Expert Systems with Applications 37 (2010) 3910–3920

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Modeling a flexible manufacturing cell using stochastic Petri nets with fuzzy parameters

Fatih Tüysüz [a,*], Cengiz Kahraman [b]

[a] T.C. Beykent University, Department of Industrial Engineering, Ayazaga, Istanbul, Turkey
[b] Istanbul Technical University, Department of Industrial Engineering, 34367 Macka, Istanbul, Turkey

ARTICLE INFO

Keywords:
Stochastic Petri nets
Fuzzy sets
Fuzzy probability
Flexible manufacturing cell
Non-linear optimization

ABSTRACT

In this paper, an approach for modeling and analysis of time critical, dynamic and complex systems using stochastic Petri nets together with fuzzy sets is presented. The presented method consists of two stages. The first stage is same as the conventional stochastic Petri nets with the difference that the steady-state probabilities are obtained parametrically in terms of transition firing rates. In the second stage, the transition firing rates are described by triangular fuzzy numbers and then by applying fuzzy mathematics, the fuzzy steady-state probabilities are calculated. A numerical example for modeling and analysis of a flexible manufacturing cell is given to show the applicability of proposed method. The importance of the proposed approach is that it can take into consideration both dimensions of uncertainty in system modeling, stochastic variability and imprecision.

1. Introduction

A flexible manufacturing system (FMS) is a discrete-event system and contains a set of versatile machines, an automatic transportation system, a decision-making system, multiple concurrent flows of job processes that make different products, and often exploits shared resources to reduce the production cost (Jeng, 1997a; Zuberek & Kubiak, 1994). The layout of a complex FMS is given in Fig. 1 (http://www.denford.co.uk/). These systems require both qualitative and quantitative aspects to be considered in modeling and analysis. Qualitative analysis searches for structural properties like the absence of deadlocks, the absence of overflows or the presence of certain mutual exclusions in case of resource sharing. Quantitative analysis looks for performance properties (e.g. throughput), responsiveness properties (e.g. average completion times) or utilization properties (e.g. average queue lengths or utilization rates). Quantitative analysis concerns the evaluation of the efficiency of the modeled system whereas qualitative analysis concerns the effectiveness of the modeled system.

There are many methods and tools used for modeling and analysis of FMSs such as queueing networks, Markov chains, simulation, and Petri nets. Petri nets (PN) introduced by Petri (1962), as a graphical and mathematical tool, can be used for modeling and analyzing complex systems which can be characterized as synchronous, parallel, simultaneous, distributed, resource sharing, nondeterministic and/or stochastic (Bobbio, 1990; Marsan, Balbo, Conte, Donatelli, & Franceschinis, 1995; Murata, 1989; Zhou & Venkatesh, 1999). The complex systems of these types exhibit characteristics which are difficult to describe mathematically using conventional tools like differential equations and difference equations (Jeng, 1997b; Murata, 1989). On the other hand, Petri nets as a mathematical tool provide obtaining state equations describing system behavior, finding algebraic results and developing other mathematical models. With respect to other techniques of graphical system representation like block diagrams or logical trees, Petri nets are particularly more suited to represent in a natural way logical interactions among parts or activities in a system (Bobbio, 1990). In modeling point of view, Petri net theory allows the construction of the models amenable both for the effectiveness and efficiency analysis (DiCesare, Harhalakis, Proth, Silva, & Vernadat, 1993).

Due to the graphical nature, ability to describe static and dynamic system characteristics and system uncertainty, and the presence of mathematical analysis techniques, Petri nets form an appropriate conceptual infrastructure for modeling and analysis of FMSs.

Although the concept of time was not included in the original work by Petri (1962), for many practical applications, the addition of time is a necessity. Without an explicit notion of time, it is not possible to conduct temporal performance analysis, i.e., to determine production rate, resource utilization. In modeling a FMS with PNs, timing and activity durations for analyzing temporal performance and dynamics of the system should be taken into consideration.

In PNs, time is often associated to transitions. The reason for this is that transitions represent events in a model and it is more natural

* Corresponding author. Tel.: +90 506 773 33 67.
E-mail address: fatihtuysuz@gmail.com (F. Tüysüz).

0957-4174/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.eswa.2009.11.026

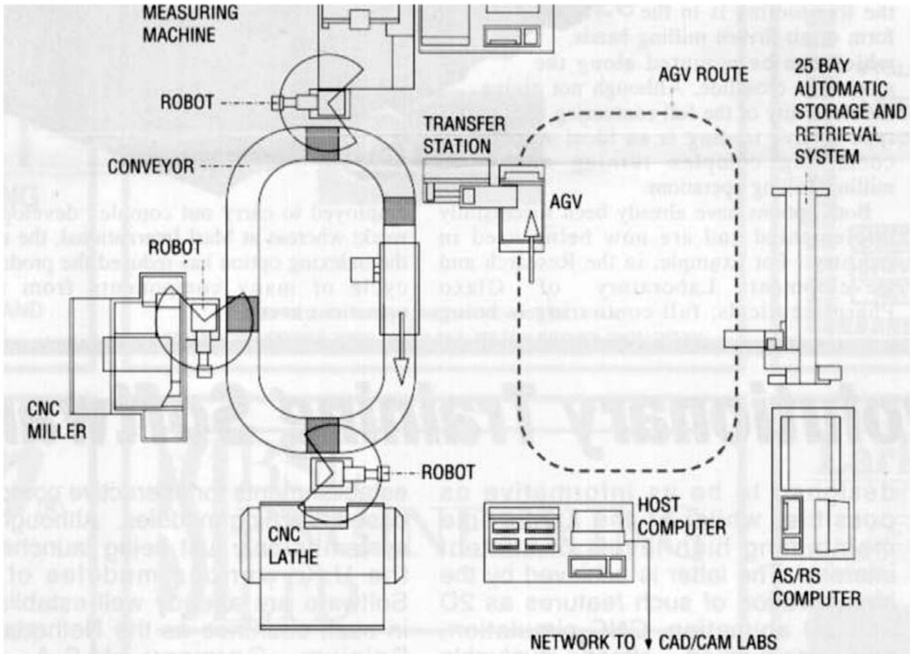

Fig. 1. The layout of a complex FMS (Denford Co., UK).

to consider events to take time rather than time to be related to conditions, that is, places (Bowden, 2000; Gharbi & Ioualalen, 2002; Murata, 1989; Zhou & Venkatesh, 1999). The time delays in a PN model can be specified either deterministically or probabilistically. If the time delays are deterministically given, such a PN model is called as deterministic timed net and if the delays are probabilistically specified, the PN model is called stochastic net. Timed PNs and stochastic PNs are two popular extensions of PNs which are widely used in the application field of manufacturing systems.

A stochastic PN (SPN) is a Petri net where each transition is associated with an exponentially distributed random variable that expresses the delay from the enabling to the firing of the transition. Due to the memoryless property of the exponential distribution of firing delays, Molloy (1982) showed that the reachability graph of a bounded SPN is isomorphic to a finite Markov chain. Queueing networks and Markov chains provide flexible, powerful and easy to use tools for modeling and analysis of complex manufacturing systems and are widely used (Al-Jaar & Desrochers, 1990). However, it is difficult to describe the causal relation of uncertain events explicitly in the complex models using Markov chain and queueing network models because of their unrealistic mathematical assumptions (Hatono, Yamagata, & Tamura, 1991). In SPN models, we can explicitly describe the causal relation of uncertain events by using places, transitions, and arcs. Therefore, using SPNs, we can construct the model of a FMS more easily than using the other models. SPNs combine the modeling power of PNs and the analytical tractability of Markov processes for the purpose of performance analysis (Molloy, 1982).

The limitation of the SPN is that the number of states of the associated Markov chain grows very fast as the complexity of the SPN model increases (Marsan, Bobbio, Conte, & Cumani, 1984, 1995). Marsan et al. (1984) introduced the generalized SPNs to reduce the complexity of solving a SPN model in which the number of reachable markings is smaller than that in a topologically identical SPN. A generalized SPN is basically a SPN with transitions that are either timed (to describe the execution of time consuming activities) or immediate (to describe some logical behavior of the model). Timed transitions behave as in SPNs, whereas the immediate transitions have an infinite firing rate and fire in zero time.

Petri (1987) presented some criticism related to timed and stochastic PNs about the conceptualization of time and chance. In his latter study Petri (1996) presented many axioms, among which the axioms of measurement and control related to time and nets, and emphasized mainly on uncertainty. These studies turned the attention on fuzzy set theory and fuzzy logic (Zadeh, 1965, 1973) which have been applied successfully in modeling and designing many real world systems in environments of uncertainty and imprecision.

There are several approaches that combine fuzzy sets and Petri nets theories, differing not only in the fuzzy tools used but also in the elements of the nets that are fuzzified. A PN structure is a four tuple consisting of places, transitions, tokens and arcs, and theoretically each of these can be fuzzified (Srinivasan & Gracanin, 1993).

Analysis and design of complex systems often involve two kinds of uncertainty: randomness and fuzziness (Hu, Wu, & Shao, 2002). Randomness refers to describing the behavior of the parameters by using probability distribution functions. In other words, the randomness models stochastic variability. Fuzziness models measurement imprecision due to linguistic structure or incomplete information. In modeling a FMS, input and model parameters are usually in the form of uncertain parameters. The possible sources of imprecision causing uncertainty in system modeling are system inputs, system outputs, and imprecise inner operations (Virtanen, 1995). In some cases, the uncertainty arises from both randomness (stochastic variability) and imprecision (fuzziness) simultaneously. SPNs in which time is the only random variable and time delay is described by probability functions well characterize the uncertainty in the system with the measures of variance and probability distributions. During the analysis, the uncertainty in parameter values can be hidden in the results. The use of fuzzy sets theory to be able to compensate this can be considered as an important alternative.

Although the dominating concept to describe uncertainty in modeling is stochastic models which are based on probability, probabilistic models are not suitable to describe all kinds of uncertainty, but only randomness. Especially the imprecision of data which is for example as a result of the limited precision of measuring is not statistical in nature and cannot be described by using