R A P P O R T

D'ACTIVITE

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* On leave from R.I.I. (ROMANIA), presently at LAFORIA (P. & M. Curie University - Paris VI), under a French grant of "Ministère de l'Enseignement Superieur et de la Recherche (M.E.S.R.)" n° 1353/AP/MDLM/CB.

Paris, septembre 1994

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RAPPORT D'ACTIVITE

Personnnalité invité: Moïse Maria

Durée du séjour: 15 mai au 15 septembre 1994
Montant de la bourse: 14.000 F/mois

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Programme de travail:

Recherche sur:

- ***PRISE DE DECISION EN GESTION DE LA PRODUCTION AVEC DES SYSTEMES INTERACTIFS D'AIDE A LA DECISION (S.I.A.D.) A BASE DE CONNAISSANCE FLOUE***

  - Imprécision et incertitude en gestion de la production;
  - La théorie et la logique floue (des concepts et quelques implications utilisés);
  - Applications la prise à la décision en gestion de la production:
    - La gestion des opérations de production;
    - L'audit d'une entreprise:
    - La planification manageriale.

- ***UTILISATION DE LA MODELISATION STRUCTURELLE FLOUE***

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DANS LES DECISIONS MULTI-ATTRIBUT

1. La comparaison des décideurs avec les relations floue
2. Le développement d'un modèle pour le choix des variantes,

qui font l'objet d'une étude de faisabilité.

- ***PREPARATION D'ARTICLES POUR DES PROCHAINS CONGRES***

- ***PREPARATION DU PROJET DE COLLABORATION SUR " INTELLIGENT DECISION SUPPORT SYSTEM EN MANAGEMENT "***

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I. INTRODUCTION

Grâce à la bourse du Ministère d'Enseignement Superieur et de la Recherche (M.E.S.R.) n° 1353/AP/MDLM/CB, j'ai eu de la chance d'effectuer mon séjour au LAFORIA, sur "*l'utilisation des techniques d'Intelligence Artificielle (IA) et de la Logique Floue*" pour développer

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des Systèmes Interactifs d'Aide à la Décision (S.I.A.D.) en gestion de la production.

Je veux donc commencer par remercier M. J.-Ch. Pomerol pour ses bonnes suggestions et son soutien concernant mon travail, ainsi que tous les membres du LAFORIA pour leur amabilité et gentilesse, qui ont facilité mon accès aux matériels, aux logiciels et à la documentation existante au laboratoire.

L'évolution actuelle des systèmes informatiques destinés aux différentes activités économiques dépend du développement des domaines prioritaires des technologies informatiques avancées, concernant l'interface l'homme-machine, les techniques de la Recherche Opérationnele, l'Intelligence Artificielle, ainsi que les réseaux de machines modernes, la gestion distribuée des données etc. Cette évolution est soutenue par une évolution technique imposée par les machines et les logiciels.

Actuellement, une interface importante est liée à la réalisation des (S.I.A.D.) et des Systèmes Experts (S.E.) pour aider le preneur de décision dans le processus de raisonnement en gestion, ainsi que pour résoudre les problèmes d'expertise et/ou de diagnostic, de contrôle et surveillance.

L'idée d'automatiser des prises de décision complexe est de plus en plus abandonnée au bénéfice de la conception de systèmes d'aide à la décision pouvant permettre non seulement de suggérer des solutions, mais aussi d'explorer rapidement les conséquences possibles d'une décision. Les techniques qui permettent de développer de tels systèmes sont nombreuses, et les systèmes interactifs d'aide à la décision à base de connaissance et les systèmes experts représentent une des solutions envisageables lorsqu'une expertise sur le domaine est disponible.

Dans de nombreux domaines, l'expertise disponible peut s'avérer difficile à exploiter, parce qu'elle peut être entachée de divers " défauts " comme imprécision, flou ou incertitude.

Dans ce contexte, pendant mon stage, durant 4 mois (du 15 mai jusqu'au 15 septembre 1994), je me suis intéressée à l'utilisation des techniques d'Intelligence Artificielle et de la logique floue en gestion de la production. Ceci me permettra de développer des S.I.A.D. à Base de Connaissance Floue en gestion de la production, en collboration avec des chercheurs du LAFORIA, ainsi que d'autres spécialistes français que j'ai connu pendant mon séjour.

Je veux remercier encore le M.E.S.R. pour la bourse accordée, et je pense que mon séjour au LAFORIA pourrait ouvrir des nouvelles perspectives d'échanges scientifiques et de collaboration, en valorisiant le potentiel de recherche existant.

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II. OBJECTIFS DU STAGE

Les objectifs du stage sont axés sur les points suivants:

- **Intérêt sur le développement des S.I.A.D. à Base de Connaissance Floue en gestion de la production.**

Le premier objectif était d'étudier les techniques de l'IA et de la logique floue utilisés dans le développement des S.I.A.D. à Base de Connaissance Floue en gestion de la production. Les concepts étudiés ont permis de présenter trois exemples d'applications possibles de développer pour aider le processus de prise à la décision en gestion de la production:

- Gestion des opérations de production;
- L'audit d'une entreprise;
- La planification manageriale.

Les examples présentés ont le but de développer des S.I.A.D. spécifiques en gestion de la production et de les intégrer dans une plate-forme générale " S.I.A.D. INTELLIGENT EN GESTION ", qui pourrait constituer le cible d'un prochain projet de coopération internationnale (l'objectif 4).

- **Intérêt sur l'utilisation de la modélisation structurelle floue dans les décisions multi-attribut.**

Le deuxième objectif portait surtout sur le développement d'un modèle de décision multi-attributte, utilisé dans les choix des alternatives (technologies, etc.) qui font l'objet d'une étude de faisabilité. Souvent, dans le processus de choix des alternatives participent plusieurs décideurs qui ont des différentes compétences et des positions sociales dans l'entreprise. Donc, entre ces décideurs il y a une

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comparaison imprécise, et j'ai utilisé les relations binaires floues pour faire la comparaison entre décideurs. Pour l'identification et la sélection des attributs, qui caractérisent les alternatives, il est nécessaire de développer la diagrame de structure du système.

- **Publications des articles.**

Cet objectif concerne la proposition sur quelques articles pour des congrès prochains.
Les articles proposés se réfèrent à:

- " La prise de décision en gestion de la production en utilisant la logique floue ";
- " La modélisation des systèmes hybrides de contrôle ".

- **Préparation du projet de collaboration sur " S.I.A.D. Intelligent en gestion ".**

L'objectif est de finaliser le projet de collaboration ***" S.I.A.D. INTELLIGENT EN GESTION "***, destiné à l'informatisation du processus de gestion de la production.

Le projet inclura des techniques, des outils et des logiciels, qui permettront, d'une part, de développer une architecture générale capable de faciliter la communication et la coopération entre différents systèmes spécialisés et d'autre part, une interface approchée pour le processus de gestion et ses utilisateurs. Cette architecture générale sera un " S.I.A.D. INTELLIGENT "

DECISION MAKING IN PRODUCTION MANAGEMENT BY USING FUZZY LOGIC

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Key words: production management, managerial planning, production activity control, fuzzy logic, generalised modus ponens.

Abstract: Decision making in production management corresponds to various levels of management: strategic, tactical and operational.
At the strategic level, "managerial planning" requires decision making in order to take into account the behavioural, organisational and environmental factors.
At the operational level, "production activity control" requires quick decision making in order to react to changes on the resources or on the workshop environment.
Imprecise and uncertain information is used in production management at each level, and this vagueness is often unproperly managed. Two conceptual models of managerial planning and of production activity control are suggested, in order to identify the types of reasoning used. The uncertainty and imprecision of the information led us to use fuzzy logic in order to select various inference semantics, adapted to the types of decision identified.
We propose in this paper two examples of applications of the "generalised modus ponens" in order to develop decision support systems for production management :
- at the strategic level, or "managerial planning" level;
- at the operational level, or "production activity control" level.

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1. Introduction

Production management decisions in a complex production system are far too simple. Supporting management decision must therefore be based on a framework. Some frameworks are given in [Anthony, 65], [Hax, 84], [Hayes et al., 87], [Hillion et al., 88] etc. Our framework is described in §. 2 of this paper. Three main decision-making levels can be identified, namely *strategic*, *tactical* and *operational*.. Each level is characterised by different types of decision-makers, with different
functions, responsibilities and scope. The set of decisions is made usually by the corresponding management level and these sets of decisions are interrelated hierarchically: decisions made at a higher level provide constraints for lower level decision-making; in turn, lower level decisions provide feedback to evaluate the quality of upper level decision-making.

In this paper we propose two examples of applications of the "generalised modus ponens", in order to develop decision support systems for production management at strategic and operational levels.
At the strategic level, one of the most broadly activity is the "managerial planning". This complex human activity can be defined as the series of mental processes preceding to, leading to the making of important decisions or actions, concerning the future of enterprise. These processes involve a significant amount of information from many sources: setting of objectives, estimating and evaluating strategies and tactics. In order to make decision in managerial planning, it is necessary to take into account uncertain and imprecise information on behavioural, organisational and environmental factors. Much of the knowledge of these sources may be expressed by different vague linguistic variables and linguistic terms, characterising these linguistic variables. Human reasoning making inferences from inexact or fuzzy knowledge, expressed in such linguistic terms is called "approximate", because the conclusions drown from inexact knowledge cannot be exact.
Existing information technologies products lack real performance in a number of areas, but these include the limitations when processing uncertain and imprecise information.
However, recent developments in the area of Decision Support & Expert Systems, taking into account the uncertainty and imprecision, by using a fuzzy logic and fuzzy set theory aiding the higher level mental processes is facilitated.
In the area of managerial planning, although managers are used to dealing with precise numeric data in respect of, for example, *production prevision*, *markets selected*, *production process*, *number of products* etc.; there is nevertheless considerable uncertainty when translating them into the implementations of tactics and action plans. This uncertainty and imprecision arises because the implementation involves the interactions of a large number of behavioural, organisational and environmental factors.
At the operational level, imprecision may be linked
to an imprecise knowledge on the real state of the workshop (e.g. due to follow-up problems), or on difficulties in order to evaluate the precise duration of some operations (manual operations depending on the operator skill or seldom operations such as some maintenance operations). This imprecision on the data may lead to an uncertainty on the best way to react to the unexpected events that may occur at the operational level.
In the production management, and also in a real-word environment, the uncertainty may arise in a number of ways, for example [Moise, 93]:

- uncertainty due to measurement errors;
- uncertainty due to lack of sufficient data;
- uncertainty due to lack of available theory to describe a situation;
- uncertainty due to the way knowledge is expressed.

The applications proposed in this paper are especially interested in uncertainty of knowledge when that knowledge is expressed by a form of word which implies a degree of vagueness.

2. Production system and decision system

A production system is composed of a physical system, an information system and a decision subsystem (Doumeingts et al. 87). The product is manufactured by the physical system, whereas the decision system coordinates, manages and optimises the production resources and satisfies the customers' requirements such as respect of the due dates or quality insurance. In order to provide the decision system with data, the information system creates, stores, aggregates and distributes information.
The decision system may be considered as a hierarchy of decision centres. A master decision centre sends to each decision centres it controls a decision frame composed of:
- objectives,
- means in order to reach these objectives, described by decision variables,
- procedures in order to use the decision variables.

Decisions made within the decision system involve the production system during a time interval which is called the decision making horizon. This horizon may be graded from long term (for strategic decision makings) to short term (for operational decision makings). A decision making may be set into question by the occurrence of unexpected events, such as machines failures at the shopfloor level or changes in the factory environment at the management level. The period of a decision making may then be defined as the time interval during which the decision remains valid. The period and the horizon of a decision making may provide a criterion in order to hierarchise the decision system (Doumeingts et al. 87). Figure 1 summarises this model of the decision system.
In a manufacturing system, decision making can be very difficult since the workshop context is characterised by uncertain and imprecise data, either at the strategic level (e.g. interest rates or orders forecasting) or at the production activity control level (e.g. maintenance durations) (Smith 92). .

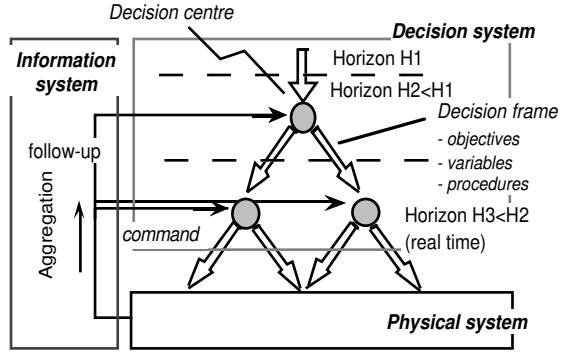

Fig. 1. *Conceptual model of the decision system*

This uncertainty and imprecision is most of the time empirically considered through average values, and the confidence on an information is seldom taken into account in the decision makings. Fuzzy logic may provide an easy way to model and manipulate information pervaded by imprecision and/or uncertainty, both at the strategic and operational levels, and may allow to provide powerful an efficient decision support.
A way to deal with imprecise and uncertain knowledge thanks to fuzzy logic is described in next section. Examples of reasoning modelling based on such techniques are then described, first at the strategic level, then at the operational level.

3. Application to the strategic level

3.1. Managerial planning
The strategic level of the decision centre hierarchy consists mainly in the "managerial planning", that operates on a time horizon between one year and five years, and the decisions have long lasting influence on the practices of the enterprise. The managerial planning is a complex human activity, involving a significant amount of information provided by different sources. In this activity, is distinguishes the following stages (Fig. 2).

- develop strategies, objectives, targets;
- select generic strategies & generic objectives & targets;
- evaluate external and internal environment factors;
- apply decision rules;
- develop/evaluate tactics;
- action plans, budgets;
- monitoring & control;

• Development of strategies, objectives and targets.

This stage is not necessary in strict sequence of managerial planning, and it is considered as the constituent parts of planning activity, concerning previsions, strategies, scenarios and targets. In order to develop information technologies products supporting develop of strategies, objectives and targets, it is necessary to use statistical models, simulation models etc.

• Select generic strategies and generic objectives and targets.

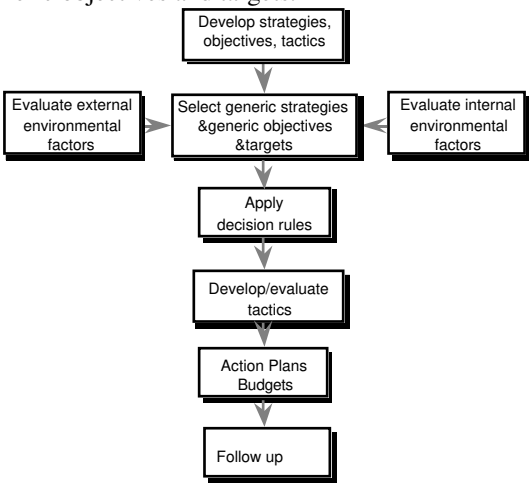

Fig. 2. *The stages of managerial planning*

The decisions of this activity have long lasting influence on the practices of the enterprise. Generic strategies can be expressed by linguistic variables such as: markets selected, production process, number of products etc.

• External and internal environment factors.

The planning decisions and actions are taken within the context of the external and internal environment factors. External environmental factors can be expressed by linguistic variables such as: product demand, competition, borrowing terms etc.

Internal environmental factors can be expressed by linguistic variables such as: products, production process, personnel, research & development etc.

• Apply decision rules.

Decision rules express the interactions between the generic strategies and objective targets, external and internal environment factors. These rules describe relationships between factors, strategies, objectives and tactics. They are of the form: IF… THEN…

• Tactics.

The tactics can be obtained as the conclusions resulting from inference of the rules. These conclusions can be expressed by linguistic variables such as: introduction of new product, reduction of prise of product etc.

3.2. Rules of managerial planning

The set of tactics and actions can be obtained by an inference of significant planning factor knowledge. The domain knowledge for typical application "managerial planning" can be elicited from the experts (management theorists and practics consultants) employing structured interviews and verbal protocol analysis of planning scenarios. The structured interviews can be administered to small and medium sized enterprises with financial performance and viability prospects. The verbal protocols of planning scenarios can provide information on the internal and external environment of a hypothetical enterprises, and can present future changes of two factors.

This knowledge can be represented using production rules of the form:

IF *antecedent* THEN *consequent*

Fuzzy logic allows both the antecedent and consequent to be fuzzy propositions. These propositions are composed of statements involving linguistic variables, which have varying degrees of truth. An antecedent of any rule may be a composite of a number of clauses (or atomic propositions) connected via the fuzzy logical operators: AND, OR, NOT AND et NOT OR.

Such rules can be developed in three different ways [Laios et al., 87]:

a) Statistical rules:

They can result from statistical analysis of data collected from structured interviews.

For example,

IF demand of product IS high
AND industrial sector IS fast growing
AND managerial support IS satisfactory
THEN (you can consider implementing the following tactics)
increase marketing expenses
develop R&D

differentiate your products
improve delivery
increase vertical integration
redesign layout
use CAD equipment etc.

The above conclusions can be ordered by the system according to their membership following the de-fuzzification values specified by the user.

b) Directly observed rules
They result from the verbal protocol analysis of the structured interviews.
For example,

IF competition IS high
AND type of competition IS low quality, low price
AND economic environment IS improves
AND flexibility in changes of product type Is high
THEN
focus on high quality products
Differentiation of product characteristics.

c) Scenario rules
They can be extracted from the scenario verbal protocol analysis by examining selected tactics and associating them with the described factor values.
For example,

IF competitions IS high
AND type of competition IS low price
AND distribution channel IS weak
AND number of products IS important
AND assets liquidity IS high
AND production capacity IS high

THEN	Advertising	
	Financial incentives to customers	
Tactic 1	Improvement of distribution	channel
	Price competition + decrease of	production costs.
Tactic 2	Focus on product types with no	competition
	Financial incentives to customers	
	Penetration in new markets +	Purchase of new equipment
	Procedural planning aids.	

3.3. Approximate reasoning
The approximate reasoning of this applications consists of the following three processes: fuzzification, inference and de-fuzzification.

a) fuzzification
The goal of fuzzification is the transformation of managers-supplied facts (factors of managerial planning, expressed by linguistic variables) into fuzzy set membership (Fig. 3).
For example,
IF demand of product IS high THEN increase marketing expenses is medium
IF demand of product IS medium THEN increase marketing expenses is low.

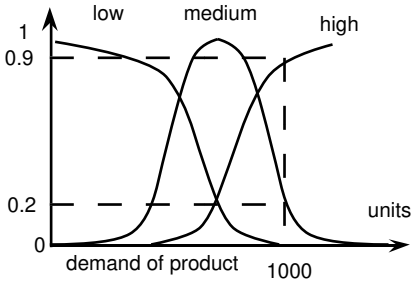

Fig. 3. *Fuzzification of the input*

User facts are discrete values of linguistic variables, and in the system the facts are defined by arbitrary pairs {value, membership grade}. Since fuzzy sets are defined for each linguistic variable, a fact supplied by the user will have a membership for each fuzzy set.

b) inference
The inference is performed using generalised modus ponens, after all transformation have occurred. If a component proposition is true, then all antecedents containing this proposition will be true. The membership grades of component propositions of an antecedent are according to the fuzzy operator rules, defined above. The combined membership grade of any antecedent is propagated to its consequent. Therefore consequents of rules are tagged with a degree of truth. Since many conclusions can be found which may consist of the same fuzzy set and, even more often, of the same fuzzy variable, a decision area for the consequent fuzzy variable, rather than a distinct value is produced. This area is a truncated composition of the areas of the membership functions of the activated consequents featuring this fuzzy variable (Fig. 4).

c) de-fuzzification
This process translates the conclusion back into some domain-specific notation. This process involves projecting the membership of a consequent to the fuzzy set of the conclusion (Fig. 4). For de-fuzzification is used maximum method, which consists that from among the consequent fuzzy sets for the particular linguistic variable, the one with largest membership grades is used to interpret the conclusion.

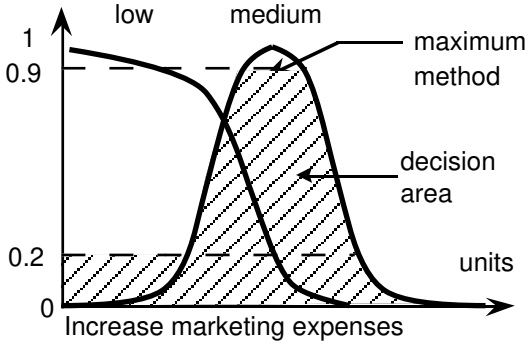

Fig. 4. *Inference on the rule*

4. Application to the operational level

4.1 Production Activity Control
The operational level of the decision centre hierarchy consists mainly in the Production Activity Control system (PAC), that operates on a time horizon between one month and real-time [Higgins and Browne, 90]. Four main functions are insured by the PAC system [Huguet and Grabot, 94]:
- to plan, that considers the production plan and the objectives transmitted by the upper decisional level, and details it,
- to react, that allows real-time adaptation of the decisions taken at different management levels each time it is necessary,
- to dispatch, that breaks down, synchronises and executes decisions taken within a PAC module,
- to follow-up, that collects all the results provided by the sensors or the lower decisional levels as well as the requests coming from outside the shopfloor, processes them according to their type and aggregation level and transmits them to other functions and other PAC modules.

Decision support is mainly required for the "react" function, which is often performed by human operators.
4.2 Rules on Production Activity Control
At the Production Activity Control level, decision support is mainly needed at the "react" level, and it is interesting to classify the production rules according to their role in the reaction process. We may distinguish between:
- rules that aim at triggering the "react" function, such as:

IF the average delay of the manufacturing orders IS important
AND the date of next planning IS far
THEN a reaction is required

- rules that aim at choosing an appropriate way to react to an unexpected event:

IF the machine breakdown IS short
THEN postpone the launching of the jobs on the machine

- rules that aim at computing an action:

IF the machine breakdown IS short
AND the date of re-planning IS far
THEN allocate an important part of the load to a replacement machine

The semantics of these rules are quite different, since in the two first cases the problem is only to know if the facts are close enough to the component propositions to infer the conclusion, whereas in the third case the imprecision in the satisfaction of the component propositions can modify the conclusion (here for instance, the expert wants to express a complex proportionality between the breakdown duration and the quantity of load to transfer). Moreover, the imprecision on the satisfaction of the components may lead to an uncertainty and imprecision on the conclusion. Let us consider for instance the following rule:

IF the maintenance duration IS long
AND the machine IS a bottleneck
AND there is a replacement machine
THEN allocate an important part of the load to the replacement machine

The fact that the machine is or is not a bottleneck depends on its load and on its capacity, that may be both imprecisely known. In that case, an imprecision on the components must lead to an uncertainty on the conclusion since the load re-allocation must not be performed if the machine is not a bottleneck.

4.3 Approximate reasoning at the Production Activity Control level

The fuzzification may be realised at that level as described in §3.3 for the managerial level, but the inference is more complex.

Let us consider that a rule is defined by IF (x is A) THEN (y is B) were the propositions (x is A) and (y is B) are modelled by fuzzy sets. The membership function of B', $\mu_{B'}$, can be computed from a combination between the definition of the chosen implication, noted (x->y) and the membership function of A', $\mu_{A'}$ thanks to the following expression:

(1) $\forall y \in Y \ \mu_{B'}(y)=\sup_{x \in X} T(\mu_{A'}(x),(x->y))$

where Y' is the referential of y, X the referential of x, and T a triangular norm, called "generalised modus ponens operator", that makes the generalised modus ponens compatible with the classical one (i.e. when A'=A, the result has to be B'=B). Zadeh's T-norm is for instance defined by TZ(u,v)=min(u,v), and Lukasiewicz's T-norm by TL(u,v)=max(u+v-1,0).

This framework is well adapted to our problem since implications of various semantics have been defined; some of them are for example detailed in [Dubois and Prade, 88], [Mizumoto and Zimmermann, 82] or [Zadeh, 73]. Some implications take only into account imprecision, e.g. Brouwer-Gödel's, Goguen's or Rescher-Gaine's implications. In these cases, an imprecision on the premises on the rules leads only to an imprecision of the conclusion. Others implications, e.g. Kleene-Dienes', Lukasiewicz's, Reichenbach's or Willmot implications may also take into account uncertain facts or premises. The difference between a fact and a premise may in that case lead to an imprecision and an uncertainty on the conclusion. An increasing uncertainty on a fuzzy proposition may be interpreted as an increasing eventuality that the opposite proposition becomes true. This uncertainty may then be modelled by a non-null minimum membership degree of the elements of the reference set to the fuzzy set that models the proposition. Figure 5 illustrates this way of modelling the uncertainty of an imprecise proposition.

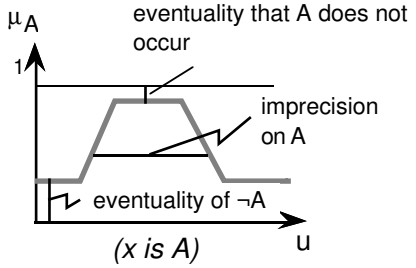

Fig. 5. *Modelling of an uncertain and imprecise proposition*

Let us consider the following rule R as an example:

R: IF the maintenance duration IS long
AND the machine IS highly loaded
AND there is a replacement machine
THEN allocate an important part of the load on the replacement machine.

Since the possibility that the maintenance duration should not be long sets into question the opportunity of allocating its load to another machine, we can choose three implications for which the distance between facts and premises induces both an imprecision and an uncertainty on the conclusion (Kleene-Dienes, Lukasiewicz and Reichenbach). Let us suppose that the fuzzy sets of the imprecise propositions may be described by the following 4-uplets:

- the maintenance duration is long (0,20,20,20)h
- the machine is loaded (60,80,150,200) % (an overload is possible)
- allocate an important part of the load (0,100,100,100)%.

Figure 6 gives the result of the inference of this rule in three cases describing facts that do not fit, fit a little, and fit well the premises of the rules (the upper curve is the inferred conclusion, and the lower one the standard conclusion): the uncertainty level decreases from left to right in the three cases. With the three considered implications, the fact relative to the load of the machine in the first case is too far from the premises of R in order to give a solution: the uncertainty is then total.
A precise interpretation of the conclusions may be done after a defuzzification process, e.g. through a gravity centre computation. In real cases, the implication that best approximates the required behaviour of the rule must be chosen.

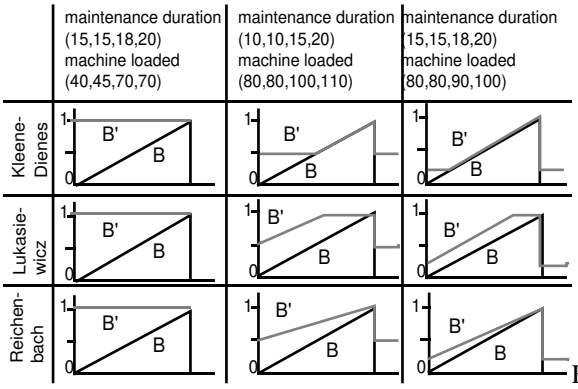

Fig. 6. *Result of the inference with R*

The first tests done on the modelling and implementation of the reasonings used in PAC showed the interest of the manipulation of imprecise information. A prototype software that contains ten rules allowing to react to disturbances has been validated [Grabot and Geneste, 94] and the development of a real scale system is in progress, on the base of the analysis of a manufacturing workshop.

5. Conclusion

The application area of decision making in production management provides a rich variety of vague and uncertain knowledge. This knowledge can be identified using the methods of data collection (structured interviews, verbal protocols analysis of planning scenarios, etc.) in order to take into account all factors (behavioural, organisational and environmental) and it can be modelled using fuzzy concepts.
The concepts described in this paper allow to design decision support systems based on fuzzy knowledge, in order to manage available imprecise knowledge and in order to perform approximate reasoning on this type of knowledge in production management. The fuzzy inference used in such systems allow to obtain results when inconsistencies are present on the inputs, or when some information is lacking.
In order to insure the efficiency of the systems, an adequate expertise on the knowledge is required. The real significance of the linguistic terms for the expert is very important to define in order to build the knowledge base, since fuzzy inference is mainly based on these terms.
We wish especially to thank the Mr. J-Ch. Pomerol, laboratory director of LAFORIA, for his good suggestions and his support on this research, and thanks again to the French "MESR" and the EEC, which have accorded to Mrs. M. Moise a fellowship of the LAFORIA. Each of these participants should contribute to the opening of some better joint research in this field.

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MODELING OF HYBRID CONTROL SYSTEMS

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Key words: numeric submodel, continous submodel, discrete submodel, discrete-event submodel, knowledge-based submodel, control variable, state variable, hydrological system, behavioural rule, control rule, decision rule, numerical simulation problem, fuzzy submodel, linear system, nonlinear system, hybrid control system, fuzzy set and fuzzy logic.

Abstract: In this paper we describe a MIX system. It is designed to handle compound models based on various types of formalisms. The different submodels are coupled by sharing some variables or parametres. More precisely, we will address issues related to continous-time systems, discrete time systems, discrete-event systems, knowledge-based systems and fuzzy systems.

* On leave from R.I.I..(ROMANIA), presently at LAFORIA (P. & M. Curie University - Paris VI), under a French grant of " Ministère de l'Enseignement Superieur et de la Recherche (M.E.S.R.) " n°1353/AP/MDLM/CB.

1. Introduction

In general, several types of formalism are necessary to describe adequately a process. For example, some authors developed applications that combined: expert systems and numeric simulation, fuzzy systems and numeric simulation, continous-time systems and discrete-event systems. As a direct consequence of the difference of these types the coupling of implementations of these formalisms becomes complicated.

In our approach a model is subdivided in submodels in such way that different types of formalism are not combined in a submodel, and the model includes the following types of variables: continous variables, discrete variables, event (logic) variables, linguistic variables (e. g. long, very long etc.) and fuzzy variables. Three submodels types will be treated in this work:

- numeric submodels;
- knowledge-based submodels;
- fuzzy submodels.

2. Numeric submodels

A numeric submodels is:

- continous submodels based on ordinary differential equations,
- discrete submodels based on discrete equations,
- discrete-event submodels.

¥ A continous submodel is of the form:

$dx/dt = f(x, u, t)$

$y = g(x, t)$

$x(t0) = x0$

where x, u, t, y are continues variables.

A continous submodel is solved by means of a selected numerical integration method. The following integration methods are implemented: linear-method, euler-method, adams-method, gear-method and runge-method.

¥ A discrete submodel is of the form:

$x_{t+1} = f(x,u)$

$y_t = g(x), \quad t \in$ " Sample-time "

where x, y, u are discrete variables, and " Sample-time " contains a set of values for variable t.

The state variables of discrete submodel are changed only at specified times in the " Sample-time ". More discrete submodels can be connected as is illustrated in next example.

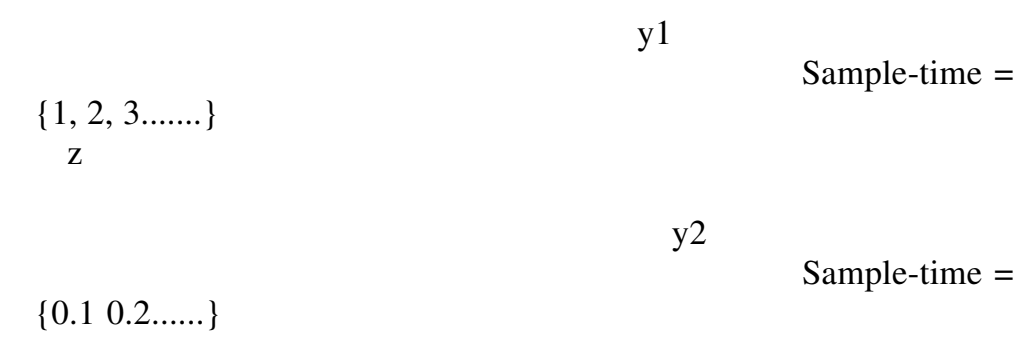

Figure 1.

The two submodels have the same input, the output "y1" is updated at times: 1, 2... and output "y2" is updated at time: 0.1 0.2 ...

Also, continous and discrete submodels can be connected as it is illustrated in following example:

$dx/dt = f(x, z, u)$

$z_{t+1} = g(x_t, z_t)$; Sample-time = {0.1 0.2 ...}

$x(t0) = x0$

$z(t0) = y0$

The integration method updates continous variable x at any time, and integration method updates discrete variable z at time: 0.1 0.2.....

When the integration method for continous submodel reached time: 0.1 0.2 ...the discrete state y is updated.

A discrete-event submodel is of the form:

<s, P(x), P1>

where s is a event (logic) variable, x is a continous state variable, P is a predicate and P1 is a procedure.

When the submodel is called, predicate P is tested, if it is true procedure P1 is executed.

Usually, the discrete-event submodels are associated with discontinous process. From a numerical perspective these processes poses the most problems since no integration algorithms cannot deal with them. Thus the integration method should be prevented from passing through any discontinuity. In order to do it demons are installed that watch over discontinuity, once the discontinuity has been located the numeric integration is suspended and the discontinuity is processed using the procedure associated with it. In order to illustrate how discontinuity is treated, we consider the following model:

$$dx/dt = \begin{cases} f(t, x, u) & \text{if } a \; x \; 0 \\ g(t, x, u) & \text{if } 0 < x \; b \end{cases}$$

The model is divided in two continous submodels and one discret-event submodel.The integration method testes the logic variable " s " from discrete-event submodel, if it is 0, fonction f is integrated; if it is 1, function g is integrated.

3. Knowledge-based submodels

A knowledge-based submodels is a set of rules of the form:

IF P(y) THEN x = expression

where yY, xX, Y is input set of linguistic variables of submodel, X is output set of linguistic variables of submodel and P is a predicate.

If the predicate P is true then " expression " is assigned to variable x.

The variables X and Y can be connected with any kind of variables from others submodels.

If a linguistic variable is connected with a fuzzy variable then each value of linguistic variable must has an associated fuzzy set.

We have used this type of submodels in order to determine the control variables, able to rest the state variable into the suboptimality intervals, when they exit from these intervals. The basic architecture of knowledge-based submodel is shown in Figure 2. Each KSi is composed of a knowledge base and an inference engine. All KSs are under the control of a scheduler. The blackboard is a global data base which provides a communication medium for all KSs. The functions of these components are described as follows:

The KS1 consists of behavioural rules of the form:

C1(k) C2(k) .....Cp(k) S(x(k+1)) (if the condition C1, C2,...Cp are accomplished at the time moment k, the state of the subsystem is x at k+1).

The KS2 consists of control rules of the standard form:

C1(k) S(x(k)) [u(k+1) u(k)+delta*u(k)] S(x(k+2)) (if the condition C1 is accomplished and the state is x, and we modify the control variable u, by adding-or substracting-of delta*u at k, and we assign the new value to the control variable u(k+2), then the system pass in a new state x(k+2)).

The KS3 consists of decision rules of form:

x(k) < x1 [u(k+1) u(k)+delta*u(k)

or

x(k) > x2 [u(k+1) u(k)-delta*u(k) (if the state x(k) is less than x1 or bigger than x2, then assign to control variable the ancient value plus or minus an increment delta*u).

The scheduler selects and then activates the next KS according to the changes in the blackboard.

Using a numeric submodel and a knowledge-based submodel, the above problem of control can be solved as follows:

solve the numerical simulation problem;

if at each time k, x(k) belong to the given interval [x1,x2] plot x

search a new value for control variables using knowledge-based submodel and go step 1.

Figure 2.
Next we detail the above example.

4. Application

This example refers to a large scale hydrological systems. The problem we have to solve is to simulate the behaviour of the system, and to control the evolution of state variable.The first is to establish:

the input set: the precipitation (p), the water inflow through canals and channels (Q_{ij}) a.s.o;

the endogenus parameters: the roughness of canals and channels (ro), the surface of the lakes (A_j);

the exogenus parameters: the temperature (T), the sil parameters (s) a.s.o.;

the state space:the depth of water in the lakes (H_j), the volume of water (V_j), the water refreshment (W_j) a.s.o;

the output set: the evaporation of water (e), the water outflow through canals and channels (Q_{je}) a.s.o;

the objectives of system: to mentain H_j and W_j into suboptimality intervals, to improve W_j.

We write now the so-called mathematical submodel and knowledge-based sumodel.

$$H_j(k+1) = H_j(k) + p(k) - e(t) + B_j Q_{ij}(k) - B_j Q_{je}(k) + B_j u_j(k),$$

$$V_j(k) = A_j H_j(k),$$

$$W_j(k) = V_{ij}(k) / V_j(k) + V_{ij}(k), \qquad (j = 1,2...n; \text{ in our case } n = 10)$$

where:

$$Q_{ij}(k) = ro_{ij} A_{ij} \operatorname{sqrt}(2g) \cdot \operatorname{sign} x_{ij} \operatorname{sqrt}(|x_{ij}|),$$

$$x_{ij} = z_i + V_i / A_i - (z_j + V_j / A_j)$$

$$A_{ij} = L_{ij} H_{ij}$$

$$H_{ij} = 0.5 (V_i / A_i + V_j / A_j)$$

$$Q_{je}(k) = ro_{je} A_{je} \operatorname{sqrt}(2g) \operatorname{sign} x_{je} \operatorname{sqrt}(|x_{je}|)$$

$$x_{je} = z_j + V_j / A_j - (z_e + V_e / A_e)$$

$$A_{je} = L_{je} H_{je}$$

$$H_{je} = 0.5(V_j / A_j + V_e / A_e)$$

$$V_{ij} = Q_{ij} dt$$

$B_j = 1/A_j$

The initial condition: $H_j(0) = H_{j0}$. Also we specify that L_{ij}, H_{ij} represent the breadth and respectively the depth of water in the canal which binds the lakes i and j, V_{ij} is the volume of water which enter in the lake.

We add also on the above model, the constraints:

If $H_j < H_0$ (the minimum depth) $Q_{je} = 0$ (the water flow no more);

If $H_j > H_m$ (the maximum depth) V_j = constant (the surplus of water is drawn out)

H_j $[H_{j1}, H_{j2}]$, V_j $[V_{j1},V_{j2}]$, W_j $[W_{j1},W_{j2}]$.

The knowledge-based model is:

a) behavioural rules

IF $(p < p_1)$ $(e > e_2)$ $(Q_{ij}(k) < Q_{ij}(k-1))$ $(Q_{je}(k) > Q_{je}(k-1))$
THEN
$(H_j(k+1) < H_j(k))$ $(V_j(k+1) < V_j(k))$ $(W_j(k+1) < W_j(k))$;

IF $(p > p_2)$ $(e < e_1)$ $(Q_{ij}(k) > Q_{ij}(k-1))$ $(Q_{je}(k) < Q_{je}(k-1))$
THEN
$(H_j(k+1) > H_j(k))$ $(V_j(k+1) > V_j(k))$ $(W_j(k+1) > W_j(k))$,
(j = 1,2,...,n; in our case n = 10).

b) control rules

IF $(H_j(k) < H_j(k-1))$ $(V_j(k) < V_j(k-1))$ $(W_j(k) < W_j(k-1))$
$(Q_{ij}(k+1)$ $Q_{ij}(k) + delta^* Q_{ij}(k))$
THEN
$(H_j(k+2) > H_j(k+1))$ $(V_j(k+2) > V_j(k+1))$ $(W_j(k+2) < V_j(k+1))$;

IF $(H_j(k) > H_j(k-1))$ $(V_j(k) > V_j(k-1))$ $(W_j(k) > W_j(k-1))$
$(Q_{ij}(k+1)$ $Q_{ij}(k) - delta^* Q_{ij}(k))$
THEN
$H_j(k+2) < H_j(k+1))$ $(V_j(k+2) < V_j(k+1))$ $(W_j(k+1) < W_j(k+1))$.

c) decision rules

IF $(W_j(k) < W_{j1})$ $(dH_j/dk > 0) \vee (W_j(k) > W_{j2})$ $(dH_j/dk < 0)$
THEN
$Q_{ij}(k+1)$ $Q_{ij}(k)$;

IF $(W_j(k) < W_{j1})$ $(dH_j/dk < 0)$ $(W_j(k) > W_{j2})$ $(dH_j/dk > 0)$
THEN
$(Q_{ij}(k+1)$ $Q_{ij}(k) + delta^* Q_{ij}(k))$.

Note: Naturally, both parts (premise and conclusion) of a rule are affected by a certainty factor.
The knowledge base for simulation and control of hydrological system contains 3x2x10 = 60 rules which ensures the simulation of the behaviour of depth of water in the 10 lakes (H_j, j = 1,2..10), the volumes of the same lakes (V_j) and the water refreshment factor (W_j) ,and the control of these variables in order to belong to the suboptimality intervals: $[H_{j1}, H_{j2}]$, $[V_{j1},V_{j2}]$, $[W_{j1}, W_{j2}]$.

5. Fuzzy submodels

The following notation will be used: X = state set; U = control set; Y = output set; F(A)= set of all the fuzzy subsets of A.
Our time-invariant fuzzy submodels are of 2 types:
¥ Submodels of type 1 are of the form:

f: X x U F(X)

g: X F(Y) where, function "f" is dynamic of submodel and function "g" is output of submodel.
We solve this submodel considering "f" and "g" as fuzzy relations:

f: X x U x X [0,1]

g: X x Y [0,1]

Extending function f on U^* we obtain:

f: X x U* x X [0,1] [0,1]

$f(x,<u_1,u_2,...u_n>,x) = [f(x,u_1,x_1) \ f(x_1,u_2,x_2) \ ..... \ f(x_{n-1},u_n,x)]$

$(x_1,x_2,..x_{n-1}) \ X$

If x0 initial state, then function :

$f_{x0} : U^* \ x \ X \ [0, 1]$, with $f_{x0} (<u_1,u_2,..u_n>,x) = f(x0,<u_1,u_2,..u_n>,x)$ defines behaviour of system.
Another way used to solve the above fuzzy submodel consists in transforming it in a nonfuzzy submodel using for example defuzzification rule:

If f(x, u) = A then define f1(x, u) = a

where,

$$a = \frac{(\text{value of member} * \text{membership value of member})}{\text{membership values}}$$

¥ Submodels of type 2 are of the form:

f: F(X) x F(U) F(X)

g: F(X) F(Y)

where states, controls and outputs are fuzzy sets.

Ecuations for such submodels can be written:

$x_{t+1} = f(x_t , y_t)$

$y_t = g(x_t)$

In order to solve this submodel, the function "f" is extended as follows:

$f : F(X) \times (F(U))^* \to F(X)$

$f(x, \langle u_1,u_2\rangle) = f(f(x,u_1),u_2)$

. .

$f(x,\langle u_1,u_2,...u_n\rangle) = f(f(x,\langle u_1,u_2,....u_{n-1}\rangle),u_n))$

If x0 is initial state then:

$f_{x0} : (F(U))^* \to F(X)$ and $f_{X0}(u_1, u_2, .. u_n) = f(x0,\langle u_1,u_2,..u_n\rangle)$ defines behaviour of system.

A particular case is obtained when function "f" and "g" are obtained by fuzzification of classical linear system:

$x_{t+1} = Ax + Bu$

$y = Cx$

The fuzzy system associated with it,is:

$x_{t+1} = A\tilde{}x + B\tilde{}u$

$y = C\tilde{}x$

where: x, y, u, A~, B~, C~ are fuzzy sets.

The following functions:

$A\tilde{} : F(X) \to F(X)$

$B\tilde{} : F(U) \to F(X)$

$C\tilde{} : F(X) \to F(Y)$

are obtained by following reason:

If $h : M \to N$ is a classical function, then we define:

$h\tilde{} : F(M) \to F(N)$ $h\tilde{}(x)=x'$

with

$$x'(n) = \begin{cases} \sup x(m) \text{ when } m \in h^{-1}(n) & \text{if } h^{-1}(n) \text{ is not empty} \\ 0 & \text{if } h^{-1}(n) \text{ is empty} \end{cases}$$

Another way of fuzzification of linear systems which is in course of implementation is as [1]. In some conditions it can be applied to nonlinear systems. Next we describe summar this methods.

If dx/dt = ax+bu for $a, b \in R$, is the linear system and if s1, s2 > 0 are two given numbers, we consider three fuzzy set collections:

$$S_n^{S1} = \begin{cases} x-(n-1)s1 & \text{if } (n-1)s1 < x \le ns1 \\ s1 & \\ (n+1)s1-x & \text{if } ns1 < x \le (n+1)s1 \\ s1 & \\ 0 & \text{otherwise} \end{cases}$$

$$S_m^{S2} = \begin{cases} x-(m-1)s2 & \text{if } (m-1)s2 < x \le ms2 \\ s2 & \\ (m+1)s2-x & \text{if } ms2 < x \le (m+1)s2 \\ s2 & \\ 0 & \text{otherwise} \end{cases}$$

$$S_p^{S3} = \begin{cases} x-(p-1)s3 & \text{if } (p-1)s3 < x \le ps3 \\ s3 & \\ (p+1)s3-x & \text{if } ps3 < x \le (p+1)s3 \\ s3 & \\ 0 & \text{otherwise} \end{cases}$$

where:

$s3 = abs(a)s1 + abs(b)s2$ $(a.n.s1+b.m.s2)/s3$ if $a > 0,\ b \ge 0$

$n = \{... -2, -1, 0, 1, 2, ...\}$ and $k = [a.n.s1+b(m+1)s2]/s3$ if $a > 0,\ b < 0$

$m = \{... -2, -1, 0, 1, 2, ...\}$ $[a(n+1)s1+b.m.s2]/s3$ if $a < 0,\ b > 0$

$p = [k]$; integer floor of k $[a(n+1)s1+b(m+1)s2]/s3$ if $a < 0,\ b < 0$

Fuzzification of system consists of following fuzzy rules::

IF x is S_n^{S1} S_{n+1}^{S1} AND u is S_m^{S2} S_{m+1}^{S2}

THEN

dx/dt is S_p^{S3} S_{p+1}^{S3}

This approach can be extended to MIMO linear systems and to nonlinear systems:

$dx/dt = f(x,u)$

$x(t0) = x0$

if function f statisfies some conditions.

Implementation;

MIX system is composed from:

- editeur module;
- supervizor module;
- numeric module;
- symbolic module;
- fuzzy module.

The editeur module is loaded to construct a valid model (without loops). The supervisor module controles the system and loads other modules when need.

6. Concluding remarks

The system described above can be applied to both numeric and symbolic modeling.The application we implemented refers to a large scale hidrological systems, composed from a network of large lakes interconnected by canals and channels.

We wish especially to thank the Mr. J.-Ch. Pomerol, laboratory director of LAFORIA, for his suggestions and his support on this work , and thanks again to the French " MESR ", which has accorded to Mrs. M. Moise a fellowship of the LAFORIA. Each of these participants should contribute to the opening of some better joint research in this field.

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