Task Analysis for Behavioral Factors Evaluation in Work System Design

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Abstract. This paper deals with the application and development of a systematic methodology called Task Analysis which is based on the analytical investigation of the task allocation processes and bottlenecks in terms of work system goals, in order to evaluate synergy between worker's essential motions and mental activities of different functional levels which contributes to conduct worker's adaptive behavioral performances during the execution of production operation. A comprehensive consideration of adopting this approach to analyze some key behavioral factors in work system design is expanded to acquire consecutive work performance feedback, determine the instructional work goals, describe the detailed work flowchart, structure the clear interaction assessment, improve the standard procedures, and supply the useful criteria.

Keywords: Hierarchical Task Analysis, Cognitive Work Analysis, Behavioral Factors, Work System Design.

1 Introduction

Human is a key element in safe and reliable industrial production processes, effective and efficient behavioral function allocation of human operators in the work system that able to accommodate flexible production demands continues to be of interest to a substantial amount of automated manufacturing enterprises due to the dexterity and flexibility of human workers' manual handling operations in conjunction with the automation.

Task Analysis explicitly analyses how a predetermined work task is appropriately carried out to achieve by workers' physical activity and cognitive processes according to the inherent work system goal. It includes a detailed description of task definition, task structure, task allocation, task duration, task frequency, equipments, environmental conditions, and any other declarative or procedural factors required for workers to perform a given task. Then the structured behavioral functions operating procedures and rigorous characterized conditions flow to be included within the work system can be accurately specified and conducted. In other words, Task Analysis is the study of the way workers perform their work, it takes account of what they do, how they do, and why they do. Eventually, the capability of Task Analysis is extended to provide and develop a framework for the investigation and representation of workers' behavioral performances to facilitate the design of complex work system.

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The entire development of this research conducive to implementation in work system design is illustrated in a modeling study of workers' behavioral factors evaluation, and the outline is arranged as follows: Section Background gives a brief overview of Task Analysis and sets the objective for effectuation; Section Method provides a clear and precise description of the procedures used in task analysis; Section Framework lays out the main features of this approach via its functional model; Section Conclusion discusses the merits of the proposed framework and presents the relevance of possible future work.

2 Background

2.1 Task Analysis

Task Analysis is studied in relation to the context in which it is performed to examine how specific work flows through understanding and assessing behavior of human, machine or its combination, it is a critical stage in work system design that involves task definition, task decomposition, task data collection, data analysis, and documented representation production of the analyzed task suitable for work system purpose [1]. The importance of Task Analysis and numerous methods have been well documented in the literature of various human factors and ergonomics studies, such as interface design, usability evaluation, man-machine collaboration, system control, error reduction, workload measurement, and so on.

Richardson et al. presented a reformulation of Hierarchical Task Analysis that focused upon the analysis of user goals rather than an existing task implementation to encourage novel and apt interface design based on the sub-goal template scheme which provided a notation for goal-oriented task analysis [2]. Norros and Savioja developed a new activity theory based approach named Core Task Analysis and an integrated evaluation method named Contextual Assessment of Systems Usability to analyze the appropriateness and acceptability of human conduct in complex work system with high usability and reliability requirements [3]. Tan et al. extended task analysis capability in hierarchical task analysis structure to model the collaboration between human and robot in cell production operation system for the sake of effective man-machine system [4]. Barbera et al. derived and organized a task-decomposition-oriented methodology to acquire and structure the complex real-time processing control system for the control tasks of autonomous vehicles [5]. Carstens et al. used task analysis to identify a web-based healthcare delivery system process flow affiliated with elder patients transitioning, conducting to reduce the likelihood of error and gain improvement within the system [6]. Dey and Mann performed a complete task analysis which was consisted of a structured written questionnaire and subsequent observation of experienced sprayer operators to measure the workload of operating an agricultural sprayer equipped with a navigation device [7].

These task analysis methods can be classified into two different categories as sequential approach and contextual approach [8]. The sequential model of task analysis like Hierarchical Task Analysis [9] or Goal Operator Method Selection [10] is considered as a goal oriented procedure of hierarchical sub-goals achievement via going through a sequence of formalized processing actions serially reached by the operator.

And the contextual model like Executive-Process Interactive Control [11] is formulated for modeling human multiple-task performance while the processor activates a wide range of cognitive capabilities to cope with work constraints in the scope of a known task without a predetermined restrictive sequence. Both of these two approaches have their own strengths and weaknesses, the sequential one is specific but lack of flexibility to unexpected emergencies, while the contextual one has the property of adaptability but hard to control with identical standard, it is only through integration that can give perfect records to the task analysis for behavioral performance.

2.2 Objective

This paper aims to create a new structured model which has the potential to bridge the gap between fixed and flexible working cell, and then provide a way to improve the implementation of behavioral performance measures involved in work system based on the theoretically rigorous approach initiated by Task Analysis. It is proposed that this integrated framework, by combining the sequential model Hierarchical Task Analysis together with the contextual model Cognitive Work Analysis [12], as well as incorporating the generic procedures of task analysis embedded in the work domain into it, will greatly enhance the understanding of behavioral factors situation, and then design a suitable work system.

3 Method

3.1 Hierarchical Task Analysis

Hierarchical Task Analysis (HTA) typically provides a model to analyze and represent the behavioral components like setting goals, defining tasks, identifying subtasks, planning operations, making diagnoses and decisions that essentially occur during a complex task executing in a wide context. It helps to graphically sketch the overall task, show the correct sequence and guide the formulation of constraints by using a practical structure chart to breaks tasks into subtasks and operations which interact through various inputs and outputs without focusing on too much detail. In the first instance the prospect for HTA as an adjunct tool to describe and analyze a complicated work system in terms of its goals which are expressed via some real operation units and objective criteria is quite capable of producing a goal-based systems analysis. And then the operation is broken down into subordinate operations which are defined by sub-goals with the purpose of producing an outline of the hierarchy that is concern with the adequacy of the hierarchical relationship description between the goals and sub-goals.

There are some basic heuristics and broad principles for proposing a framework within which HTA can be conducted to guiding the progressive goal description and adaptation other than a rigidly prescribed convention: define system purposes and boundaries, access multiple sources of system information, describe system goals and sub-goals, review the sub-goal groupings and triggering conditions, stop re-describing sub-goals at right point, and revise the final sub-goal hierarchy [13].

It is HTA that used in multifarious circumstances. Ainsworth and Marshall applied a universal task analysis technique HTA in the armed services and nuclear industries to allocate function, identify human error and assess systems by direct observation, questionnaire, and scenario modeling [14]. Shepherd devised a tabular format to illustrate the task taxonomy which analyzed constraints of the tasks and their associated sub-goals, for the purpose of investigating redesign opportunities in a batch control process [9]. Hellier et al. helped to uncover the complexities of HTA as a basis for predicting potential errors of a chemical sample analysis procedure by accomplishing observational studies and interviews with chemists [15]. Marsden and Kirby circumvented allocation problems of system function by focusing attention on the purposes of enabling impartial function allocation via sub-goal hierarchy in HTA [16]. Lane et al. demonstrated how HTA can be used as a systematic human error prediction and mitigation technique to prevent error or reduce the effects of error by means of modeling the process of drug administration [17].

3.2 Cognitive Work Analysis

Cognitive Work Analysis (CWA) is gaining momentum as a structured evaluation approach which emphasizes on the analysis, evaluation, and design of the complex and dynamic socio-technical systems for investigating and examining the significant effect of some key psychosocial factors on the performance of work system, thus to measure, implement, and improve the procedures for psychosocial personnel subsystem analysis in work system design. It leads to the consideration of the reason why the work system exists, the environment where the work takes place, the constraint that the system ability is performed, the domain that the activity is conducted within, the way how this activity is achieved, and the people who is performing it [18].

A theoretic foundation is extended the basic concepts of CWA by discussing the methodological guidelines as five defined phases: Work Domain Analysis, Control Task Analysis, Strategies Analysis, Social Organization and Cooperation Analysis, and Worker Competencies Analysis. It contributes to the general understanding of specific work-related psychosocial factors which are grouped into five categories as work demand, work relationship, work perception, work autonomy, and work reward. Comprehensive cognitive task analysis data and questionnaire data of workload, performance feedback, work content, support, conflict, stress, benefit, morale, communication, and union can be specified at each stage of the five CWA phases through the theoretical and empirical work, in order to estimate the structural equation modeling of the work system performance.

CWA was originally developed at the Risø National Laboratory in Denmark [19], and has been developed and applied in a wide range of socio-technical domains. Higgins explored the supervisory control of discrete manufacture by extending the suitable usage of CWA in particular Work Domain Analysis [20]. Naikar and Sanderson proposed a complementary framework for evaluating design proposals of a new Airborne Early Warning and Control System by describing its unique characteristics based on developing the first phase of CWA [21]. Miller presented a recursive diagnostic framework which conformed to the broader aspirations of CWA to represent an appropriate foundation for patient system information display [22]. Ahlstrom described how the CWA modeling tools could help to extract the development of weather display concepts and set up a high-fidelity simulation environment, thus to provide possible improvements in aircraft efficiency and safety of terminal operations

[23]. Jenkins et al. evaluated the advantages of exploring the Social and Organizational Analysis in the military domain through introducing a constraint-based description which is focused on the transfer of information and optimum working practices between workers within the system [18].

3.3 Procedures of Task Analysis

Task Definition. In general, task is a combination of goal and operation, the goal is a desired state of affairs while the operation is an activity for attaining this goal. Therefore, the basic idea of task refers to the purposeful work activities that user is attempting to accomplish for the overall system goal. Task definition involves a description of what the user has to do (the mission), what the user needs to know (the domain), and how the system supposes to work (the way) in the context of the whole system consisting of integrant parameters like machines, humans, skills and knowledge.

Task Decomposition. Task decomposition is the way how a task is split into subtasks to identify what goals, plans, and operations are involved in the overall task. Developing initial task decomposition can help to break the whole task situation down into sub-parts for further analysis of how the functions are allocated and how the operations are arranged. Function allocation represents the causal and sequential information-flow relationships of the functions performed in a rigorous measure. Operation is a generic term emphasizing on the associated series of actions that users carry out in the prescribed sequence, and each operation in turn could lead to a hierarchical structure.

Task Data Collection. It is necessary to resort to collecting information about task parameters and components which is accessible to compose the user's situation and activities while performing the task. Here are some useful methods for task data collection: sampling, observation, questionnaire and interview. To explain these in detail, sampling means the thorough process of selecting a random sample, observation refers to the documented description of observing actual user's behavior with little interference, questionnaire is a fixed set of some simple questions about the task information, and interview involves talking to users with a series of systematic questions about all kinds of task comments.

Task Data Analysis. Once the task data is collected, the next step is relevant to analyze it on the practical aims of producing a qualitative and quantitative synthesis of the detailed characteristics of a given task that is propitious to specify the design of the work system. This analysis goes beyond subjective intuitions or conjectures, and it concentrates on the interpretation of the data with classic statistical criteria in schematic forms which are derived from task behavior assessment methods like Event Trees Analysis [24], Hazard and Operability Study [25], Failure Modes and Effects Analysis [26], and Influence Diagrams [27]. The most important thing revealed by data analysis is that the analysis result is directly serving as reference material of great benefit to assessing and identifying critical bottlenecks in the task flow, specifically low-value activities, excessive workloads, inconsistent procedures, and so on.

Task Representation. Traditionally, the key function of representing the task is to provide a blueprint of visible and apparent task structure that supports the user to understand what aspects of the task are predominant, how much detail they are represented, and what sequences they are obeyed after collecting information into systematic format to sustain task execution. A logical representation that states and documents exactly what the task involves on the basis of its goal is structured by using some deductive approaches which are derived from graphical flowcharts or diagrams like Function Performance Diagrams, Input-output Diagrams, Critical Process Charts, Information Flow Charts, and Signal Flow Graphs [28].

4 Framework

4.1 Theoretical Framework

A theoretical framework which is founded on the aforementioned Hierarchical Task Analysis in tandem with Cognitive Work Analysis, namely Generalized Task Analysis Framework is presented in Fig. 1 to offer a heuristic procedure for capturing both the behavioral and cognitive aspects of work activities according to the main work aims in complex and dynamic industrial systems. The description of this framework is generally generated as decomposing a set of goals and states with constraints into their constituent sub-goals hierarchy in successive stages, as well as executing the sequential performance by which the final sub-goal hierarchy with plans are achieved to carry out the actions intervened in different cognitive representation situations that workers are likely to meet while operating the task.

It is therefore the central feature of GTAF in an overall sense is that it consists of two complementary unit named Sequential Processing Unit and Contextual Processing Unit for structuring and adjusting process of simple work actions which are the lowest level of task decomposition and have no further structure. The Sequential Processing Unit focuses on representing the mechanisms of work system through the breakdown of prototypical task into an extensive hierarchy charting of goals and operations, meanwhile, the Contextual Processing Unit is explicitly concerned with measuring behavioral human performance in conjunction with human cognitive variation in context of task data analysis execution stage, after the initial task definition with a high proportion of determining the instructional goals and also the constraints that affect the ultimate goals but cannot be changed.

To summarize, this structural modeling depicts the tangible way in which an exhaustive guide of task analysis is implicated for analysis, verification, implementation and development at each step within the process to determine more detailed tasks goals, resources, constraints, priorities, functions and processes. For clarity, an intensive theoretical layered description of Generalized Task Analysis procedures is organized as follows: defining and describing the task goals and domain in detail; refining task goals and splitting task into object based hierarchical subtasks until the basic task at the lowest level is simple enough to act on, then prioritizing and sequencing these sub-tasks; observing worker behavior and collecting empirical data; assessing and extracting the behavioral data to clearly manifest endogenous human variables feedback as reference; arranging and modulating a coherent task procedure to meet the primary task goal and fills out the principal sequence of steps in accordance with the actual behavior.

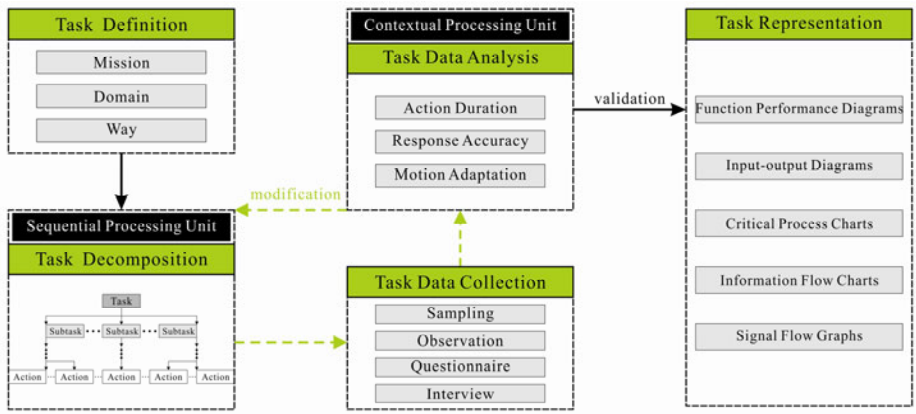

Fig. 1. Generalized Task Analysis Framework

4.2 Mathematical Framework

In addition to the previously mentioned qualitative interpretation, a quantitative consideration is proposed to examine the significant effect of three key behavioral factors on the work system performance via a composite measurement of the empirical performance data Action Duration, the observational cognition data Response Accuracy, and the available questionnaire data Motion Adaptation. A mathematical framework is defined to takes into account these synergy variables for quantifying the generalized behavioral performance output value, and the function is given by:

$$G = \sum_{i=1}^{n} (\sigma_d d_i + \sigma_a a_i + \sigma_m m_i) \quad (1)$$

Where σ is a parameter which determines the priority weight for each variable, d_i corresponds to the action duration, a_i is a rate of response accuracy, m_i is a degree of motion adaptation, n is the number of subtasks at the lowest hierarchical stage.

5 Conclusion

To conclude, this proposed conceptual framework incorporates Hierarchical Task Analysis as well as Cognitive Work Analysis into work system design, and thereby it offers a number of potential benefits to the behavioral factors evaluation aspect of the highly complex and dynamic production system which consists of extensive interactions between human, machine, and such relevant work factors. It raises work efficiency, work accuracy, and worker adaptation by adjusting work goals, assignments and procedures in accordance with consecutive worker performance variation feedback. It also could be used to ensure work safety through investigating work hazard, and increase work system availability via assessing work reliability.

The possible development trend of Task Analysis in work system design is Green Task Analysis because low carbon production is generally recognized as a valuable aid to harmonious society from an environmental tactical perspective. Consequently, the next stages of this research will focus on enhancing awareness of green inception in task analysis process through developing a green model for appropriate work performance evaluation, since minimizing waste is a universal goal for workers regardless of their specific objectives. This Green Task Analysis could be leveraged to energy saving and emission reduction, and eventually, in order to accommodate the great strategy of sustainable development.

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