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Modelling a Manufacturing Line using Extended Object Oriented Bayesian Network

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Abstract: Bayesian Network (BN) is a widely used modelling tool in probabilistic reasoning; however it turns out to be difficult to use this tool to model a large scale complex system such as a manufacturing line due to the number of parameters when the system exceeds a certain amount of components. Motivated by the necessity to both reduce the complexity of the model while increasing the capacity of integrating a large number of parameters, this communication ambitions to propose a new modelling approach, called Extended Object Oriented Bayesian Network (EOOBN). The EOOBN is an underlying mathematical tool which has much more flexibility than classical Bayesian Networks. The main aim of the communication is then to present a methodology dedicated to EOOBN construction. After having introduced the main concepts and described the EOOBN building principles, an industrial application is proposed to illustrate the developments.

Keywords: complex system, modelling, Extended Object Oriented Bayesian Network, risk management

1. INTRODUCTION

Due to dynamic evolution of industrial production systems and the multiplicity of interactions among its constitutive elements, an abnormality or a component failure may result in a cascade phenomenon that can lead to unacceptable risks or to the collapse of such networked systems. Within this framework an efficient tool is required to assist decision-makers. The modelling tool should simulate the system's behaviour by considering all together the character dynamic and uncertain associated with the big amount of variables related to complex systems. Supplying such a decision support system becomes a challenge for researchers. Modelling risks requires indeed considering the nature of the relationships (influence, causality, etc.), the related uncertainties (about the existence of a relationship, of its intensity or even about the delimitation of the system under consideration), the evolution dynamic (modification over the time of the model structure and/or parameters) Kamissoko et al. (2011), Godichaud et al. (2012a),Bouzarour-Amokrane et al. (2015). Taking into account of all these characteristics, is likely to result to a complex and large scale system Pérès and Grenouilleau (2002),Godichaud et al. (2011). In this communication, we attempt to model such a system through an extension of Bayesian Network techniques subsequently referred as Extended Object Bayesian networks (EOOBN) based on components sharing a same structure. The main idea is first to use Bayesian networks properties to describe elementary components characterized by uncertainties of interactions among their constitutive variables. Then the whole system will be described by associating these components through object oriented mechanisms. This modelling approach will help monitoring and measuring the evolution of the system for a better understanding and controlling of its behaviour. The communication is structured as follows. Section 2 gives a brief overview of complex systems and Bayesian Networks. Section 3 presents the Extended Object Oriented Bayesian Networks (EOOBN) and its application in modelling a manufacturing line. Simulation results are provided. Finally, a conclusion and some perspectives are presented in the last section.

2. COMPLEX SYSTEMS AND BAYESIAN NETWORKS

2.1 Complex systems

A complex system is composed of a large number of components. These components are often interconnected through uncertain and dynamic relationships. The goal of this communication is to propose a new modelling approach for the characterization of these complex systems in order to evaluate the resulting performance when one or several components are either destabilized by an

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external event or affected by an internal issue. Such kind of model can be used to assess some key indicators and assist the decision making process. It can be applied to different domains such as economy, medicine, production and many other fields. In Amaral and Ottino (2004), the author points out issues related to classical modelling methods based on assumptions which eventually can skew the results by ignoring the aspects of interdependency, dynamic and size of the system. Finding another approach to simulate these complex systems when avoiding a great number of hypothesis is worth of research. Bayesian Networks are very efficient for modelling uncertainties. Meanwhile Dynamic Bayesian Network may be used when there is a temporal dimension in the system behaviour Murphy (2002). In the case of system with a huge number of components, a possibility to reduce this complexity is to use the so called Object Oriented Bayesian Networks (OOBN) in order to exploit possibilities offered by this modelling technique. The idea of modelling repeatable systems by object oriented techniques has been already considered in a certain number of studies such as Jaeger (2000),Weber and Jouffe (2006) to mention just a few. In the following paragraph, we introduce basics of static and dynamic Bayesian network characteristics.

2.2 Bayesian Networks

A Bayesian Network is a directed acyclic graph (DAG) that represents a certain relationships (in general causal relationships) between variables in a certain knowledge domain; each node represents a random variable associated with a conditional probability table (CPT) characterizing its parameters. Bayes theorem is the central theory in the mechanism of inference in Bayesian Networks. It permits to propagate some local observations through the graph in order to update a priori knowledge about the state of other nodes Nielsen and Jensen (2009), Pearl (1988). Figure 1 shows an example of a Bayesian Network which has three nodes A, B and C. The nodes A and B are the parents of C. There are two types of probability tables in a BN Godichaud et al. (2012b): prior probabilities tables for root variables (variables without parents) like A and B and conditional probabilities tables for variables with parents like C Godichaud et al. (2012a),Godichaud et al. (2012b). Indeed, a BN model is not only a static representation of knowledge but also a tool for the evidence inference which updates the probabilities in the network and enables the refinement of the results according to the observed situation Ben Hassen et al. (2013).

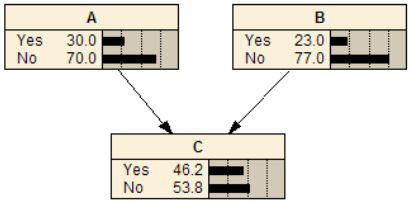

Fig. 1. Bayesian Network

Dynamic Bayesian Network In order to take into account of possible dynamic behaviour of systems, dynamic Bayesian networks (DBN), are introduced as a possible extension of a BN. The DBN is a series of time-slice BN corresponding to a Hidden Markov Model (HMM) Rabiner and Juang (1986),Murphy (2002). In the former example of Fig.1, if we assume that B evolves over time, so that the node B becomes a dynamic node then Fig.2 shows the corresponding DBN model with 2 time-slices, where the dynamic node is B_{t_i}. The communication between time-slices uses the transition model determined by a transition matrix A as:

- *the transition model:* $A = P(B_{t_i}|B_{t_{i-1}})$
- *the intial state:* $\pi = P(B_{t_0})$

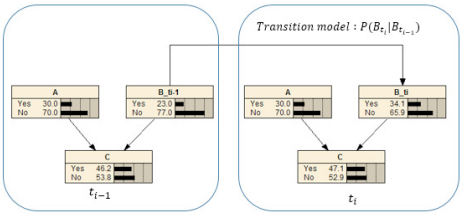

Fig. 2. Dynamic Bayesian Network with two time slices

Object Oriented Bayesian Network Using BN techniques for modelling risk assessment processes becomes all the time more complex when the size of the system increases. For a large scale system with many interacting elements, constructing a BN to represent its functioning behaviour may be very challenging. Meanwhile, when the size of network grows, the model visibility reduces and the update of parameter becomes burdensome. For this reason, an object oriented techniques might be an alternative to reduce the complexity by highlighting a generic pattern representative of the various dimensions of the problem. An object oriented Bayesian network (OOBN), is a direct application of the object paradigm Bangsø and Wuillemin (2000), Koller and Pfeffer (1997). The basic element is the class, fragment of a Bayesian network who has three sets of nodes: input, output and internal nodes see Figure 3. The input and output nodes are the interface of a class which can be seen from the outside.

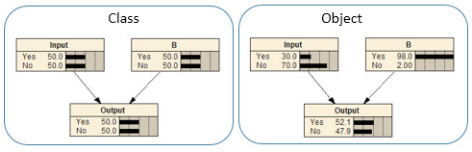

Fig. 3. Object Oriented Bayesian Network

The OOBN takes advantage of classic BN but introduces the concept of instance nodes. An instance node is an abstraction of a part of a network which can be used as an elementary component to represent the whole structure. The notion of encapsulation allows the transmission of all properties of the network fragment. An object oriented network can be viewed as a hierarchical description/model of a problem. This makes the modelling process easier since the OOBN-fragments at different levels of abstraction are more readable. An OOBN model can be built through expertise or by using learning techniques. In Langseth and Nielsen (2003) and Wuillemin and Torti (2012), the