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Integrated Markov-neural reliability computation method: A case for multiple automated guided vehicle system

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ABSTRACT

This paper proposes an integrated Markovian and back propagation neural network approaches to compute reliability of a system. While states of failure occurrences are significant elements for accurate reliability computation, Markovian based reliability assessment method is designed. Due to drawbacks shown by Markovian model for steady state reliability computations and neural network for initial training pattern, integration being called Markov-neural is developed and evaluated. To show efficiency of the proposed approach comparative analyses are performed. Also, for managerial implication purpose an application case for multiple automated guided vehicles (AGVs) in manufacturing networks is conducted.

1. Introduction

Industrial systems can perform their functions in different levels of efficiency usually referred to as performance rates. A system that can have a finite number of performance rates is called a multi-state system (MSS) [16,20]. Multi-state models are widely used in different industrial environments reliability assessment [4]. It has been recognized that using simple two- state models for an industrial system assessment can yield pessimistic appraisals [5]. In order to more accurately assess industrial system reliability, the related utilities now are in multi-state mode which complicate the reliability assessment [22]. A method called the apportioning method is usually used to create steady-state multi-state generating unit models based on real world statistical data. Using this technique, steady state probabilities of units is defined. When the short-term behavior of a MSS is studied, the investigation cannot be based on steady-state (long-term) probabilities. This investigation should use a MSS model where transition intensities between any states of the model are known. Point estimating of transition intensities for a two-state (binary) Markov model is a widely known solved problem [19,15]. However, until today no investigations have been conducted that consider this problem in a multi-state context where transitions intensities can be varied.

Based on a diagram describing the influences between the components of the system, the effective states on a system performance can be determined. Tombuyses [24] developed a presentation method to approximate state transition error bounds for the approximate results.

The Markovian approach is well-known for its flexibility for modeling systems like industrial plants, queuing and fault-tolerant systems [3]. The main drawback is the size of the state space associated to the Markovian description: the number of states increases exponentially with the number of 'components' (valves, pumps … for industrial plants; processors for computer systems …). The build-up and the numerical solution of the associated ordinary differential equations (ODE) system become rapidly unfeasible because of memory and calculation time problems [24].

Under some special circumstances, a Markovian system may have particular properties allowing the reduction of its size. For example, the computation of the availability is obvious for a set of independent components. The existence of symmetries, for instance because of identical components (or groups of components) performing the same task, leads to an exact aggregation of the system, hence to a size reduction [21]. For queuing and fault-tolerant systems, the use of Petri nets is widely spread and the automatic build-up of the transition matrix exploits directly such properties [18,1].

For industrial plants, symmetries also exist (as redundancies), but it is not necessarily the case and in most cases, the associated size reduction is not enough to get a Markovian system of 'reasonable' size. Devooght and Tombuyses [11] developed a new method based on the influence graph of the components. The influence graph represents

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the various dependences existing between the components of the plant. If there are not too many 'interdependences' between the components, the graph is a tree and gives an ordering among the components. The original Markovian system of ODE is replaced by a set of smaller systems, describing the behavior of the components, following the order suggested by the influence graph. This method already gave convincing results for benchmarks for which the exact solutions were still computable [25].

Calabria et al. [6] organized an approach to solve an important task in the reliability management of manufacturing systems: the definition of reliability and maintainability specifications of parts, the general objective being to increase productivity while maintaining costs low. An analytical approach has been considered to evaluate an average index of production capability in series-parallel systems. A heuristic optimization procedure has been developed to solve the problems such as, determine the optimal reliability and maintainability allocation of parts to achieve the maximum production index at a given cost, and determine the optimal reliability and maintainability allocation of parts which minimizes the total cost of investments, subject to the constraint of meeting a system production requirement.

The universal generating function (UGF) technique was greatly extended by Levitin [26], is an efficient technique to evaluate the availability of different types of multi state systems (MSSs). The UGF function extends the moment-generating function, and reduces the computational complexity of MSS reliability assessment. Thanks to its efficiency, the UGF technique is also suitable for solving different MSS reliability optimization problems, as it can quickly evaluate a systems reliability. The increased susceptibility of lifeline systems to failure due to aging and external hazards requires efficient methods to quantify their reliability and related uncertainty. Monte Carlo simulation techniques for network-level reliability and uncertainty assessment usually require large computational experiments. Also, available analytical approaches apply mainly to simple network topologies, and are limited to providing average values, low order moments, or confidence bounds of reliability metrics. Dueñas-Osorio and Rojo, [12] introduced a closed form technique to obtain the entire probability distribution of a reliability metric of customer service availability (CSA) for generic radial lifeline systems.

The surrogate model method is widely used in structural reliability analysis to approximate complex limit state functions. Accurate results can only be obtained when the surrogate model for the limit state function is approximated sufficiently close to the failure region. Dai et al. [10] developed a novel local approximation method for efficient structural reliability assessment. The adaptive Markov chain simulation was utilized to generate samples in the failure region. The support vector regression technique was used to obtain an explicit approximation of the original complex limit state function around the region of most interest.

Lisnianski et al. [17] presented a multi-state Markov model for an industrial application. They proposed a method for the estimation of transition intensities (rates) between different levels. The technique can be applied when the output data is uniformly distributed. In order to estimate the transition intensities a special Markov chain was designed. By using this technique, all transition intensities can be estimated from the observed realization of the unit generating capacity stochastic process.

Primarily universal generating function (UGF) was introduced in Ushakov [28]. The UGF technique allows one to find algebraically the entire multi-state system (MSS) performance distribution through the performance distributions of its elements. However, the main restriction of this powerful technique is that theoretically it may be only applied to random variables and, so, concerning MSS reliability, it operates with only steady states performance distributions. In order to extend the UGF technique application to dynamic MSS reliability analysis in Lisnianski [27] was introduced a special transform for a discrete-states continuous-time Markov process that is called LZ-transform. The transform was mathematically defined, its main properties were studied, and numerical example illustrating its benefits for dynamic MSS reliability assessment is presented

Faria and Azevedo, [13] presented an analytical approach for the evaluation of multi-user safety critical systems presenting a failure delayed behavior pattern. As a consequence of a failure event, the performance of the systems reduces progressively due to the internal fault tolerance mechanisms or the complacency of the users regarding the temporary unavailability of the services. A distinctive feature of the approach is the ability to handle stochastic models containing multiple processes with generalized distributions. The approach was based on the determination of analytical expressions to measure reliability, for instance, frequency and probability of failure states being evaluated using general purpose mathematical tools.

Fazlollahtabar and Saidi-Mehrabad, [14] developed a mathematical model to assess the reliability of machines and automated guided vehicles (AGVs) in flexible manufacturing systems (FMSs). The model considered two features of automated flexible manufacturing systems equipped with AGV namely, the reliability of machines and the reliability of AGVs in a multiple AGV jobshop manufacturing system. The optimisation objectives in the proposed model were maximising the total reliability of machines in shops in the whole jobshop system, maximising the total reliability of the AGVs, and minimising the total repair cost in the system. To solve the proposed multi-objective mathematical model, fuzzy goal programming was adapted and the results showed the effectiveness and applicability of the proposed approach.

The remainder of the paper is organized as follows. Next, the problem is stated and modelled. In Section 3 a case study is developed to imply the application of the proposed model. Section 4 analyzes the results from different aspects using variety of techniques. Discussion on the results is presented in Section 5. We conclude in Section 6.

2. Statement of the problem and modelling

The studies in the literature merely computed reliability using some failure probability of an item extracted from the collected data. The current methods for modeling reliability of a system involve determination of system state probabilities and transition states. Since, the failure of the items could be considered in different states. It is necessary to incorporate reliability into the model to ensure the level of service for each item. Note that, we can compute the reliability in two cases, first for current state, and second for steady state. The steady state computations lead to strategic decisions for periodic and preventive maintenance planning. To obtain an appropriate steady state reliability values, suitable current state values are required. Thus, Markovian modelling for state transition is employed to provide proper current state values.

Although, a Markovian model is proposed for reliability assessment, a neural network model is developed to point out the difference in the accuracy of the Markovian model in comparison with the neural network. Using Markovian property, we can configure the transition diagram and the corresponding matrix. The result of the Markovian process is the failure probability for items. These probabilities are applied in reliability computations. For reliability, first we conceptualize different scenarios exist in the proposed system. The items are in parallel and the sequence of the sub-items may be important or not. Therefore, two separate cases of series and parallel can be modeled. Items are in series since if one item breaks down then the whole system should wait until the item is repaired or taken out of the system.