Reliability Engineering and System Safety 94 (2009) 1416–1421

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

Analyzing maintenance strategies by agent-based simulations: A feasibility study

M. Kaegi *, R. Mock, W. Kröger

Swiss Federal Institute of Technology Zurich (ETH), Sonneggstrasse 3, 8092 Zurich, Switzerland

ARTICLE INFO

Available online 14 February 2009

Keywords:
Agent-based modeling
Monte Carlo simulation
Markov chains
Maintenance
Reliability analysis
Risk analysis

ABSTRACT

Thoroughly planned and implemented maintenance strategies save time and cost. However, the integration of maintenance work into reliability analysis is difficult as common modeling techniques are often not applicable due to state explosion which calls for restrictive model assumptions and oversimplification. From authors' point of view, agent-based modeling (ABM) of technical and organizational systems is a promising approach to overcome such problems. But since ABM is not well established in reliability analysis its feasibility in this area still has to be demonstrated. For this purpose ABM is compared with Markov chains, namely by analyzing the reliability of a maintained n-unit system with dependent repair events, applying both modeling approaches. Although ABM and Markov chains lead to the same numerical results, the former points out the potentiality of an improved system state handling. This is demonstrated by extending the ABM with operators as additional "agents" featuring their location $(x; y)$ availability (0;1) and different maintenance strategies. This extension highlights the capability of ABM to analyze complex emergent system behavior and allows a systematic refinement and optimization of the maintenance strategies.

1. Introduction

Nowadays, extended system engineering has to integrate risk and reliability analysis including maintenance considerations (this area of application is subsequently called risk analysis). Established techniques like Markov chains or fault tree analysis (FTA) have been applied successfully. Nevertheless they have well known shortcomings. Markov chains suffer an inescapable state explosion when applying them to large systems and fault trees reach their limit when the system models comprise complex feedback loops.

In the past, many techniques have been successfully developed and adapted to include maintenance in risk analysis, e.g., genetic algorithms and Monte Carlo simulation [1], graph theory [2], stochastic Petri-nets [3] or object-oriented Petri-nets [4] (see review [5]). In recent years, however, novel system analysis approaches evolved based on the rapid development in computer science. Innovative frameworks for distributed simulation like the high level architecture (HLA) opens new possibilities in modeling complex and hybrid systems [6]. One of these novel approaches, the so called agent-based modeling (ABM), has recently experienced a success in many fields of application, but it is surprisingly almost invisible in risk engineering science.

In many modern analysis approaches, systems are decomposed into their subsystems and components and the interdependencies among components and subsystems are studied [7]. As such interdependencies often comprise *interactions* and some form of *communication*, a core attribute of ABM (see Section 2), this approach is regarded as a promising modeling extension for risk analysis.

One aspect of extended ABM and simulation is the possibility of detecting unknown (or unexpected) behavior of a complex system [8]. Well known examples of such emergent phenomena are the collective behavior of fish shoals or bird flocks often referred to as swarm intelligence [9,10] and self organization.

Literature on the application of ABM in the field of risk analysis is surprisingly scarce. The literature research conducted to show the novelty of this attempt also caused the authors to establish a definition of terms to have standardized selection criteria for the search of scientific publications.

In order to challenge the ABM approach in the field of risk analysis, its applicability is exemplified by a classical reliability analysis problem and the results are compared with the outcome of a classical Markov model. Finally the example is successively extended by adding basic maintenance strategies in order to explore the potential of ABM.

2. Definitions of terms

The basic idea of ABM is to model only the units — called agents — of a specific system and to simulate their interplay in order to derive and analyze the overall system behavior.

* Corresponding author. Tel.: +41 446320282; fax: +41 446321094.
E-mail address: kaegi@mavt.ethz.ch (M. Kaegi).

0951-8320/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ress.2009.02.002