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Expert System for Fire Vulnerability Analysis

Système expert pour l'analyse de la vulnérabilité au feu

Expertensystem zur Ermittlung der Brandgefährdung

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SUMMARY
In this paper we discuss the design and implementation of an expert system to estimate the fire vulnerability of a building. The expert system technique allows for a global approach taking into account people, environment and goods safety as well. Fundamental features like fire dynamics und building design process are integrated. Many techniques are combined to solve the complex problem production rules managing technico-economical constraints, weighted hypothesis trees dealing with uncertainty and tasks manager improving flexibility.

RESUME
Nous décrivons dans cet article la conception et l'implémentation d'un système expert destiné à l'estimation de la vulnérabilité liée à un bâtiment face au risque incendie. La technique des systèmes experts permet une approche globale intégrant la sécurité des personnes, de l'environnement et des biens. Des aspects fondamentaux tels que la dynamique du feu et le processus de conception du bâtiment sont aussi pris en compte. Différentes techniques sont combinées pour résoudre le problème: règles de production traitant des contraintes technico-économiques, arbres à hypothèses pondérées pour les analyses à forte incertitude, gestionnaire de tâches pour la flexibilité d'accès aux connaissances.

ZUSAMMENFASSUNG
Dieser Beitrag beschreibt Entwurf und Anwendung eines Expertensystems zur Abschätzung des Feuerrisikos von Gebäuden. Das System erlaubt eine gesamthafte Betrachtungswiese unter Berüchsichtigung der Personensicherheit, der Umwelt und der Sachwerte. Die Art der Baukonstruktion und die Branddynamik sind grundlegende Parameter. Zur Lösung des Problems werden verschiedene Techniken kombiniert: technische und wirtschaftliche Rahmenbedingungen sowie Fehlerbaumanalysen mit Gewichtung der verschiedenen Unsicherheiten.

1. THE PROBLEM

1.1 The Vulnerability concept

A discussion about fire safety evaluation needs at the begining a dialog frame setting. Within this frame we find a thematic object seen from different points of view as shown below :

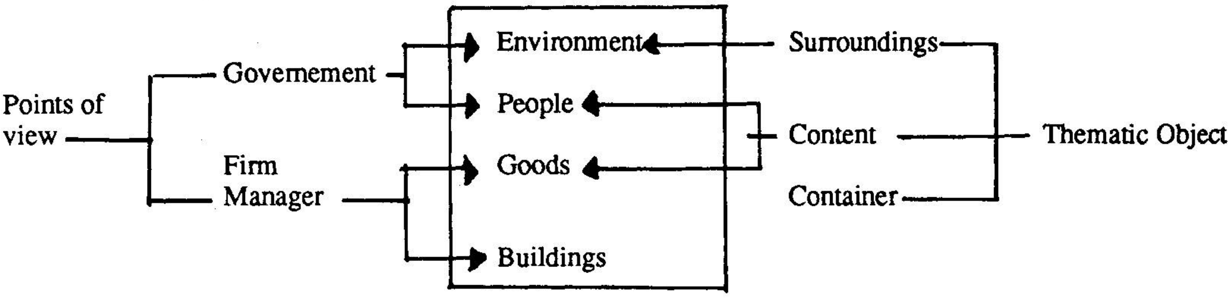


FIGURE 1

Goverments tend to concentrate on people and environment safety, while firm managers are more attentive about goods and building safety. However, even a restricted fire leaving the thematic object (people, environment, goods and buildings) safe can have a catastrophic impact on production and many indirect complications : loss of market place, penalties due to not respecting the terms of contracts. Those are manifestations of vulnerability. The more sensitive the thematic object the higher the vulnerability.

After a closer look it becomes obvious that the points of view are not divergent. A reliable government is indeed concerned with mastering different kinds of threats for people :

- whether direct, like injuries and deaths,
- or indirect, like unemployement and many other social impacts of an undesirable event. Governments sometimes must support a firm financially to avoid social disturbances.

On the other hand, firmes must preserve their standing and do not need to become unpopular because of careless attitude about employees and environment safety.

The fire vulnerability analysis is a systemic approach attempting to gather all points of view. Its field ranks from eliciting fire likelihood to forcasting probable impact on firm perenialty. It considers direct and indirect impacts, social, jurdicial and financial aspects. It is therefore more encompassing than fire safety analysis.

1.2 Today's solutions

1.2.1 Insurance approach

Insurance is probably the oldest kind of solution of the fire vulnerability problem. However it cannot be considered as a total solution for many reasons. Insurance policies have limitations. Some kinds of risks are not insurable. Insurance companies encourage their clients to take some technical measures (spinkler systems, fire resistant walls) and reduce the insurance prime accordingly. That leaves room for some optimization. Furthermore insurance does not solve the problem of people and environment safety.

1.2.2. Mandatory solution

In public buildings the problem is tackled by application of regular solutions. One of the major problems today with regulations is that their complexity and content is increasing. This is due to their too descriptive form. Another drawback is that sometimes there is no mandatory solution, since regulations are unable to forecast all situations (e.g. some office and industrial buildings in France).

On the other part, regulations are rigid and do not leave alternative possibilities to the designer. Though some non-regular solutions can be as good as mandatory ones and cheaper. It is because regulations do not give methods to evaluate the level of safety.
Finally, regulations do not care about reducing the cost effectiveness ratio and do not produce personalized solutions (i.e. suited for the actual risk).

1.2.3 Technical approach

A better knowledge on materials and fire behavior allows for scientific approachs today. There are several main features in a technical approach :
- the fire model used can be :
* deterministic : the fire is supposed to occur and the systems involved in controlling its development and propagation are supposed to work when needed as planned.
* probabilistic : the fire has probabilities of occurence, development and propagation. The control systems have a failure rate.
- the thematic object model can be :
* holistic : if it uses nominal classes for building materials and people. Nominal classes are described by a small number of attributes which many of them have a fixed value obtained from statistics.
* atomistic : if building, materials and people are modelised as systems described by parameters. There is no *a priori* value for those parameters.

Technical solutions can be difficult to apply because of a great number of sub-fields to manage. It is indeed technically possible to reduce fire risk by :
- architectural means,
- constructive means,
- mechanical engineering,
- fire detection,
- alarm managment,
- human organisation,
- people evacuation,
- smoke control,
- fire extinguishing systems .

Some of them are competitive (e.g. smoke control and sprinkler controversy). Moreover those sub-fields involve a great number of professionals from different areas with different working practices to coordinate :
- architect, civil, heat and accoustic engineers for the building field,
- safety engineer, fire brigade for the safety field,
- fire fighting materials constructors,
- insurance companies,
- tests laboratories,
- control offices authorized in supporting the local authorities when mandatory solutions are involved.

From a technical point of view the fire safety domain is too large for one man to manage. As a result there is no human expert able to operate at the global level. This has lead to sub-field limited solutions. Worse, those solutions are often introduced after the design process, since the architect works alone. So they are more expensive and less efficient.

As a final note the sub-field limited solutions generally do not take the dynamics of the fire phenomenon sufficiently into account.

2. A SOLUTION

2.1 Overview of our global solution

According to the intrinsic deficiencies mentioned above, an expert system based only on regulations (though useful) does not solve the problem. A technical and global approach is possible as we will shortly show.

A global approach implies a number of features :
- opportunity of action for all of the professionals concerned,
- a model of the fire dynamics,
- a model of the thematic object,
- a model of the thematic object evolving.

We have chosen :
a) a midway solution for the fire model between deterministic and probabilistic. The fire is considered in three states :
> state 1 is ignition : the fire begins in a small region of a room,
> state 2 is development : the fire grows to the room size but is restricted to this area,
> state 3 is propagation : the five leaves the ignition room.

The initial state is numbered 0 (no fire). So we have three transitions to consider : state 0 to state 1 and so on. Each transition is supposed to have identifiable causes and impacts, and there is specific measures to reduce them.

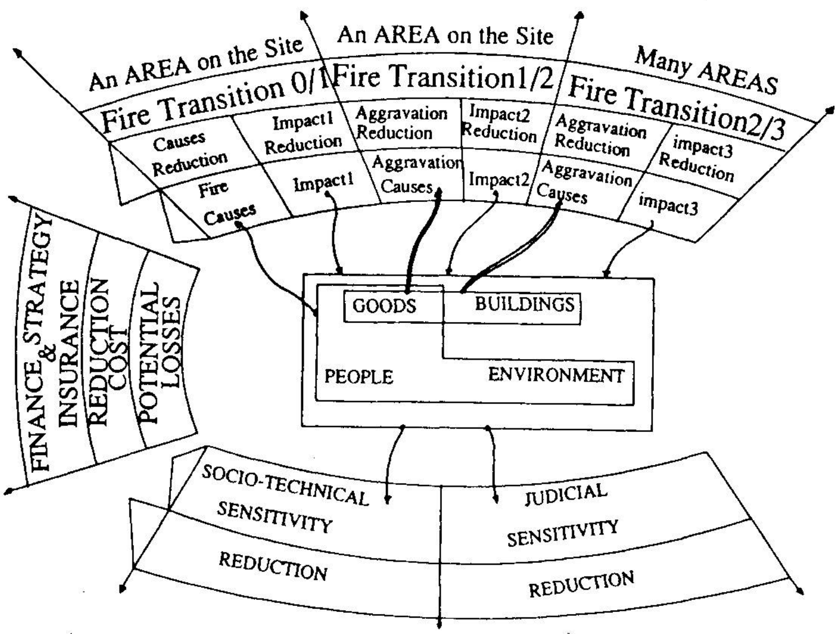
People, goods and environment can initiate the fire. This initial fire can then threaten people, goods, environment and buildings. Therefore we must have specific meausres to reduce both the causes and impcts of ingnition.

Goods and building can favour the development and propagation of an initial fire. During theses fire transitions all entities can be threatened. Here again we must have measures to reduce causes and impacts of aggravations.

People, goods, buildings and environment have an intrinsic sensivity. An entity is a highly sensitive one if a small disturbance can have a significant impact on it. It is the reason why, for us , the term risk refers to a couple hazard-sensitivy.

b) a systemic model for the thematic object : the system is the site in which we find buildings, goods and people. The environment of this system is composed of the site surroundings, the atmosphere and the substratum.

To take into account the evolution of the thematic object we consider three stages :
> stage 1 is the rough plan,
> stage 2 is the project,
> stage 3 is the built object.



Overview of the Global Approach
FIGURE 2

Vulnerability evaluation and measures to reduce it vary with the thematic object stages, except for sensitivity. we have a scheme like figure 2 for each stage, this is what is shown in figure 3.

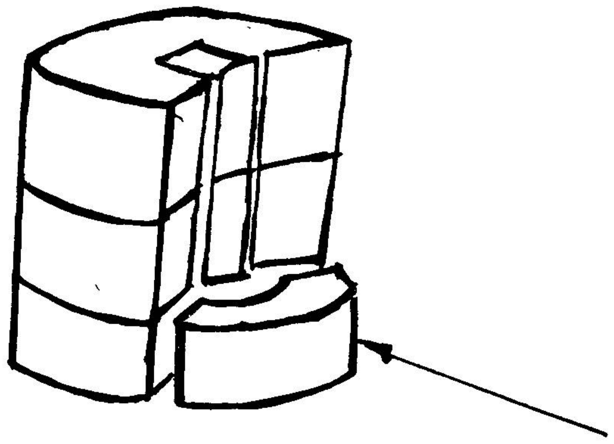


FIGURE 3

The functional aspects of the thematic object in terms of :
- MISSION : one of the major purposes of the firm, e.g. car manufacture,
- FUNCTION : one of the main tasks necessary for a mission, e.g. communication
- ACTIVITY : low level task necessary for a function, e.g. photocopy, raw material conveyance.

2.2 Strategy for the global solution

a) Identification and estimation
- identifiy sensitive entities (people, activity, ...) and their geographic location,
- identify hazard factors (people, goods, environment, ...) and their geographic location,
- superimpose the two resulting maps to see hazard and sensitivity proximity,
- determine entities that need hazard or sensitivity reduction,
- estimate the expected losses related to the selected entities.

b) Prevention and protection measures
For the selected entities consider :
- mandatory measures,
- alternative measures.

c) Financing studies
- estimate the cost of all measures of risk (the couple hazard-sensitivity) reduction
- estimate the cost of insurance in two cases :
  * with measures of risk reduction,
  * without measures of risk reduction.
- using these different cost estimates (expected loss, reductions'cost, insurance cost) apply a financial method to see which solution is the best among :
  * increase the technical measures,
  * take an insurance policy,
  * put money aside (auto-insurance),
  * or a combination of the three possibilities.

This strategy is applicable for each fire transition and each stage of the thematic object. But the knowledge used differs.

3. WHY AN EXPERT SYSTEM

Obviously the global solution is a complex task. It involves managing a massive knowledge with many symbolic parameters. Moreover this knowledge is open to improvement, since it is not well formalised. There is no global expert but there are experts able to submit their knowledge relative to each sub-field (cf. paragraph 1.2.3). Those reasons have guided our choice of a multi-expert system solution.

4. ABOUT THE KNOWLEDGE AND ITS REPRESENTATION

4.1 Categories of knowledge underlied by the global strategy.

4.1.1. Identification and estimation

Identify an hazard and estimate its likelihood and consequences is a predictive task. Therefore it involves dealing with past and future of a system with incomplete and unreliable data. Prediction involves also contingent reasonning.

4.1.2 Prevention and Protection

Preventing an hazard occurence and selecting suitable protection measures are design tasks. They imply keeping track of many constraints, dealing with spatial relations and normative (taken as certain) data. Design involves tentative and qualitative reasonning. The solution space is large and continuous but it can be abstracted because of the scale effect.

4.1.3. Financing

Financing hazard reduction measures and insurance solutions are planning tasks. The need to take the future into account leads to incompleteness and unreliability in data. It is also necessary to proceed by a tentative, contingent, non-monotonic reasonning. In spite of a large solution space there are a few reasonnable solutions. As in design and for the same reason the solution space is abstractable.

4.2 Knowledge representation

4.2.1 Weighted hypothesis trees (WHT)

For the predictive tasks such as hazard or sensitivity identification, fire impact estimation, we have used weighted hypothesis trees. A WHT is a tree whose nodes are hypothesis weighted by a conditional distribution. The conditionning factor is the confidence allowed to the hypothesis. Confidences are real numbers comprises between 0 and 1. Weights are real numbers ranked from 0 to + . Figure 4 below shows an example of distribution for one hypothesis.

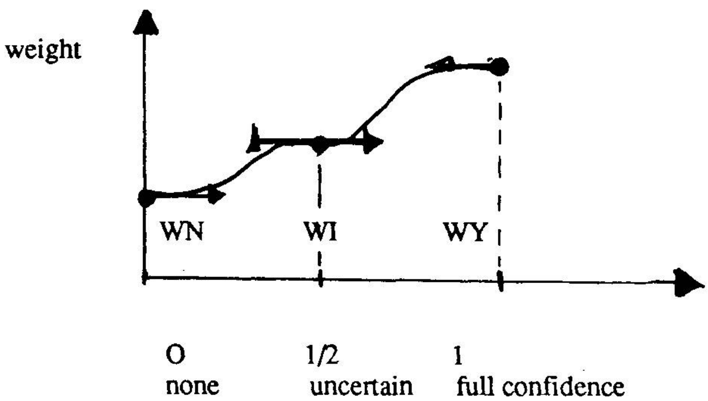


FIGURE 4

WN, WI, WY are subjective values given by an expert pannel. The confidences of terminal hypothesis are given by the end user. For non terminal hypothesis the confidence is evaluated according to the kind of node :

- AND node

let H = (H1 AND H2 ... Hn)

each Hi has a matrix distribution (w_{ij}) , j = 1,2,3.

confidence (H) = $\prod_i w(H_i)/w_{max}$

where $w_{max} = \max_{i,j} w_{ij}$. $w(H_i)$ is the current weight of Hi according to its current confidence. Π is the product operator.

- OR node :

let H = (H1 OR H2 ...Hn)

with the same definitions of w_{max} and $w(H_i)$,

confidence (H) = $\prod_i (1 - w(H_i)/w_{max})$

4.2.2. Rule base

For design tasks such as setting prevention and protection measures we have used a rule base approach. The production rules used can be classified in two categories :

a)- rule for solutions proposition :

Assuming that the context is a room and the action the expert system wants to perform is a proposition about the kind of smoke control to install, a rule can be :

rule smoke 50

IF the number of storeys above the room is > 1 and

the room is not located in an underground zone

THEN the type of smoke control ="NATURAL INLET AIR , MECHANICAL EXHAUST AIR

À more sophisticated form of this kind of rule is those using alternatives. For example

IF .... <same conditions>

THEN alternative solutions :

1.- the type of smoke control ="NATURAL INLET AIR , NATURAL VENT" (prf : 5, 10)

2.- the type of smoke control = "NATURAL INLET AIR , MECHANICAL EXHAUST AIR" (prf : 10,7)

END

b)- rules for solutions evaluation :

Typically this kind of rule involves alternative constraints. For example, assuming the context is a staircase and the action needed a verification :

IF the number of doors by floor > 6

THEN alternative constraints :

1.- the stairshaft is enclosed (prf : 10, 7)

2.- All the corridors leading to the stairshaft are partitionned with 1/2 h fire doors (prf : 8, 10)

END

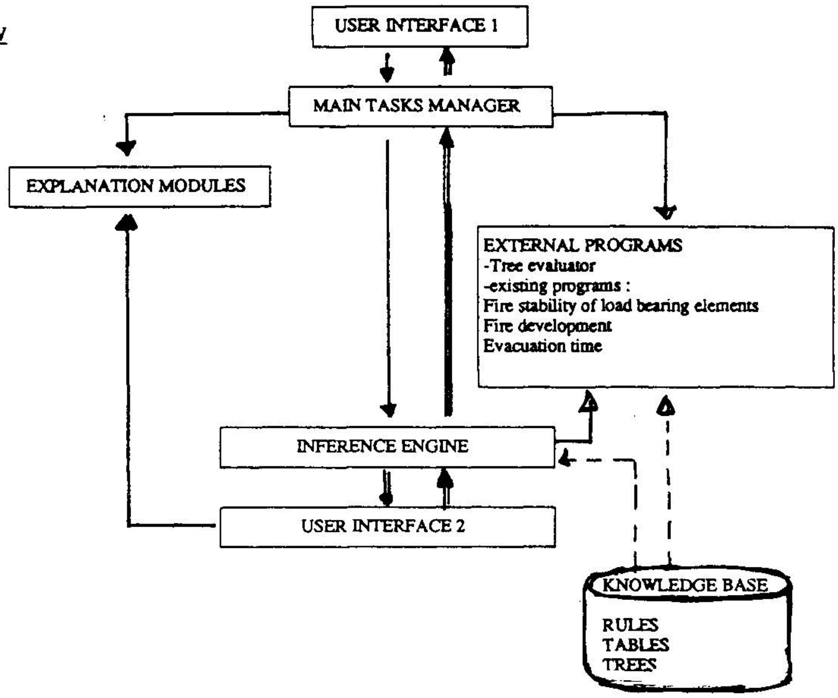
In the above rules prf : denotes experts' preferences about the solutions. The first number indicates the level of technical preference and the second gives the level of economic preference. Preferences can be combined in three ways :

* Technical tendance : sort alternatives by decreasing technical preferences,
* Economic tendance : sort alternatives by decreasing economic preferences,
* Optimizing tendance : sort alternatives by decreasing ratio economic/technical preferences.

Alternatives constraints or solutions can be propagated. This is a tentative reasoning strategy i.e. alternatives are selected one by one regardless to experts' preferences. The solutions or constraints having lead to the best global performance are then chosen.

5. SYSTEM DESCRIPTION

5.1 Overview



* existing programs

Fire stability of load bearing elements
Fire development
Evacuation time

FIGURE 5

5.2 Components description

- the main tasks manager insures project management : selects knowledge base, calls inference engine, calls external programs, solves inference engine deadlock,
- the explanation modules : show the rule under consideration, or the current goal, paraphrase questions,
- the user interface 2 : stops the inference engine or the session, submits explanation requests to the Explanation module, prompts the user for parameter value,
- the user interface 1 : calls main task manager, browses rules and deductions, selects goals, modifies parameters,
- external programs are any executable ones.

By now the knowledge base contains 20 separate rule bases of 10 to 60 rules each, 3 tree files totalizing about 150 hypothesis.

6. SYSTEM DEVELOPMENT

6.1 Development steps

We have followed the classic steps : identification, extraction, formalisation, implementation, test. The validation step is not yet considered.

- Problem identification : a pannel of eleven experts covering all of the sub-fields guided by a knowledge engineer has setted specifications. A work plan has been established which specifies which experts gives what knowledge. This has lead to sub-groups of two or three experts. Plenary meetings were forecasted to insure feedback interaction,

- Extraction : the knowledge of each sub-group of expert has been collected in a cyclic process (from sketch to more refined knowledge). For subjectivity prone knowledges seminars of about two or three days were organized and methods to reduce biaises were used.

- Formalisation : the knowledge has been translated in many forms, rules, tables, procedures, weighted hypothesis trees,

- Implementation : using an ad hoc tool we have feeded the knowledge in a microcomputer

- Test : In addition to the immediate tests done by the knowledge engineer we have forecasted more realistic tests. Five copies of the experimental expert system are submited to five different experts for improvment. This is the reason why the implementation tool must accept knowledge in a natural language form and allow flexible access to the knowledge during a session.

6.2 System organization

6.2.1. Overview

As shown in figure 6 the domain has been divided into fields, themselves divided into sub-fields. Sub-fields are described by logic factors which are high level information (e.g. building geometry) supporting the global judgement. So they have a level of confidence to determine. This is achieved by reasonning about lower level information : the parameters (e.g. building height).

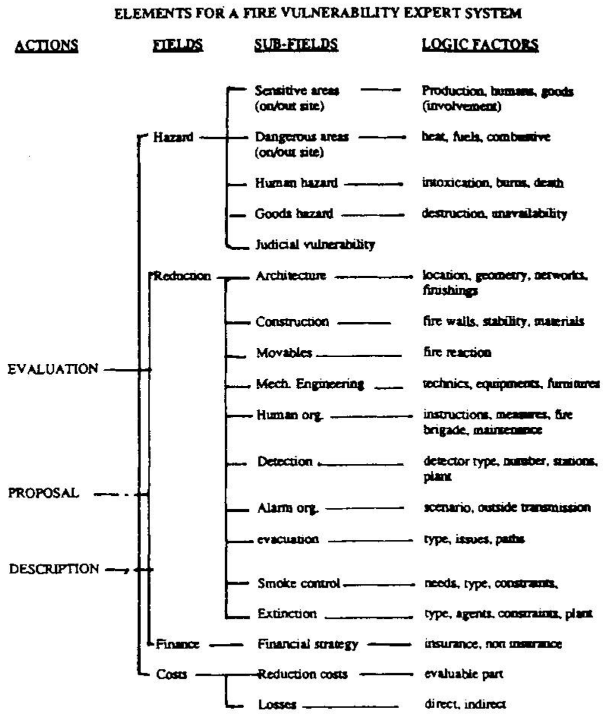


FIGURE 6

Actual system behavior is obtained by operational goals. These are specific actions on a specific logic factor (e.g. propose a smoke detector type).
The thematic object and its functionnal aspects are put in concerete form by entities called contexts : firm, site, environment, building, room, activity, fire brigade are examples of contexts. An operational goal involves at least one context (e.g. propose a smoke detector type for a room).

6.2.2. System modules

Logic factors are put in separate modules that are trees or rule bases for three reasons :
- since there are many experts, it is necessary for each of them to manage his own knowledge only during improvment sessions,

- the end user may want to check only a specific point. Therefore it is necessary to allow him to go straight on the needed expertise. This is what we call focused expertise.
- this improves the efficiency of the inferences as well as the rule base testing.

6.2.3. Modules interactions

There is a graph, as in figure 7 below, for each building stage and for each fire transition. These graphs represent the way many kinds of knowledge interact. For example in figure 6 the double arrows show what hypothesis will be modified in the WHT (in terms of distribution) according to the confidence determined for a specific logic factor.

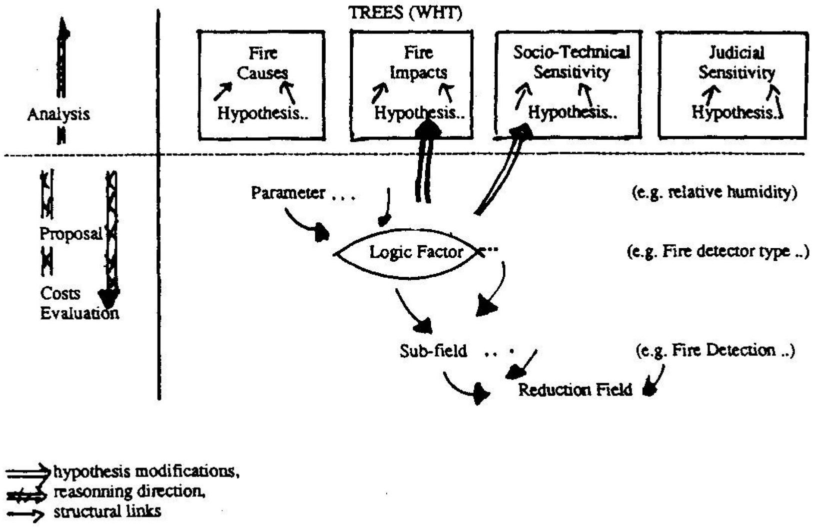


FIGURE 7

There are also interactions between logic factors (not shown in figure 7). For example :
- two logic factors are competitive if the performance of one tends to diminish the other's. Proposal about such logic factors are postponed, as late as possible.
- a logic factor can depend on another. It is then suggested to look at the first before the second.
- a logic factor can compensate another. If the confidence of one is too low we can try to raise the confidence of the other.

All of these interactions are used to guide the global reasonning.

7. ON GOING WORK

The current experimental system achieves focused expertise. We are implementing the global reasonning. The tool used primarily, a 0+ inference engine, is too weak for the global reasonning so we have turned our attention to object oriented environments. That kind of tool should allow us to implement semantic nets on the contexts, and specific behaviour of contexts. Furthermore we have planned to take advantage of access to data bases and realise a coupling with a graphic interface. This should lead us closer to the architect's world.

Economical and technical supports :

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ESPACE TECHNIQUE : Design office.

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