

Expert judgments collecting and modeling: application to the Integrated Risks Analysis methodology

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Expert judgments collecting and modeling: Application to the IRA methodology

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3rd International Workshop on
Dependable Control of Discrete Systems
June 15 – 17, 2011, Saarbrücken, Germany



1. Problem statement
    - General context
    - Principle of IRA methodology
    - Highlighting issues of the problem of uncertainty

2. Uncertainty modeling frameworks
    - Typology of uncertainties
    - Probability, Interval and Evidence theories

3. Application and discussions on a case study

4. Conclusion and Perspectives



1. Problem statement

- **General context**
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General context

- Industrial risks analyses are becoming increasingly complex
  - Increasing number of components and their interactions
  - Recognition of employees and the organization acting on them
  - ...



Three Mile Island (1979)



Tchernobyl (1986)



Fukushima (2010)

- Need to deal with several sectors in a same approach
  - Correlated hazards (technical, environmental, human, organisational)
  - Influences on different issues (safety, availability, etc.)

General context

1996 SAM [Paté-Cornell et Murphy, 1996]

1997, 1998, 1999 — I-Risk (European Project, 1996-1999)

2000

2001 ARAMIS (European Project, 2001-2004)

2002 GLORIA [Deleuze, 2002] / AcciMap [Svedung et Rasmussen, 2002]

2003 I-Risk [Papazoglou et al., 2003] / [Delmotte, 2003]

2004, 2005, 2006, 2007 — MIRIAM - ATHOS [Plot, 2004] / ARAMIS [Andersen et al., 2004]; SHAPERISK (European Project, 2004-2007); EPS + organizational factors [Galàn et al., 2007]

2008 Workload analysis [Gregoriades et Sutcliffe, 2008] / [Lee et al., 2008]

2009 **IRA [Léger et al., 2009]**

2010, 2011 — **IRA (PhD G. Fallet, 2009-2012)** / iNTeg-Risk (European Project, 2009-2012)

Principle of IRA methodology

- Developed by EDF in partnership with CRAN & INERIS
  - Including technical, human, organisationnal and environmental components
  - Taking into account all the risks of each areas and all of their interactions

  ➔ Assessment of various issues: safety, availability, etc.

- Main objectives
  - … prioritizing the different types of risks
  - … helping the choice of prevention or mitigation barriers
  - … helping the decision-making
  - … contributing to the risk communication

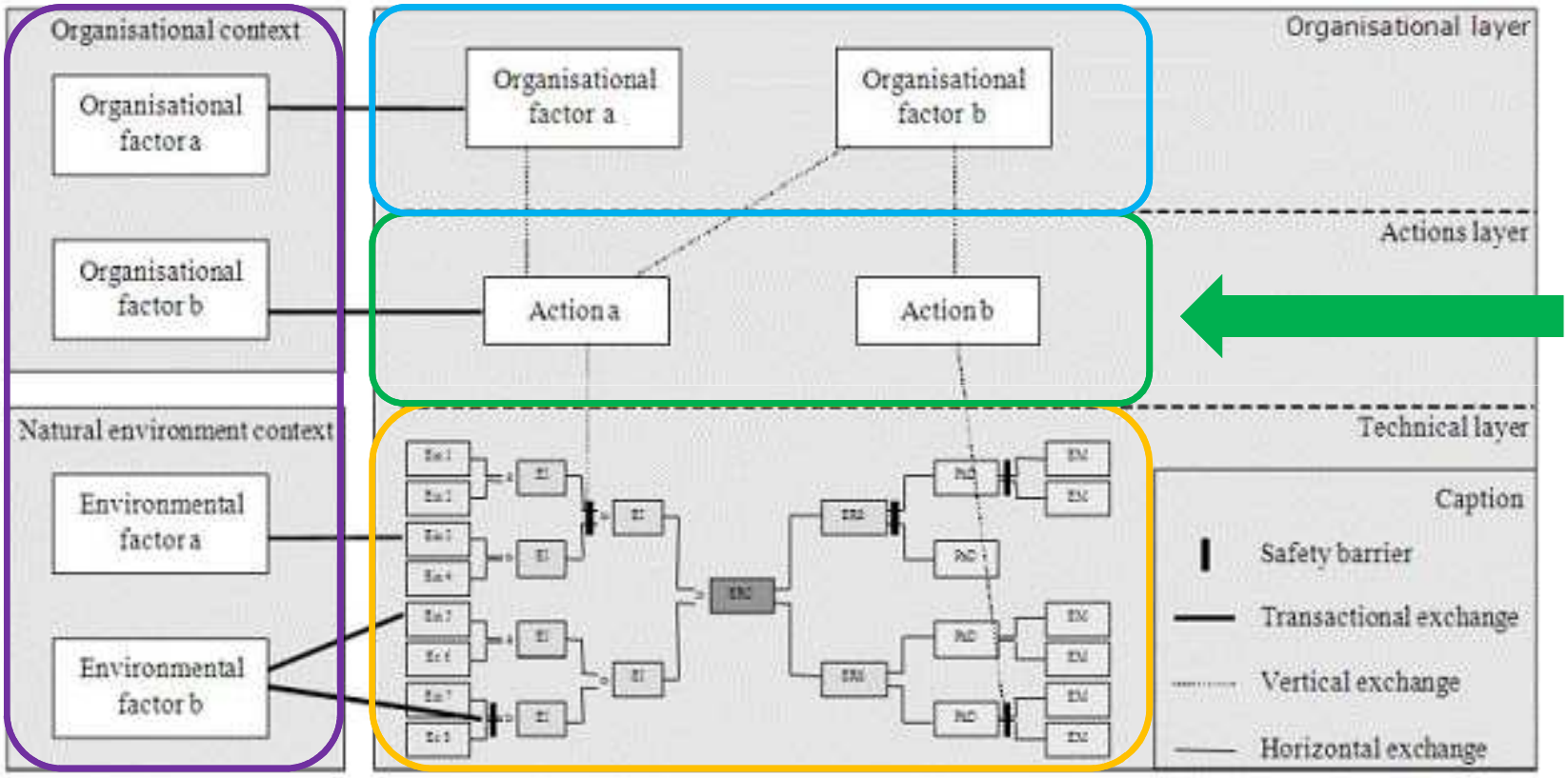
Principle of IRA methodology

- Conceptual framework (based on [Paté-Cornell & Murphy,1996])

Pathogenic Organizational Factors

Poor handling of organisational complexity

Production pressures …



Items

- *Delegation*
- *Experience*
- *Training*
- *Aids*
- *..*

Bow-tie (Faults Tree + Events Tree)

Diapositive 7

S1 Titre

Tout dépend de ce que tu vas dire avec ce slide.
SIMON ; 24/05/2011

Highlighting issues of the problem of uncertainty

- Technical and Environmental assessment
  - Through the use of statistical distribution
    - Data of experience feedback, probability distributions, etc.
    - Modeling of physico-chemical variables (temperatures, flows, etc.)
- Human and Organisational assessment
  - Through the use of expert judgments
    - Degradation or non degradation of items
    - Presence or absence of POFs

➔ Collection of expert judgments in IRA via elicitation grids

- Constrain the expert to choose only one pre-defined single value

- Objectives
  - How to collect and model the expert's knowledge in a less biased way?
  - How to implements tools to collect and handle expert judgments?

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Impact	Influencing factor
No impact	1
Little impact	0,75
Medium impact	0,5
Important impact	0,25
Total impact	0

➔ Collection of expert judgments in IRA via elicitation grids
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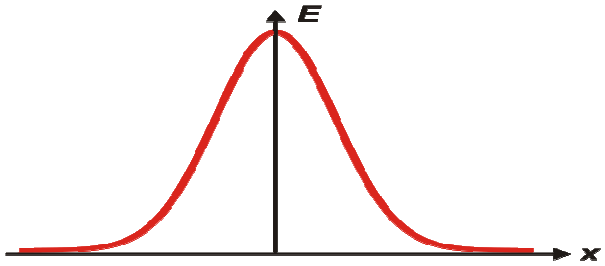
2. Uncertainty modeling frameworks
   - **Typology of uncertainties**
   - **Probability, Interval and Evidence theories**

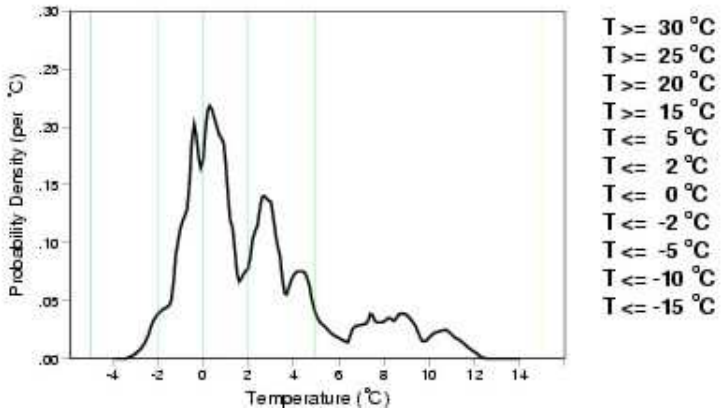
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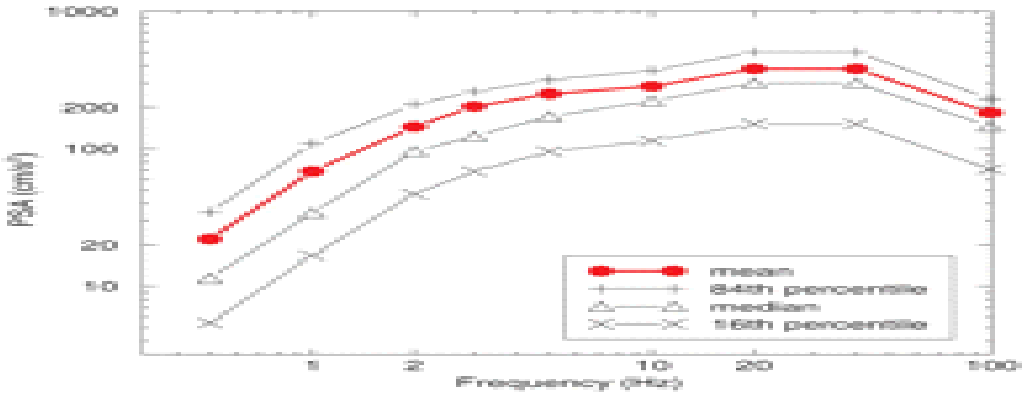
Uncertainty modeling

- Typology of uncertainties [Hoffman and Hammonds,1994]
  - Random uncertainty
    - Due to natural variability of a physical phenomenon *(e.g. failure rates, physico-chimical variables …)*





  - Epistemic uncertainty
    - Due to the imprecise or incomplete character of the information or a lack of knowledge *(imprecision, ignorance (partial or total), incompleteness)*



Uncertainty modeling

- Five types of knowledge expression

  - Hard evidence : the expert is able to choose with certainty one hypothesis
    → *Component in « Failure 1 »*
  - Soft evidence : the expert encodes his knowledge by attributing a prior distribution
    → *P(Failure1) = 0.8 / P(Failure2) = 0.2*
  - Imprecision : the expert cannot express a precise value
    → *P(Failure1) ∈ [0.7;0.8]*
  - Partial ignorance : the expert partially ignores the distribution on the modalities
    → *Component in « Failure1 » or « Failure 2 »*
  - Total ignorance : the expert totally ignores the repartition on the modalities
    → *Component state is unknown*

H_1 : no failure
H_2 : failure 1
H_3 : failure 2

Uncertainty modeling

- Probabilistic vs. Non-probabilistic theories

  - Probability theory is the usual framework for uncertainty representation

  - Introduction of new uncertainty modeling frameworks in the last decades
    - Possibility theory [Zadeh, 1977]
    - Intervals theory [Moore,1966]
    - Evidence theory [Dempster,1967]
    - …

  - Aims at better handling the different types of uncertainties

  ➔ **Can be used to manipulate data from expert judgments**

Uncertainty modeling - Basics

- Probability theory
  - Possible events H_i
    - Mutually exclusive and exhaustive
  - Possible events space Ω
    - $\Omega=\{H_1,\ldots,H_q\}$
  - Probability assignment function
    - $p : \Omega \rightarrow [0;1]$ such as $\sum p(H_i) = 1$

H_1 : no failure
H_2 : failure 1
H_3 : failure 2

- Interval theory [Moore,1966]
  - Deals only with the problems of imprecision
  - Extension of conventional arithmetic operators
    - Consider tree intervals [a], [b] and [c] with bounds $[a_1;a_2]$, $[b_1;b_2]$ and $[c_1;c_2]$
      - $[c] = [a] + [b]$ then $c_1 = a_1 + b_1$ and $c_2 = a_2 + b_2$
      - $[c] = [a] - [b]$ then $c_1 = a_1 - b_1$ and $c_2 = a_2 - b_2$
      - $[c] = [a] * [b]$ then $c_1 = \min(a_1 * b_1; a_1 * b_2; a_2 * b_1; a_2 * b_2)$
        $c_2 = \max(a_1 * b_1; a_1 * b_2; a_2 * b_1; a_2 * b_2)$

Uncertainty modeling - Basics

- Evidence theory [Dempster,1967] [Shafer,1976]
  - Possible events H_i
    - Mutually exclusive and exhaustive
  - Possible events space Ω
    - $\Omega=\{H_1,\ldots,H_q\}$
  - Powerset 2^{Ω}
    - $2^{\Omega}=\{H_1,\ldots,H_q,\{H_1, H_2\},\ldots, \{H_1,\ldots,H_q\}\}$
  - Mass assignment function
    - $m : 2^{\Omega} \rightarrow [0;1]$
  - Dual measures
    - Belief (Bel) : degree of credibility on a hypothesis H_i
    - Plausibility (Pls) : quantity of belief that would not contradict the hypothesis H_i

H_1 : no failure
H_2 : failure 1
H_3 : failure 2

$$Bel(H_i) = \sum_{H_j | H_j \subset H_i} m(H_j)$$

$$Pls(H_i) = \sum_{H_j | H_j \cap H_i \neq \emptyset} m(H_j)$$

$$Bel(H_i) \leq P(H_i) \leq Pls(H_i)$$



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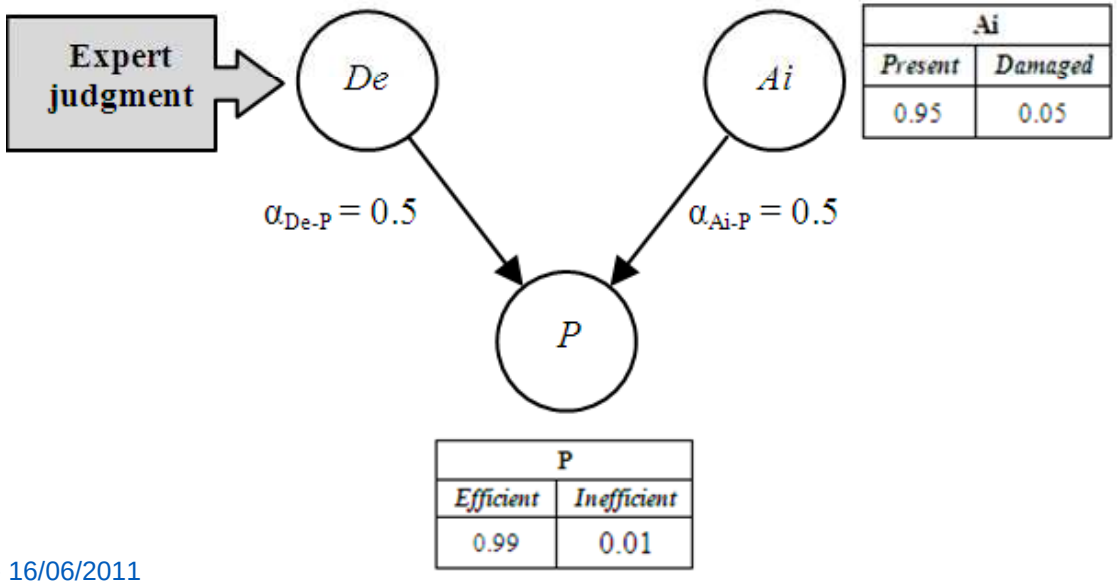
4. Conclusion and Perspectives

Case study

- IRA Risks model based on Bayesian Networks

- Focusing on an elementary pattern of IRA
  - Relationship between human and technical components
  - Focus on the assessment of item *De* by expert judgment *(consider item Ai and influencing factors perfectly known)*

➔ Efficiency of the preparation phase P ?



Ai	
Present	*Damaged*
0.95	0.05

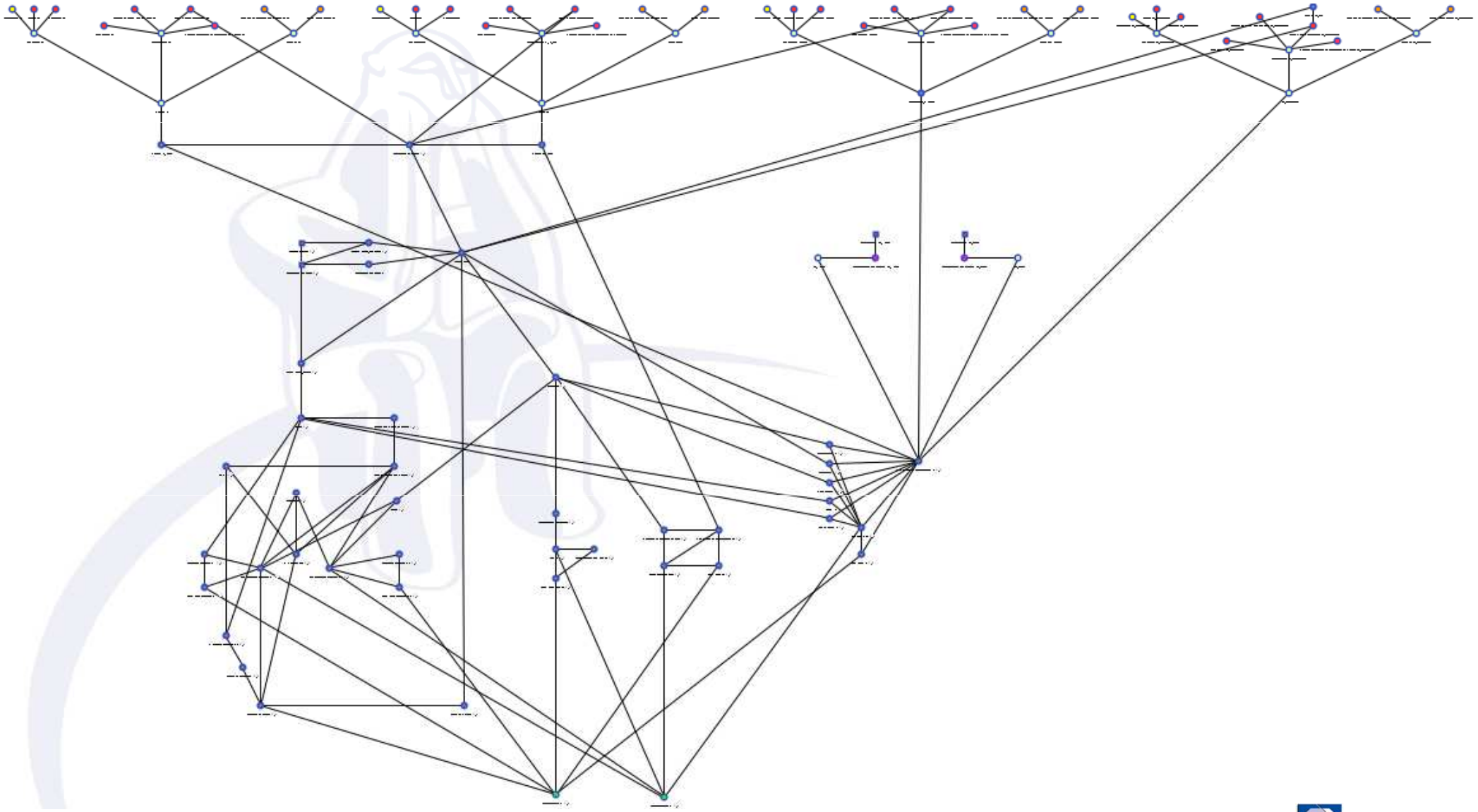
P	
Efficient	*Inefficient*
0.99	0.01

Items *De* and *Ai*
{*Present*}
{*Damaged*}

Preparation phase *P*
{*Efficient*}
{*Inefficient*}

Influencing factors
α_{De-P}
α_{Ai-P}

Integrated Risk Analysis (IRA) model



Diapositive 18

S2 Inexploitable pour le public. Tu devrais ajouter des éléments pour définir ce dont il s'agit. Mets des cercles et dit ce que représente telle ou telle zone du réseau

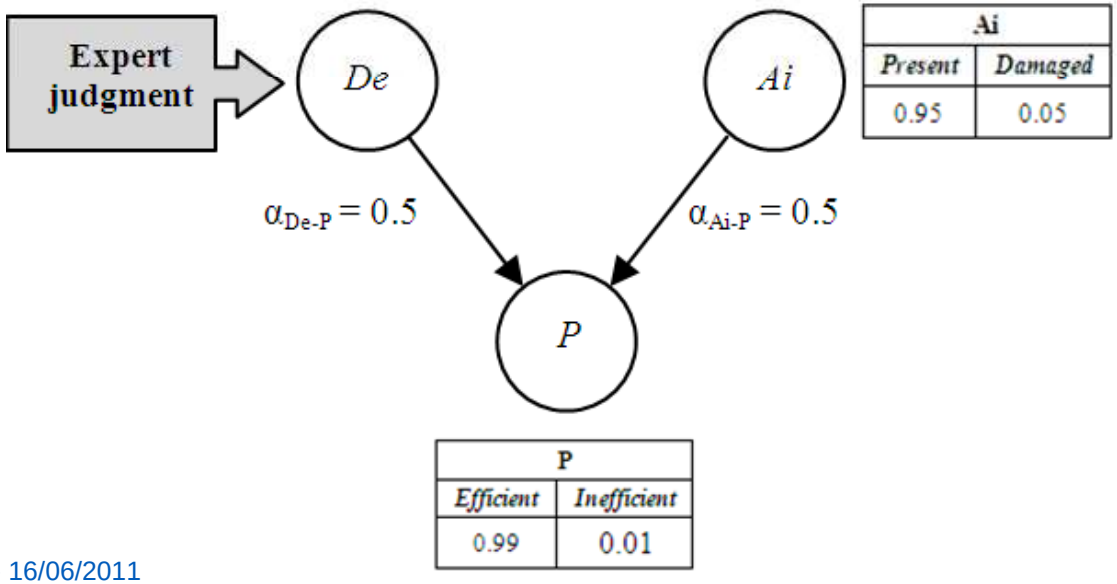
SIMON ; 24/05/2011

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Ai	
Present	*Damaged*
0.95	0.05

P	
Efficient	*Inefficient*
0.99	0.01

Items *De* and *Ai*
{*Present*}
{*Damaged*}

Preparation phase *P*
{*Efficient*}
{*Inefficient*}

Influencing factors
α_{De-P}
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Case study

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➔ Efficiency of the preparation phase P ?

TABLE I. RELATIONS BETWEEN *DE*, *AI* AND *P*

De	Ai	P	
		{*Efficient*}	{*Inefficient*}
{*Present*}	{*Present*}	0.99	0.01
{*Present*}	{*Damaged*}	$0.99 * \alpha_{Ai\text{-}P}$	$1\text{-}0.99 * \alpha_{Ai\text{-}P}$
{*Damaged*}	{*Present*}	$0.99 * \alpha_{De\text{-}P}$	$1\text{-}0.99 * \alpha_{De\text{-}P}$
{*Damaged*}	{*Damaged*}	$0.99 * \alpha_{De\text{-}P} * \alpha_{Ai\text{-}P}$	$1\text{-}0.99 * \alpha_{De\text{-}P} * \alpha_{Ai\text{-}P}$

Leaky Noisy-OR

Items *De* and *Ai*
{*Present*}
{*Damaged*}

Preparation phase *P*
{*Efficient*}
{*Inefficient*}

Influencing factors
$\alpha_{De\text{-}P}$
$\alpha_{Ai\text{-}P}$

Case study - Type of knowledge

- Hard evidence

The expert is able to choose with certainty one modality of *De*

- Soft evidence

The expert encodes his knowledge by attributing a prior distribution on *De*

- Imprecision

The expert cannot express a precise value

- Partial ignorance

The expert partially ignores the distribution on the modalities of *De*

- Total ignorance

The expert totally ignores the repartition on the two modalities of *De*

Case study - Encoding

Knowledge expression	De	Modeling framework		
		Probability theory	*Interval theory*	*Evidence theory*
Hard evidence	{*Present*}	1	[1;1]	1
	{*Damaged*}	0	[0;0]	0
	{*Present, Damaged*}	-	-	0
Soft evidence	{*Present*}	0.7	[0.7;0.7]	0.7
	{*Damaged*}	0.3	[0.3;0.3]	0.3
	{*Present, Damaged*}	-	-	0
Imprecision or partial ignorance	{*Present*}	0.75	[0.7;0.8]	0.7
	{*Damaged*}	0.25	[0.2;0.3]	0.2
	{*Present, Damaged*}	-	-	0.1
Total ignorance	{*Present*}	0.5	[0;1]	0
	{*Damaged*}	0.5	[0;1]	0
	{*Present, Damaged*}	-	-	1

Knowledge	Expression
Choosing only one hypothesis H_i	$p(H_i) = 1$
Uncertainty	$p(H_i) < 1$
Total ignorance	$p(H_i) = 1/q \ \forall \ i = 1…q$ (principle of indifference [Keynes, 1921])
Incompleteness	Impossible (events H_i are exhaustive)

Probability theory

Knowledge expression	De	Modeling framework		
		Probability theory	*Interval theory*	*Evidence theory*
Hard evidence	{*Present*}	1	[1;1]	1
	{*Damaged*}	0	[0;0]	0
	{*Present, Damaged*}	-	-	0
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Total ignorance	{*Present*}	0.5	[0;1]	0
	{*Damaged*}	0.5	[0;1]	0
	{*Present, Damaged*}	-	-	1

Knowledge	Expression
Certainty	$X \in [X_i;X_i] \rightarrow X = X_i$
Imprecision	$X \in [X_i;X_j]$
Total Ignorance	$X \in [0;1]$

Interval theory

Knowledge expression	De	Modeling framework		
		Probability theory	*Interval theory*	*Evidence theory*
Hard evidence	{*Present*}	1	[1;1]	1
	{*Damaged*}	0	[0;0]	0
	{*Present, Damaged*}	-	-	0
Soft evidence	{*Present*}	0.7	[0.7;0.7]	0.7
	{*Damaged*}	0.3	[0.3;0.3]	0.3
	{*Present, Damaged*}	-	-	0
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Total ignorance	{*Present*}	0.5	[0;1]	0
	{*Damaged*}	0.5	[0;1]	0
	{*Present, Damaged*}	-	-	1

Knowledge	Expression
Choosing only on hypothesis H_i	$m(H_i) = 1$
Partial ignorance	mass m different from 0 on a subset of Ω
Total ignorance	$m(\Omega) = 1$ (least commitment principle)
Incompleteness	$m(\varnothing) \neq 0$

Evidence theory

Knowledge expression	De	Modeling framework		
		Probability theory	*Interval theory*	*Evidence theory*
Hard evidence	{*Present*}	1	[1;1]	1
	{*Damaged*}	0	[0;0]	0
	{*Present, Damaged*}	-	-	0
Soft evidence	{*Present*}	0.7	[0.7;0.7]	0.7
	{*Damaged*}	0.3	[0.3;0.3]	0.3
	{*Present, Damaged*}	-	-	0
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	{*Damaged*}	0.5	[0;1]	0
	{*Present, Damaged*}	-	-	1

Case study - Encoding

- **Difference depending on the modeling framework …**

Knowledge expression	De	Modeling framework		
		Probability theory	*Interval theory*	*Evidence theory*
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Total ignorance	{*Present*}	0.5	[0;1]	0
	{*Damaged*}	0.5	[0;1]	0
	{*Present, Damaged*}	-	-	1

Same expression for the same assessment

Different expression for the same assessment

Case study - Encoding

- The expert knows that " the occurrence of modality {*Present*} of the item *De* is between 0.7 and 0.8 " (imprecision)

Knowledge expression	De	Modeling framework		
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	{*Present, Damaged*}	-	-	0.1

If it is asked to choose only one modality

If the expert can express his knowledge on two modalities

If the expert can express the imperfection of his knowledge

➔ **… depending on the type of collection of expert knowledge**

Case study - Simulation

- The expert knows that " the occurrence of modality {*Present*} of the item *De* is between 0.7 and 0.8 " (imprecision)

Knowledge expression	De	Modeling framework		
		Probability theory	*Interval theory*	*Evidence theory*
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	{*Present, Damaged*}	-	-	0.1

Collection Bias
if imprecision

Modelisation Bias
if imprecision

Case study - Simulation

- The expert knows that " the occurrence of modality {*Present*} of the item *De* is between 0.7 and 0.8 " (imprecision)

Modeling framework	*P*	Knowledge expression		
		Hard evidence	*Soft evidence*	*Imprecision*
Probability theory	{*Efficient*}	0.965	0.820	0.845
	{*Inefficient*}	0.035	0.180	0.155
Intervals theory	{*Efficient*}	0.965	0.820	[0.820;0.869]
	{*Inefficient*}	0.035	0.180	[0.131;0.180]
Evidence theory	*Bel*({*Efficient*})	0.965	0.820	0.820
	Pls({*Efficient*})	0.965	0.820	0.869
	Bel({*Inefficient*})	0.035	0.180	0.131
	Pls({*Inefficient*})	0.035	0.180	0.180

✔ **1 bias** *Collection*

✔ **1 bias** *Collection*

? **1 bias** *Framework*

Results analysis (1/2)

- Two observations
  - Ability of each modeling frameworks to represent different types of expert knowledge
    - Adaptation of their basic concepts
  - Influence of the type of collection on the final results and their accuracy
    - Difference corresponds to the bias induced by the needed adaptation of these frameworks

- Different results depending on …
  - … the modeling framework
  - … the type of collection of expert knowledge

Modeling framework	P	Knowledge expression		
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	$Pls(\{Inefficient\})$	0.035	0.180	0.180

Results analysis (2/2)

- By imposing a particular modeling framework or expression form of expert judgment, the risk is to force the expression of expert's knowledge
  - Risk of loosing a part of the imperfect expert knowledge by forcing him too strictly
  - Working on unique values when there are intervals may present a possibility of error/bias

Modeling framework	*P*	Knowledge expression		
		Hard evidence	*Soft evidence*	*Imprecision*
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    - Principle of IRA methodology
    - Highlighting issues of the problem of uncertainty

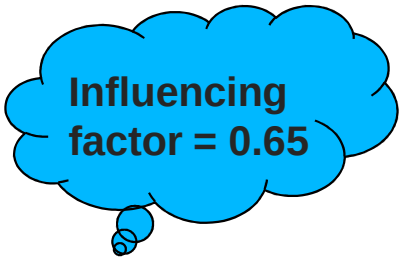
2. Uncertainty modeling frameworks
    - Typology of uncertainties
    - Probability, Interval and Evidence theories

3. Application and discussions on a case study

4. Conclusion and Perspectives

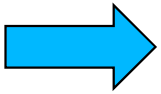
Conclusion (1/2) – Collection Bias

- The expert is guided with only one possible choice among pre-defined values in elicitation grids
  - Not the most suitable for a consistent representation of knowledge owned by the expert
  - Let him express his " real " knowledge





Impact	Influencing factor
No impact	1
Little impact	0,75
Medium impact	0,5
Important impact	0,25
Total impact	0



Influencing factors = 0.65

OR

Medium Impact $\in$ [0.5;0.75]

- Future works
  - … implement tools helping the expression of expert's judgment
    - To collect at best the knowledge of the experts
    - Including guides, questionnaire, charts, etc.
  - … implement them on a full study on a real industrial application (> hundred nodes)
    - To validate industrially works presented here
  - … provide tools to help the decision-making

Conclusion (2/2) – Modelisation Bias

- Most useable not to force the expression of the expert knowledge but to be able to handle various imperfections of his knowledge
  - A part of epistemic uncertainty → choose other modeling frameworks
    - Interval theory,
    - Evidence theory,
    - etc.

- Treatment of uncertainties in Bayesian Networks
  - Difficulty to deal with epistemic uncertainty in Bayesian Networks

➔ Implementation of Evidence Theory in Baeysian Networks [Simon & Weber]

➔ Development of uncertain pattern to take into account both uncertainties

➔ Help the knowledge collection and modelisation without biased the expert knowledge

➔ Contribute to limiting the uncertain nature of the information collected

➔ Contribute to a better assessment of different issues and help decision-making

References

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- **[Léger and al., 2009]** *Methodological developments for probabilistic risk analyses of socio-technical systems*, Proceedings of Mechanical Engineers, Part O Journal of Risk and Reliability, vol. 223, no. 4, pp. 313-332, 2009

- **[Helton and al., 2004]** *An exploration of alternatives approaches to the representations of uncertainty in model predictions*, Reliability Engineering & System Safety, vol. 85, no. 1-3, pp. 39-71, 2004

- **[Cooke and al., 1999]** *Procedures guide for structured expert judgment, European Commission, Tech. Rep. EUR18820, 1999*

Expert judgments collecting and modeling: Application to the IRA methodology

THANK YOU FOR YOUR ATTENTION



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