PERGAMON

Safety Science 41 (2003) 803–835

SAFETY SCIENCE

www.elsevier.com/locate/ssci

A Petri Net-based approach for ergonomic task analysis and modeling with emphasis on adaptation to system changes

Tom Kontogiannis*

Technical University of Crete, Department of Production Engineering and Management, Chania, Crete GR 73100, Greece

Abstract

Task analysis has been extensively used in industrial ergonomics in order to identify system demands and operator plans for achieving goals and coping with high workload. On the other hand, computer modeling has been used for simulating human–machine interactions under a range of conditions, such as changes in task allocation, team structure, operating procedures and system events. To integrate task analysis and computer modeling, a new technique is proposed that utilizes Coloured Petri Nets. The proposed technique has been developed on the basis of 12 requirements reflecting aspects of task representation, control and decision making, and usability. A Petri Net notation of tasks and a classification of Petri Net-based plans are first introduced. This article is mainly concerned with the development of routines for making task sequences and plans adaptable to system changes that could give rise to task interruptions, changes in goal priorities, changes in task allocation, high workload and human errors. An evaluation follows on the basis of the specified requirements for task analysis and task modeling. *Relevance for the industry*: Task analysis and task modeling are important for matching systems demands to operator capabilities. New computer modeling approaches, including Petri Nets, can simulate human–machine interactions under a range of conditions, such as technology innovations, changes in team structure, different allocation of tasks, and high workload.

Keywords: Coloured Petri Nets (CPN); Task analysis; Human modelling; Human error; Task allowance

1. Introduction

Modern work systems require reliable human interventions, efficient team cooperation and adaptation to changes caused by technological innovations or unforeseen

* Corresponding author. Tel.: +30-821-37320; fax: +30-821-69410.
E-mail address: konto@dpem.tuc.gr (T. Kontogiannis).

0925-7535/02/$ - see front matter
PII: S0925-7535(02)00035-8

events. To achieve these work requirements, a range of task analysis techniques have been developed in the domain of industrial ergonomics (Kirwan and Ainsworth, 1992; Luczak, 1997; Schraagen et al., 2000). Task analysis involves the study of activities and communications undertaken by operators and their teams in order to achieve a system goal. The task analysis process usually involves three phases: (i) collection of data about human interventions and system demands, (ii) representation of those data in a comprehensible format or graph, and (iii) comparison between system demands and operator capabilities. The primary objective of task analysis is to ensure compatibility between system demands and operator capabilities, and if necessary, to alter those demands so that the task is adapted to the person.

Kirwan and Ainsworth (1992) summarized several techniques developed for each phase of the task analysis process. Verbal protocols, questionnaires, and activity sampling are examples of techniques for task data collection while flow diagrams, timelines and hierarchical task analysis are helpful for describing operator's activities and plans. On the other hand, computer modeling and simulation techniques (e.g. Micro SAINT) have been developed to simulate the task and evaluate human–machine interactions under a range of conditions. Here different task configurations, team structures, operating procedures and monitoring strategies could be evaluated.

Nowadays, advances in information technology and computer modeling would allow the development of task analysis techniques that achieve both phases of task description and task simulation within the same framework. This is a challenging research issue because, on several occasions, the requirements of task analysis and simulation may be conflicting. Task analysis, for instance, requires descriptions that are easily understood by different specialists (i.e. designers, users and computer experts) while task simulation requires a formal language of specification. In task analysis, we can use abstract descriptions of human activities in cases where we want to allow for some flexibility in the way that tasks are performed, or where we don't know at a certain stage the optimal sequence of activities. This kind of 'temporal abstraction' (Killich et al., 1999) is difficult to find in task simulation and computer modeling since these require precise specification of the flow of activities. There are also different perspectives taken by these two approaches, such as the task analysis focusing on the flexibility and reliability demonstrated by human operators and the task simulation focusing on precise specification and verification of human activities.

In this sense, the purpose of this article is to present a new approach for integrating task analysis and computer modeling of performance within a single framework. Existing approaches to the integration of task analysis and simulation, such as Micro SAINT and WinCrew (Laughery and Corker, 1997) and HOS (Glenn et al., 1992), have provided useful insights. The proposed approach is based on a Petri Net representation of human activities, tools, and organizational roles. Petri Nets are cast both in a graphical form and a mathematical formalism. Although most of the modeling work can be done with the Petri Net graph, the mathematical foundation provides the basis for using a variety of formal analysis techniques that can be built into software packages to examine the structural and dynamic properties of Petri Nets. It is possible to examine, for instance, whether the task network contains deadlocks, never-ending tasks, 'dangling' tasks that do not contribute anything, and