Expert systems: AI decision support tools for fire safety assessment

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Fire safety studies conducted at IRSN aim to assess the adequacy and effectiveness of risk control measures taken by nuclear facility operators. To support these studies, IRSN is developing expert systems [1] based on the Bayesian Belief Network methodology. A limiting factor is the size of the simulation database. Thus, the challenge is to increase the complexity of expert systems by taking into account specific features of a nuclear facility, without having to exponentially increase the size of the knowledge base and the time required to build it.

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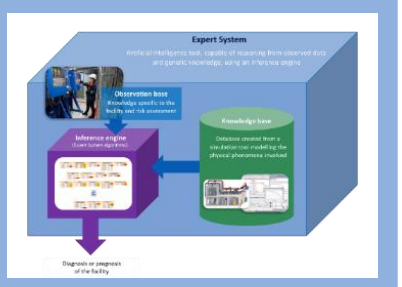
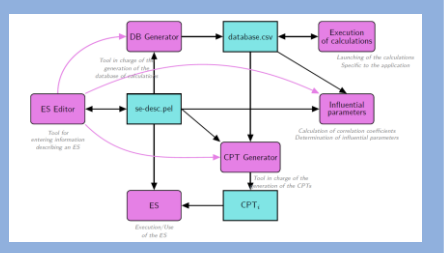
[Expert Systems]

- An Expert system (ES) is an artificial intelligence tool that makes it possible to better understand the behaviour of a nuclear facility and its systems in a given situation by dynamically crossing, the knowledge of the physical phenomena involved with the knowledge specific to the facility
- The propagation of the information is realized by means of an inference engine, based on Bayesian networks
- ES allow deriving the most likely diagnosis or prognosis of a facility, in a negligible time
- ES allow to better target the safety issues within the framework of a risk assessment



[Generation with SE-Toolbox]

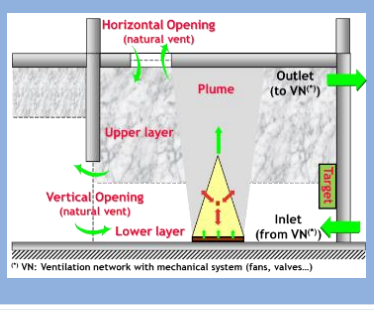
- The volume of data required to characterise the Conditional Probability Tables (CPTs) depends exponentially on the number of parameters and their levels of discretisation
- To reduce the size of CPTs - while preserving accuracy and completeness - it is necessary to adapt the expert system to the expert's use in order to make the best use of the knowledge base
- SE-Toolbox is a toolbox developed by IRSN to describe, generate and use an expert system based on a Bayesian network. This tool allows an expert to set up and check his own ES



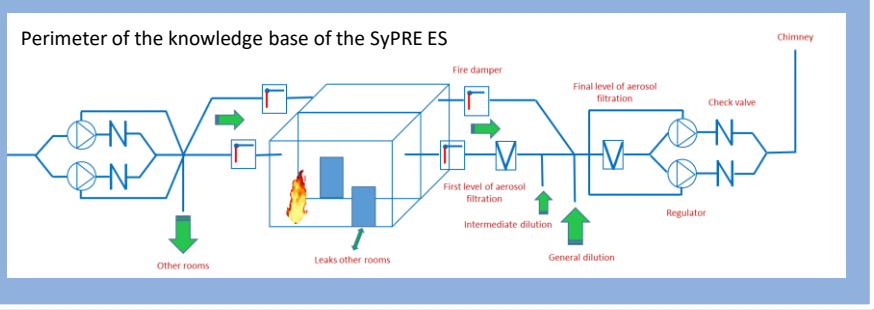
Architecture of the SE-Toolbox

[Generic knowledge from SYLVIA]

- SYLVIA [2] is the two-zone model developed by IRSN designed to predict the behaviour of mechanical/natural ventilation, fire development, smoke propagation and airborne contamination transfers in confined and mechanically ventilated enclosures
- The computation time with the SYLVIA software is short enough to perform millions of calculations. Our approach consists in performing a Monte-Carlo simulation with SYLVIA using a Latin Hyper-cube Sampling method in order to build the knowledge database
- The Monte-Carlo simulation is carried out by varying the input parameters of SYLVIA in the study area considered. As a result, a database is made up of all the data corresponding to both the parameters and the responses of the SYLVIA calculations
- This information is then encoded using Conditional Probability Tables (CPTs)



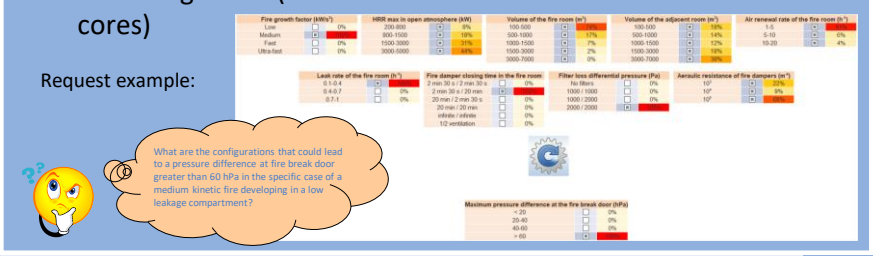
Perimeter of the knowledge base of the SyPRE ES



[SyPRE Expert System]

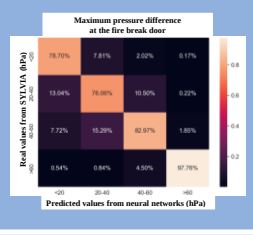
- Example of SyPRE, ES developed for the study of pressure effects on fire-barriers resulting from a fire in nuclear facilities
- Ten million SYLVIA calculations were performed to build the knowledge base (7 weeks of CPU time distributed over 120 cores)

Request example:



[Benefits of deep learning]

- Development of an ES must be compatible with the requirements of the safety assessment in terms of deadline
- SE-Toolbox will be completed with deep learning techniques in order to considerably reduce the time (by a factor of ten) needed to create databases for complex ES
- First results based on SyPRE ES are encouraging. They were obtained from ensemble methods using a set of classifier neural networks each containing 4 hidden layers of 300 neurons



[Conclusion]

Expert systems represent a new generation of computational tools in the field of probabilistic fire simulation. Currently, one of the factors limiting the development of complex ES is the time required to build the knowledge base, which increases exponentially with the number of parameters. Deep learning could be a solution to overcome this limitation

[1] E. Chojnacki, W. Plumecocq, L. Audouin: An expert system based on a Bayesian network for fire safety analysis in nuclear area, Fire Safety Journal 105 (2019) 28–40

[2] W. Plumecocq, L. Audouin, J.P. Joret, H. Prétrel: Numerical method for determining water droplets size distributions of spray nozzles using a two-zone model, Nuclear Engineering and Design 324, pp. 67-77, 2017

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