incremental, needing system analyst/scrum master leading the demonstration sessions going back to the field/users and test cases or build use scenarios that can be tested by the end-users. The bottom line is complete user involvement and empowerment to contribute and negotiate changes before the release of the software in a democratic manner.

4. Post-Deployment Reviews

System evaluation and monitoring are conducted to understand performance in relation to expected outputs by measuring system performance using technical metrics like mean time to failure, mean time to recover, integrity checks, and security checks. User attractiveness and satisfaction has also to be measured using proper techniques.

II. Conclusion

All socio-technical methods are rarely used in the industry today in a highly competitive environment, software engineers are increasingly using well-known and tested standards that can easily be measured and accommodated within shorter time frames. STSE has shown remarkable competence in this, however, it leaves the organization with a decision as to whether to use or not to use socio-technical concepts during the procurement of the system. As it has been suggested by scholars that, an approach is needed that will pervade the entire system engineering lifecycle, and this cannot be possible through manual sensitization, but through a well-integrated approach embedded in the socio-technical design as part of the system engineering process and not merely an add-on feature/function/loose-routine. It is believed that to this carry out inquiry methods has to be used from the very beginning of the project to guide the design and development of the whole system. These holistic approaches can easily inform the design team. Agile approaches can complement by coordinating and improving communication between the social and technical part throughout the system development project.

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