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iPresas: SOFTWARE FOR RISK ANALYSIS *

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1. INTRODUCTION

Risk based methodologies have gained wide acceptance in the recent years in the field of dam safety [2, 5]. However, there is not much software available for performing the risk analysis calculations which are central to these methodologies. In this article, the authors present the iPresas software [8], which covers this need. The software is useful to set up the risk model of a dam. It can then perform all the numeric calculations once the failure mode identification and probabilities estimations have taken place.

In the following sections, the methodology underlying the software is presented. Then, a risk analysis example is solved using iPresas.

* *iPresas: logiciel pour l'analyse des risques*

2. UNDERLYING METHODOLOGY

This section explains the theory behind the iPresas software. First, the two key concepts of event trees and influence diagrams are introduced and their relationship is explained. Then, the details of how influence diagrams can be built in the proposed methodology are developed.

2.1. EVENT TREES AND INFLUENCE DIAGRAMS

An **event tree** is an exhaustive representation of all the events and possibilities that can lead to the failure of a dam[1]. It is the preferred tool for carrying out the calculation of a failure probability or the risk associated to it.

Every branch of an event tree has a probability and one or more variable values associated to it. The probability of going from one point of the tree to another (usually from the tree root to one of the leaves) is obtained by multiplying the probabilities of all the traversed branches. The associated events are determined by the variable values of the traversed branches.

In this type of calculations, trees easily grow to have thousands of branches, making it impossible to manually define each branch. In order to overcome this problem, some researchers have chosen to use automatic techniques so that only some parts of the tree need to be defined. These parts are then cloned and copied by a software program following certain rules, therefore reducing the effort needed to specify an event tree. The iPresas software has followed a different path by using influence diagrams.

Influence diagrams are a compact conceptual representation of the logic of the dam system. In its most generic form, an influence diagram can be any graphic representation which includes the relationships between possible events, environment states, system and subsystem states and consequences. An influence diagram offers a visual representation of the risk model. In this kind of diagrams, each variable is represented by a node and each relationship by an arc.[2]

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[1] *A formal definition of a tree is (adapted from [6]): a finite set of one or more nodes such that there is one specially designated node called the root of the tree and the remaining nodes (excluding the root) are partitioned into zero or more disjoint sets, each of which is also a tree. These trees are called subtrees of the root. A node with no subtrees is called a leaf.*

[2] *There are methodologies which specify with detail how an influence diagram should be composed. For example: variables representing uncertainty should be drawn with circles or ellipses, variables representing decisions with squares or diamonds, cause relations with arrows (directed arcs), statistic correlations with dotted lines…*

Influence diagrams have two key advantages [3]:

- A complex problem can sometimes be represented with a simple influence diagram. Because influence diagrams represent each variable with a single node, the combinatorial explosion of branches which characterizes event trees is avoided.
- Influence diagrams explicitly show interrelationships between events. It is sometimes difficult to discern these interrelationships in event trees.

However, influence diagrams have traditionally been used only in early stages of a risk analysis, as a conceptual tool to aid in the structuring of ideas previous to the building of the final event tree. According to Hartford and Baecher [3]:

> "Influence diagrams and event trees are alternate representations for the same systems. It is often convenient to first structure a systems model as an influence diagram, and then to use the insight gained from the influence diagram to structure an event tree for the same system."

In contrast, the iPresas software enforces certain rules in the construction of influence diagrams so that they can then be automatically transformed into the corresponding event trees. iPresas is specifically tailored taking into account the specifics of risk analysis in the dam field. Some of iPresas features are as follows:

- Completely general: can be used to build event trees for any problem that may arise in the field of risk analysis applied to dam safety.
- Capable of doing the typical adjustments involved in dam event trees calculations (common cause adjustment, variable freezing).
- Represents the risk models of risk analysis in a clear, concise and visual way.

2.2. CORRESPONDENCE OF INFLUENCE DIAGRAMS AND EVENT TREES

Influence diagrams in iPresas must comply with the following rules:

- The diagram must be formed by *nodes* and *directed arcs*. See Fig. 1.
- A node is the *head* of the diagram if no arc goes into it. See Fig. 1.
- A diagram must have one and only one head. See Fig. 2.
- The diagram may not have cycles (but it may have closed loops and bifurcations). See Fig. 2.

The designed algorithm for transforming influence diagrams into event trees is recursive. In this algorithm each node of the influence diagram will expand into several branches of the event tree, starting with the head of the diagram and progressing "downstream" (in the direction of the directed arcs). The step by step process is illustrated for a simplified case in Fig. 3

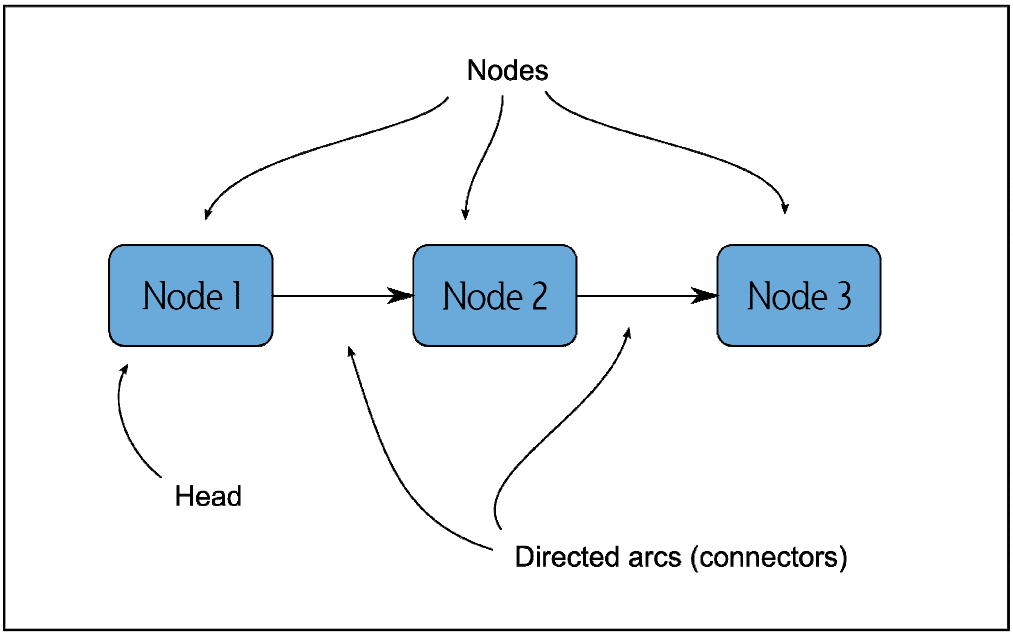

Fig. 1

Parts of an iPresas influence diagram.

Parties d'un diagramme d'influence iPresas

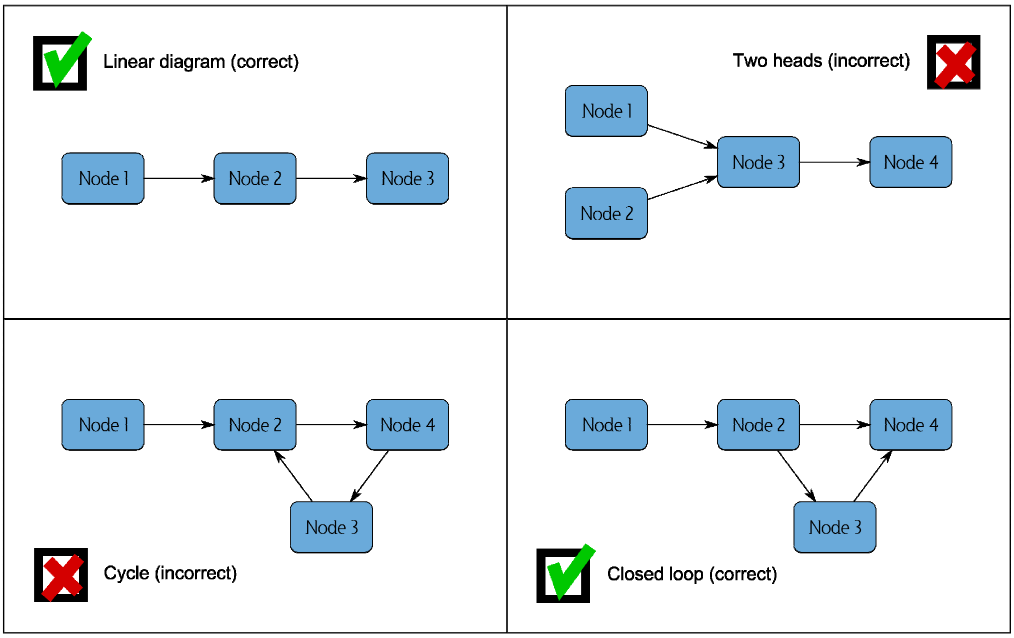

Fig. 2

Correct and incorrect simple iPresas influence diagrams.

Diagrammes d'influence simples iPresas corrects et incorrects

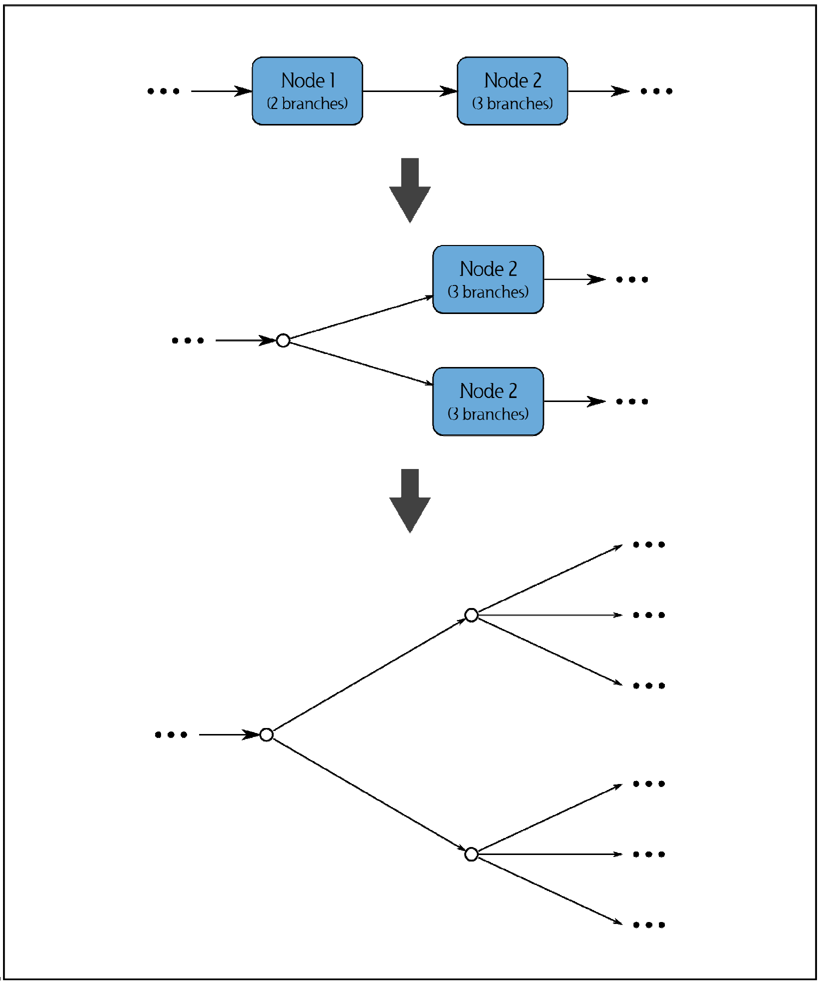

Fig. 3

Step by step transformation of a simple influence diagram into an event tree.

Transformation détaillée d'un diagramme d'influence simple en un arbre d'évènements

2.3. BASIC NODES

iPresas has four basic types of nodes which account for the typical needs of risk modeling in dam safety: *Discrete*, *FunProb*, *FunVal* and *ExcProb*.

Discrete nodes are the simplest. They are used when all the branches are completely known (both their probability and their variable values). For example, when modeling the consequences of a failure it might be important to take into account whether the failure happens during a weekend or not. A Discrete node can be used which will expand into two branches: one with probability 2/7 and variable weekend = yes and another one with probability 5/7 and variable weekend = no.

FunProb nodes are used when a yes/no situation occurs. They always expand into two branches and the probability of each branch is given by a function of previous variables. iPresas allows for this function to be specified in three ways: formula, 1D interpolation table or 2D interpolation table. A typical use of FunProb nodes is when determining whether the dam fails or not.

When obtaining some new variable as a function of previous ones, **FunVal nodes** can be used. They always expand into a single branch. As with FunProb nodes, the function can either be specified with a formula or 1D/2D interpolation table. FunVal nodes can be used for instance when calculating the downstream damages as a function of the peak discharge.

ExcProb nodes are used when the relationship between variables and probabilities is given in terms of exceedance probabilities, as is usual for maximum pool levels or peak ground accelerations. This node allows for an easy variation of the number of branches it will expand into, which will be determined by numerical stability constraints.

2.4. BRANCHING INFLUENCE DIAGRAMS

There are times when an event tree branches in such a way that the subtrees of a certain node are qualitatively different from each other. To reflect this fact in the influence diagram it is necessary to branch the influence diagram itself. In this case, each of the diagram's branches represents a different subtree of the event tree.

When the influence diagram is transformed into the event tree, it must know which of the influence diagram's branches to expand at each point, so certain conditions must be imposed on the connectors of a branching influence diagram, see Fig. 4.

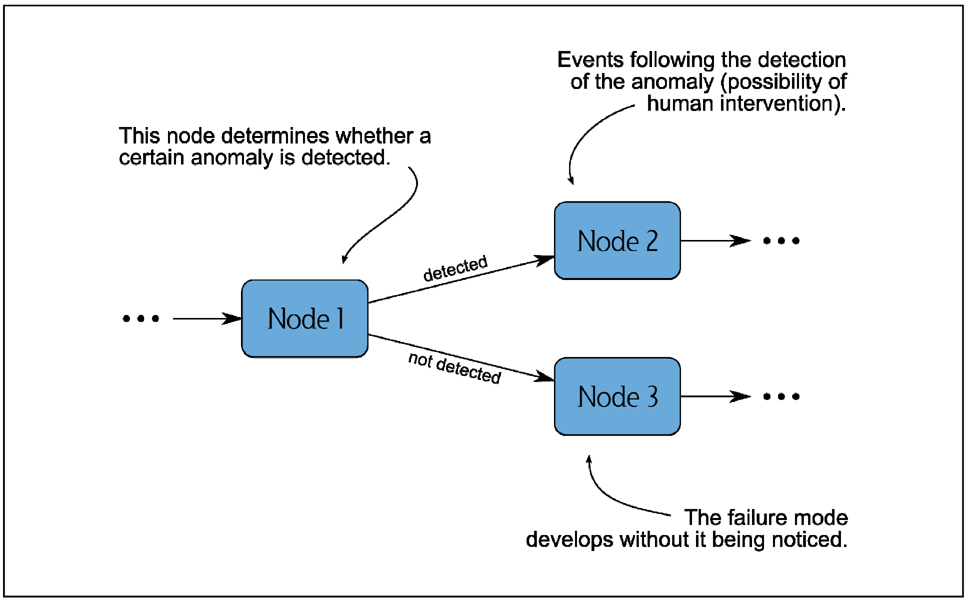

Fig. 4
Branching influence diagram example.
Exemple de ramification d'un diagramme d'influence

2.5. TAKING DIFFERENT FAILURE MODES INTO ACCOUNT

Since a dam can not fail in more than one way at a time, when taking into account different failure modes, certain adjustments must be made. The math and justification of these adjustments can be read, for example in [4]. iPresas allows for these adjustments to be made with the use of a special kind of node: the **MutExc node.**

When using this node, the influence diagram branches into the different failure modes immediately following it. The options for which type of *common cause adjustment* and whether or not to perform variable freezing are selected on the node. The example presented below showcases this type of node.

3. PERFORMING A RISK ANALYSIS WITH IPRESAS

In this section, a risk analysis is performed with the aid of iPresas. The problem is a part of the application case in the PhD dissertation of Manuel G. de Membrillera [1]. First, the problem is briefly presented. Then a solution is offered which exactly matches the one provided in the dissertation. Finally, taking advantage of the power and flexibility of iPresas, a much more numerically efficient solution is explored.

3.1. PROBLEM DEFINITION

In the PhD dissertation, a risk analysis of a concrete gravity dam is performed. The existing situation is modeled and seven risk-reduction measures are also modeled and compared. For each case, the seismic and the hydrologic scenarios are calculated. The uncertainty of the input parameters is taken into account by means of a formal uncertainty analysis.

All of these results have been reproduced with iPresas as a validation of its methodology, but this article will focus on the hydrologic scenario of the existing situation.

The results to be compared will be the probability of failure and the incremental damages resulting from the failure of the dam, including both loss of life and economic losses. The data used is:

- The relationship between annual exceedance probability, maximum pool level, maximum discharge rate if the dam fails and maximum discharge rate if the dam does not fail. The dam's spillway has four gates, and their reliability has been taken into account, so the described relationships have been obtained for the five possibilities of gate operativity (zero to five operative gates). The previous pool level has also been taken into account.
- The relationship between maximum pool level and failure probability for each of the studied failure modes. Seven failure modes are considered: toe erosion, internal erosion, hydromechanic failure and four different stability modes.
- The relationship between damages (life loss and economic damage) and maximum discharge rate. This relationship also takes into account the time of day (day/night) and the season. For a detailed explanation of the methodology behind the damage relationships, see [7].

3.2. SOLUTION OF THE PROBLEM

The first step for solving the problem with iPresas is drawing the influence diagram. See Fig. 5. The first node of the diagram is an *ExcProb* node, representing the maximum pool level and associated discharge rates.

The hydrology node is followed by the nodes describing the failure modes. Since the failure probabilities have been preprocessed and the data has been condensed into a direct relationship between maximum pool level and failure probability, each failure mode can be represented by a single *FunProb* node. However, this may not be the case in general. In order to account for overlapping probabilities of the failure modes, a *MutExc* node must be introduced previous to the branching of the influence diagram into seven *FunProb* nodes.

Next, the consequences are introduced. Since the consequences are qualitatively similar for the seven failure modes, the influence diagram can be merged again into a single branch. This branch starts with two *Discrete* nodes for the season and time of day. Then there are three *FunVal* nodes for life loss and three for economic damages. Of the three nodes, one represents the damage in the case that the dam fails, the other the damage in the case that the dam does not fail and the other the incremental damages.

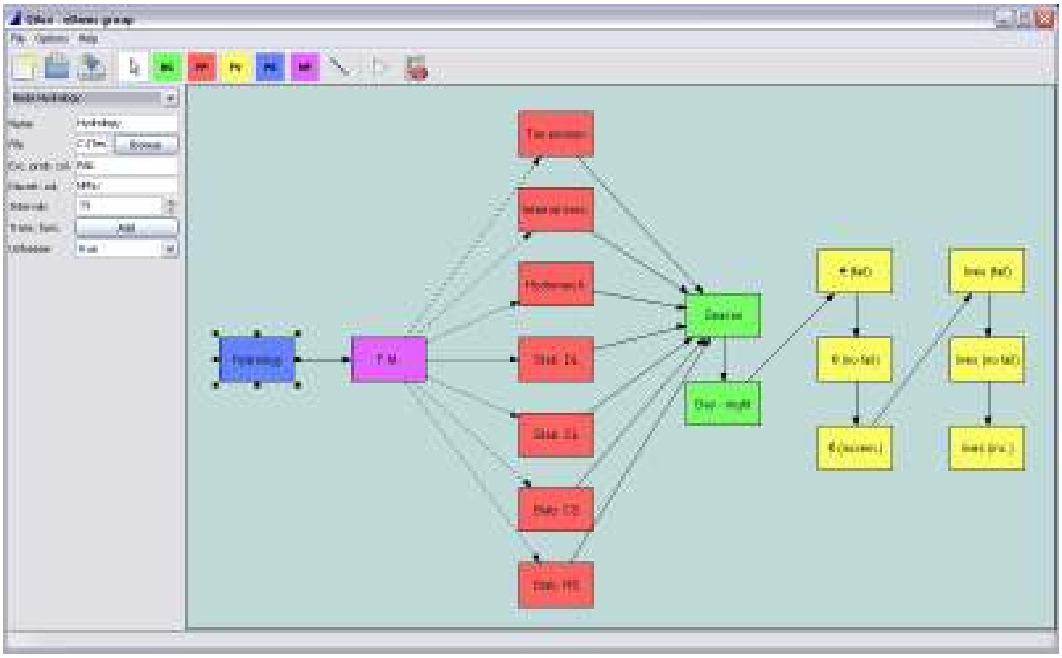

Fig. 5
Influence diagram for the studied problem.
Diagramme d'influence pour le problème étudié.

Once the influence diagram is drawn, the data has to be associated with each node. This can be done via text files or by links to a spreadsheet. The program is very flexible and powerful in this respect (see the iPresas manual for more details [8]). Also, several options have to be selected for each node. Of these options, two deserve special attention.

The first one is the common cause adjustment. This is selected in the *MutExc* node, and for this problem, the average of the upper and lower limits was selected. Again, refer to [4] or [1] for more details.

The second one is the number of branches into which the hydrology node expands. The higher this number is, the higher the numerical precision of the result will be. This matter is discussed further in the next section. In order to reproduce the results, the same discretization (80 branches) was used.

Finally, the analysis can be run, obtaining the results shown in **Erreur ! Source du renvoi introuvable.**. Since there is a direct correspondence between event trees and influence diagrams, the internal calculations which take place end up being the same as in [1] and so the results match exactly.

Table 1
Results summary.
Résumé des résultats.

	Probability	Risk (lives)	Risk (euros)
Stab. CL	2.632E-04	4.238E-02	5.304E+04
Stab. CS	1.470E-04	2.382E-02	2.996E+04
Internal eros.	4.134E-08	6.231E-06	7.981E+00
Stab. RS	2.055E-08	3.230E-06	4.076E+00
Hydromech.	7.996E-08	1.241E-05	1.568E+01
Stab. DL	3.904E-09	6.035E-07	7.641E-01
Toe erosion	1.279E-10	6.975E-08	7.647E-02
Total	4.103E-04	6.622E-02	8.303E+04

3.3. Improvement of the solution

When expanding an *ExcProb* node, the relationship between the probability - Anual Exceedance Probability (AEP) in this case - and the variable(s) - Maximum Pool Level (MPL) in this case - has to be discretized into intervals. Each of these intervals is converted into one branch whose probability is AEP_i - AEP_{i+1} and whose variable value is $(MPL_i + MPL_{i+1})/2$.

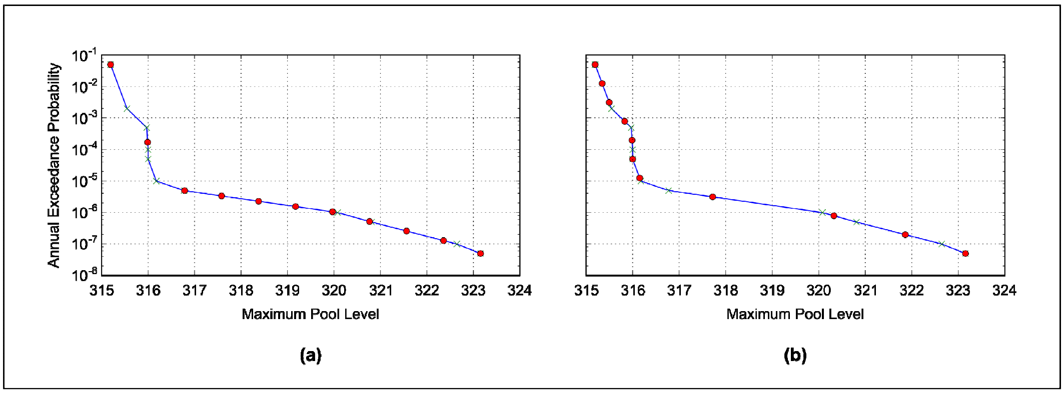

Fig. 6
Two possible discretizations of the MPL-AEP relationship.
Deux discrétisations possibles pour la relation MLP-AEP

Usually, the discretization is done so that the intervals are equally spaced on the *x* axis (MPL) as shown in Fig. 6.a. This was the case in [1]. However, the authors have found that by taking intervals which are equally spaced on the *y* axis (logarithm of AEP) as shown in Fig. 6.b, the number of intervals for which a certain level of precision was obtained could be reduced by an order of magnitude (Fig. 7). This is not a general rule, as the optimal distribution of intervals will be different for each case.

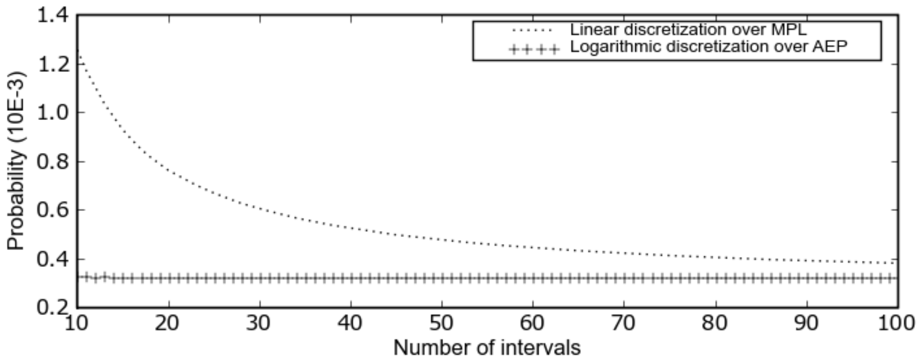

Fig. 7
Precision comparison between two types of discretizations.
Comparaison de précision entre deux types de discrétisations.

CONCLUSIONS

The iPresas software introduces a new methodology for constructing risk models. By using influence diagrams instead of directly using event trees, a clear, concise and visual workflow has been achieved. The iPresas software takes over the job of building and calculating the event trees, which previously required a large amount of time and effort dedicated to specially crafted spreadsheets. Therefore, iPresas is a crucial step in the transition of Risk Analysis from the research domain to applied engineering.

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SUMMARY

iPresas is a new software for risk analysis. The software is based on the idea of influence diagrams and can be used to build risk models for any problem that may arise in the field of risk analysis applied to dam safety. The theory behind the software is presented and a risk analysis example is solved. Besides being able to represent risk models in a clear, concise and visual way, the power of the software allows to explore numerically efficient solutions.

RÉSUMÉ

iPresas est un nouveau logiciel pour l'analyse des risques. Ce logiciel est basé sur le concept des diagrammes d'influence et peut être utilisé dans la construction de modèles pour tout problème pouvant se présenter dans le domaine de l'analyse des risques appliquée à la sécurité des barrages. Cet article présente la base théorique du logiciel et développe un exemple d'analyse de risques. Outre la représentation visuelle claire et concise de modèles de risques, ce logiciel permet également d'explorer des solutions efficaces au niveau numérique.