System architecture design based on a Bayesian Networks method

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Abstract. The objective of the proposed method is to improve the decision making for system architecture design. In this purpose, Bayesian Networks (BN) models are defined in order to take into account the availability parameters of components and they economical aspects. The model allows a decision-making aide to rationalise the design of system architecture. Based on BN inference scenarios are simulated in order to compare different solutions.

1 Introduction

Assuming a system as a set of elements organises to achieve functionality, his comportment is described by a functional decomposition. The design objective is to propose the materials and the architecture to perform the required function, according to the technical requirements. In this purpose, the first step is a definition of the functional architecture, independent to the material aspects. Then, the functions are decomposed in elementary sub-functions. The following step is performed by the physical or software components choice (Conrard 1999). The design choices have impacts on the costs availability, security and quality of the system

Moreover recent works on system safety and Bayesian Networks (BNs) are published. Bouissou M. et al (1999) propose in the SERENE project (web link: http://www.hugin.dk/serene/) a hierarchical decomposition of the decision making model for system safety. In the other hand, the papers proposed by Bouissou (2000) and Bobbio et al. (2001) explain how the Fault Tree can be achieved using BNs. These works show the increasing interest in this new statistic model for the system safety community. The method proposed in this paper is based on the same BNs principles but applied in a design project context to estimate the cost's impacts of the decisions.

This paper is organised in four parts. After this introduction, the second part describes the design problem statement. The next part presents the different BNs models used for the decision making. The part four is dedicated to an application on simple example in order to prove the feasibility of this approach, and is following by the conclusion.

2 System Architecture design and safety

Several architectures carry out the required system functionality and compose a set of solutions. The design objective is to choose the system architecture, which allows the best compromise between cost, availability, quality and security. In the availability point of view, this choice needs to evaluate specifics indicators. For the sake of simplicity only availability is considered here. In the figure 1, the solution two is not the less expensive, but leads to a system more available. Considering availability as a potential increasing of the future production, the solution two or three can be interesting. It is then important to define a model allowing the comparisons between solutions in order to aide the designer in his decision making. This evaluation is classically based on expert judgements. Due to the uncertainty, it is difficult to propose a mathematical model. In the following, a BN model is proposed in order to evaluate costs and availability of different system architectures.

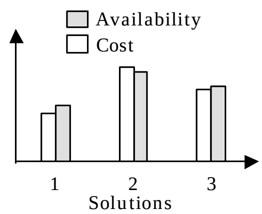

Fig. 1. Availability and Costs of 3 systems architectures.

To formalise this problem, the solution is defined as a pair of two entities: (*Components, Architecture*). The *Components* are specified by theirs parameters: the cost and the availability. These parameters can be computed using mathematical models (Markov model for instance) or evaluated by field data feedback (Lannoy (1996)). Therefore, a component i is defined by the following parameters:

- *The component cost* ($cost_i$) represents the global cost of the component i for a year. This cost includes corrective maintenance cost, component price, etc.
- *The component availability* (a_i) defined in a first approach considering a corrective maintenance method.

The *Architecture* is specified as a part of the preliminary architecture, which contains all its possible forms. The preliminary architecture corresponds to the more complex solution (Conrard (1999)) and allows the system redundancy, classically applied to increase the availability of the system. The best pair (*Components*, *Architecture*) is determined with regard to the global system cost and the system availability of each solution.

3 Bayesian Networks model

The BNs are a Directed Acyclic Graph (DAG) and are used to represent uncertain knowledge in Artificial Intelligence (Jensen (1996)). Usually, a BN is defined as a pair: G=((n,e),CPT), where (n,e) represents the DAG; “n” is a set of nodes, defined by different states; “e” is a set of directed edges describing the probabilistic dependencies between nodes. In this work, the considered nodes represent discrete random variables of the decision problem. In the pair G, each node is associated to a Conditional Probability Table (CPT) to quantify the dependencies between random variables as conditional probabilities. A node without parent is called a root node. The main interest of the BN appears when the economical aspects of the decision are taking into account. Jensen et al (1996) present the influence diagrams notion allowing the estimation of an utility function and the impacts of each decision are computed using this function. Therefore, the best decision is obtained by its maximisation.

Material cost evaluation

A Component node (C_i) is defined in the BN as root nodes and with two states “Available” or “Not Available”. In the decision making problem the decision can take two states: “Use” or “Not use” the component. This decision associated to C_i is modelled as a Decision node (D_i). According to the decision, the cost of the component is defined as a utility node (U_i). If the decision is “Not use”**,** then U_i and C_i are equal to 0. If the decision “Use” is chosen, then the U_i is affected by $cost_i$, and the probability associated to the state “Available” of C_i is equal to a_i. The graphical representation of this Influence Diagram is presented figure 2.

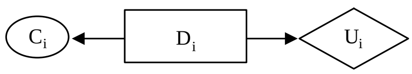

Fig. 2. Influence Diagram.

The CPT are defined in table 1, and the global architecture cost is computed summing all the utility nodes.

Decision node D_i	
Use	Not use

Utility node U_i	
Use	Not use
$cost_i$	0

Component node CPT		
Decision	Use	Not use
Available	a_i	0
Not available	1- a_i	1

Table 1. Components CPT definition.

System availability estimation

The system functionality (F_0) is a random variable defined by tow states: “Available” or “Not Available”. The probabilities of the F_0 states depend on the system structure with his redundancy and the components availability. Considering independent components and a coherent system, BNs allow to model the logic and the redundancy of the system. Then, BN inference estimates *the availability of the system functionality.* The BN structure is based on the functional decomposition of the system and the connections between the sub-functions are modelled by logical functions.

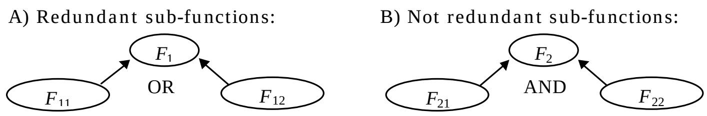

Fig. 3. Sub-functions connections.

A node (F_j) represents a function defined by tow states: “Available” or “Not Available”, and models connections between different sub-functions. The CPT of F_j are defined as noisy gates (OR/AND) (figure 3). In the case A, the “Available” of the function F_1 is calculated as follows:

$$P\left(F1 = Av. \middle| F11 = Av.,\ F12 = Av.\ \right) = 1 - \left(1 - P(F11 = Av.)\right) \cdot \left(1 - P(F12 = Av.)\right). \quad (1)$$

In the case B, the F_2 availability is calculated as:

$$P\left(F2 = Av. \middle| F21 = Av.,\ F22 = Av.\ \right) = P(F21 = Av.) \cdot P(F22 = Av.)\ . \quad (2)$$

Global cost impact

The system unavailable cost is computed using an approximation presented by Fougerousse and Germain (1992). Considering that the production is proportional to the system availability, the losses are due to the system unavailability. Assuming an operating time of one year and the system functionality available on this period, the maximum benefits due to the production sale is define as *S*, the energy and the raw materials costs *Ch* and the uncompressed charges Ch_0. The figure 4 represents the influence diagram, which evaluate the financial impacts of the F_0 availability, where utilities nodes represent the uncompressed charges (UC) which are constant, the material charges (MC) and the benefits (B) whose depend on the F_0 availability.

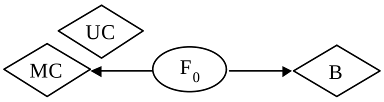

Fig. 4. Financial impacts of the system availability.

The BN inference allows the simulation of different scenarios. The global utility function is computed as:

$$U = P(F_0 = Av.) \cdot (S - Ch) - Ch_0 + \sum_{i / D_i = Use} (U_i) . \quad (3)$$

4 Application

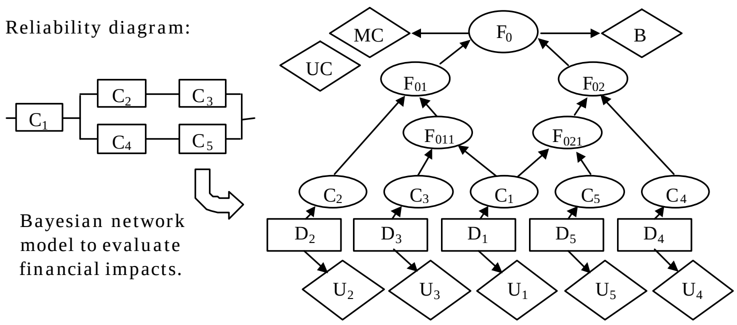

Fig. 5. System application.

The figure 5 presents the reliability diagram and the BN. A method allowing the computation of the different costs is defined in the paper written by Weber and Suhner (2001). The results are presented in the table 2.

Components	a_i	$cost_i$	*Ch*	Ch_0	*S*
C_1	0,989	980	80 kF	25 kF	1500 kF
C_2	0,986	2 160			
C_3	0,991	1 120			
C_4	0,991	1 020			
C_5	0,977	3 860			

Table 2. Cost definition.

The scenarios impacts are presented in the table 3. In regard to these results, the designer can conclude that the system architecture with redundancy is the most efficient. If no redundancy is possible, then the components C_2 and C_3 are more efficient than the components C_4 and C_5.

Scenarios	P(F_0=Av.)	Financial impact
With all components	0,988	+1 145 kF
Without C_4 and C_5	0,967	+1 120 kF
Without C_2 and C_3	0,959	+1 106 kF

Table 3. Inference results.

Conclusion

In this paper, a method using Bayesian Networks is proposed in order to take into account the expert knowledge. The model is based on parameters linked to the economical impact of the decisions and is simple and easy to construct. Moreover, it allows the aggregation of the availability parameters, classically computed with complex model, and the knowledge of the financier. Our attention is focused now on the enrichment of the model, in order to taking into account the qualitative parameters (as the production rate), as well as the maintenance strategy, with the aim to analyse their influences on the system.

References

BOBBIO A., PORTINALE L., MINICHINO M., and CIANCAMERLA E. (2001) Improving the analysis of dependable systems by mapping fault trees into Bayesian networks. *Reliability Engineering and System Safety*, *71*, 249-260.

BOUISSOU M., MARTIN F., and OURGHANLIAN A. (1999) Assessment of a Safety-Critical System Including Software : A Bayesian Belief Network for Evidence Sources. *RAMS'99 Reliability and Maintainability Symposium*. Washington.

BOUISSOU M. (2000) Deux méthodes originales pour calculer les performances d'un système possédant des états de fonctionnement dégradé. *lm 12, 12ème Colloque National de Sûreté de fonctionnement*, Montpellier, 28-30 mars, 205-212.

CONRARD B. (1999) Contribution à l'évaluation quantitative de la Sûreté de Fonctionnement des système d'automatisation en phase de conception. Thèse de Doctorat de l'Université Henri Poincaré Nancy I.

FOUGEROUSSE S., and GERMAIN J. (1992) *Pratique de la maintenance industrielle par le coût global*. AFNOR. Paris.

JENSEN F.V. (1996) *An Introduction to Bayesian Networks*. UCL Press. London.

LANNOY A. (1996) Analyse quantitative et utilité du retour d'expérience pour la maintenance des matériels et la sécurité. *Paris : Ed. Eyrolles*.

WEBER P. and SUHNER M.C. (2001) Aide au choix de strategie de maintenance par simulation de réseaux bayésiens.QUALITA 2001, Annecy, 22-23 Mars.