

# GAPS BETWEEN RESEARCH AND INDUSTRY RELATED TO MODEL BASED AND QUALITATIVE REASONING

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## 1. INTRODUCTION<sup>1</sup>

The technologies for model based and qualitative reasoning have advanced to a mature state. However, the use of these technologies by Industry is still rare.

The purpose of this document is help provide an understanding for this by cataloguing the main gaps which are perceived between the technical state of the art in research and the Industrial needs. This paper outlines several problems and issues that together describe why these technologies are not used much by industry.

Now is the time to increase the use of these technologies in industry and it is hoped that by more clearly understanding these gaps, bridges can be developed to cross them.

## 2. OVERALL GOALS

The analysis initiated in this document was originated to help achieve the long-term goals of the European Network of Excellence MONET (*MONET, 1997a*). MONET counts 50 member organisations throughout the EC. At present, network members include major European research institutions & universities, high technology SME's, large systems providers as well as end users.

A principal objective of MONET is to define a vision of the future in the technological area it addresses. It should establish an explicit "technological strategy-plan" for the R&D that will lead to the fulfillment of the vision. Such a strategy-plan provides a framework in which the projects of the different members of the network could fit. Within the strategy-plan the NoE adopts concrete activities to achieve their objectives.

MONET aims at establishing MBS & QR methods as an accepted underlying technology for industry through a wide base of applications and an integrated research effort. This involves achieving a steady flow of technology transfer, especially into SMEs, as well as the identification of technological gaps and new application areas. The wide recognition of the value-added benefits of MBS & QR methods for product development and manufacture is also essential.

In summary, MONET should provide a clear picture of the directions in which to go in order to fill the holes between MB and QR techniques and the industry needs.

The two main questions that arise are:

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Why are model-based systems difficult to get in use ?  
Which research lines and strategies should be undertaken ?

### 3. STATE OF THE ART IN RESEARCH VERSUS INDUSTRIAL NEEDS

The technology of model based systems and qualitative reasoning (MBS&QR) can be considered in its early adolescence. The technology are capable of helping with many complex problems, but needs to mature further before it can reach its full potential. Several real world products and advanced systems are now available and many advanced prototypes have been demonstrated (MONET ILC, 1998)(Cauvin et al., 1998).

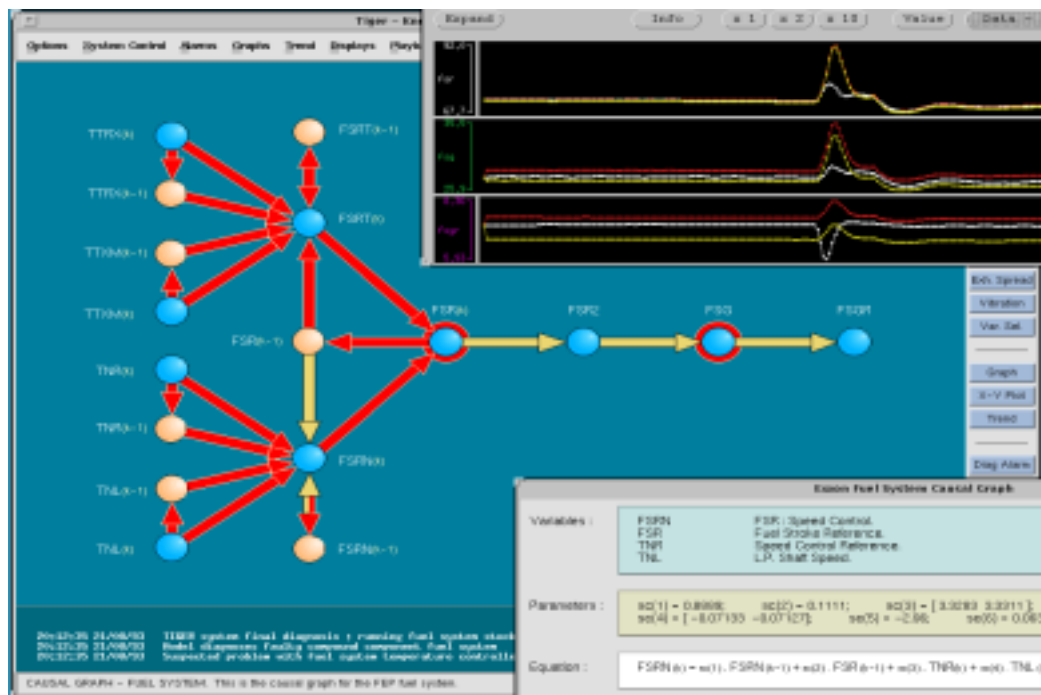


Figure 1: Qualitative Simulation and Model Based Fault Isolation in TIGER

The needs of industry stem from standard problems throughout many industries, that is, they are common needs for which many classical technologies may be able to help. However some problems have persisted, implying that these approaches are not enough to address the problems. Hence it is hoped that these technologies can make a new contribution.

The main needs are for faster product development and the ability to update existing products faster. Even when time is not the most critical factor, cost is. And reducing the time and skill requirements leads to significant cost savings. Once a product has been released, industry still needs better mechanisms to support products through their life cycle. For this reason, diagnosis has been a major focus for the application of MBS&QR technologies. Another problem that arises from the rapid product cycles is the need to understanding how systems will work before fully specified. Qualitative simulation has been shown to play a crucial role for this. Finally, for many complex systems, providing completeness is a strong requirement.

However, the industrial view is rather pragmatic: they want improvements, but they want them with short term economic returns. (Milne 1992) The result of this is that the perceived risk must be low enough and the capability of the technology high enough that a success from applying these technologies does not take long. (Milne 1994b) Fortunately, we feel that the technical state of the art is such that much of this can be achieved and that MBS&QR techniques can play a major role.

This approach is made possible by the use of concepts and techniques taken from the qualitative reasoning area of Artificial Intelligence (Weld and de Kleer, 1990) (Travé-Massuyès et al., 1997) (MQ&D, 1995). This research area was originally motivated by the idea of providing machines with reasoning skills about the physical world which would be based on common sense reasoning. It

aimed at proposing general formalisms allowing one to abstract the qualitative features of complex systems in the form of « qualitative models » as well as methods, such as qualitative simulation, which would make these models operational. Qualitative formalisms and methods are particularly useful in representing and dealing with imprecise, uncertain or incomplete knowledge.

Within the scope of MBS&QR research are included most forms of model-based reasoning and qualitative reasoning, including: functional and causal modelling, qualitative modelling, modelling ontologies, abstraction, aggregation and approximation, integration of mixed models, fuzzy QR, qualitative conceptual modelling for spatial, functional, kinematics and dynamic design. (*MONET, 1997b*)(*MONET RC, 1998*).

Model-based systems and qualitative reasoning techniques have the potential to address many of the industrial needs (*Cauvin, 1998*) (*Travé-Massuyès and Milne, 1995*). They have been shown to be particularly useful for applications requiring reusability, or when it is not possible to identify or enumerate all the rules, due to complexity or lack of information. This makes them very important in the context of knowledge management. Moreover, they facilitate explicit capturing of the underlying causality of physical phenomena and how they interact, thus providing good prediction capabilities and support for explanation (*Hamscher et al., 1992*) (*Console et al., 1994*). These techniques rely on two main ideas: the first is the separate representation of process knowledge and task knowledge, and the second is the representation of process knowledge at a sufficient level of abstraction.

In summary, the techniques from model based and qualitative reasoning are well placed to help industry with a range of needs from rapid product development, to enhanced life cycle support to understanding complex system. The potential is near, but there are a number of critical gaps that must be addressed to allow these technologies to help industry more.

## 4. THE GAPS

In this section, we provide a summary of the main gaps as they are perceived today. We use a broad definition of “Gaps” which includes at least two main viewpoints. Firstly a gap is something that is missing. i.e., there are no easy to use demonstration tools. Secondly, a gap is a major barrier and represents a chasm in the sense often used in new technology lifecycles. For example, the fact that creating a model is difficult is a barrier to rapid application development and hence a chasm that must be crossed.

The gaps are divided into three main areas:

- Technical Gaps result from technical shortcomings in the state of the art;
- Human Gaps result from Managerial or Organisational issues;
- Economic Gaps result from the understanding of the cost benefit of MB&QR approaches.

### 4.1 Technical Gaps

#### 4.1.1 Any Kind Of Modelling Is Difficult

Several technologies are available to describe a system: rules, blind methods, i.e. black box modelling, neural network based methods, or deep modelling in which the models are obtained from first principles.

Although model based methods have many advantages, describing any nontrivial system is a complex task and is never easy. It is not our purpose to say that the technologies being considered here are better than previous methods such as rules. Rather it is important to remember that modelling is not trivial and hence we should not expect it to be easy when using these technologies. Getting an accurate description of any complex system is non trivial and is likely to remain so.

*However*, modelling works well at the design stage; two possible reasons are :

- it is undertaken as an incremental task, a device/system is rarely designed from scratch.
- the allocated budgets are very significant.

One problem is that it is generally difficult to capture the critical modelling knowledge after a system is in regular usage, since much of the critical information is known at the design stage and then not passed further down the life cycle. The critical modelling knowledge of the design stage is hence lost instead of being reused.

This issue often manifests itself as a difficulty in getting the information needed for modelling for a system that has already been constructed. Indeed, organisational factors in the companies make difficult the exchange of information.

One problem, for example, is that a model based system would be helpful for the field service organisation. But the critical information is only known to the design department. The design department has no motivation to help the service department and might now be working on a very different project. Even at design time, it is likely that the design department does not have a requirement or motivation to provide the information for later parts of the life-cycle.

Conversely, it may also happen that the design department may gain from the knowledge of a given service department. For instance, there are significant benefits from combining the design with the maintenance and diagnosis process. Very often indeed diagnosis is not adequately capable of identifying faults because the diagnosability problem which answers the question of where to put the sensors was not addressed during the design stage. Many other situations exist in which significant gains could be made from circulating the information much more intensively, and in « normalised » forms, among the different organisation departments.

*However also, models are widely used in Industry:*

- Mathematical models: differential equations, etc.
- Structural models: block diagrams, flow sheets, etc.

They are intensively used for analysis and training purposes, like the large simulators for instance, but generally not in an operative way. The fact that non-optimal solutions are in use today gives us a reason for optimism. Industry is already accepting a less than perfect solution. If we can improve on this, everyone benefits.

Through a combination of setting realistic expectations and using information from earlier in a systems life cycle, these technologies can help to improve what industry does today.

#### ***4.1.2 Tools For Automated Model Building Are Still Missing***

It is highly desirable to build models from data that already exists, ideally in an electronic form. This saves the need to re-input the data and possibly to have to redefine the information.

Today, modelling is a specialised, hand crafted process dependent on the model based environment to be used. For example, tools do not exist to take existing standard data and build appropriate models directly from that data. There is not currently a standard methodology or approach to making models, which makes the provision of automated model building more difficult.

It is often claimed that better libraries of models are needed in association with the reasoning engines. Building a model based system would indeed be much easier if a library of components already existed for a system. Prototyping would be greatly facilitated. However, who has the motivation and benefit to build the model library. The current researchers do not have to do this as part of their work but in industry they do not have the skills to build the libraries and the cost of building the libraries makes the cost of a project much higher. In conclusion, it is too expensive for industry to build some model based systems without a library, but it is not the task of the researcher to make the library.

However, some « modern » quantitative modelling techniques exist and are used in industry. For instance the SIMULINK package provides an object-oriented representation of the models and is well-suited to compositional modelling, i.e. primitive models can be assembled to a global model. Other simulation packages even provide an initial library of models for the most common devices. Where possible, model libraries should be built, although this is likely to only be for restricted application areas and tasks.

The problem comes indeed from several facts:

- the « modern » modelling tools do not include « modelling intelligence », i.e. the methodology is left to the user and modelling remains a specialised, hand crafted process depending of the model based environment to be used.
- libraries of models do not solve the problem in many application domains in which the component models cannot be context-free. For example, many times one makes a linear approximation to a non-linear system. The range over which this approximation is valid depends on the use of the model.
- Industry provides a high diversity of products, even when the needed device function is standard. They also have many variations, which require small changes in the models and model structure. This is actually a good reason to use qualitative model based techniques but such abstracted models may not be adequate to the task.
- a related problem is that it is impossible to automatically identify the type of components from electronic information. For example, determining what options are fitted to a car, a gas turbine or the exact type of valves used in a process plant. What would be nice is something like Plug and Play under Windows 95, where the system automatically detects what components are present. Otherwise, many problems are introduced when the system is not configured as expected.

It should be noted that our own model-based diagnosis techniques can be used to debug the models, hence providing valuable aid to the modeller. Testing and debugging a model can be quite difficult, and more use should be made of using the techniques within model based diagnosis to make that more straightforward. A few contributions to this problem have already been presented in the DX workshops.

What is needed is a wide range of tools to assist with mode building from existing electronic information and to transform a model in the form that is adequate to the task. It is unlikely that a single solution will address the wide range of problems in industry.

At the moment, several techniques are already available but they are still sparse and generally solve a very local problem. For example, the parameter identification techniques (*De Nicolao, 1997*) which come from the dynamic systems control community and have been intensively used for many years. These techniques are able to tune the parameters of a model in accordance with the measurement data which is available. They are a very useful step forward although it cannot be ignored that they leave the choice of the model structure to the user. Machine learning techniques have been proposed to solve the model structure problem as well (*Schut and Bredeweg, 1996*) (*Xia and Smith, 1996*). Although they generally end up with a solution, the solution is often poor in the sense that it is too complex and very difficult to interpret.

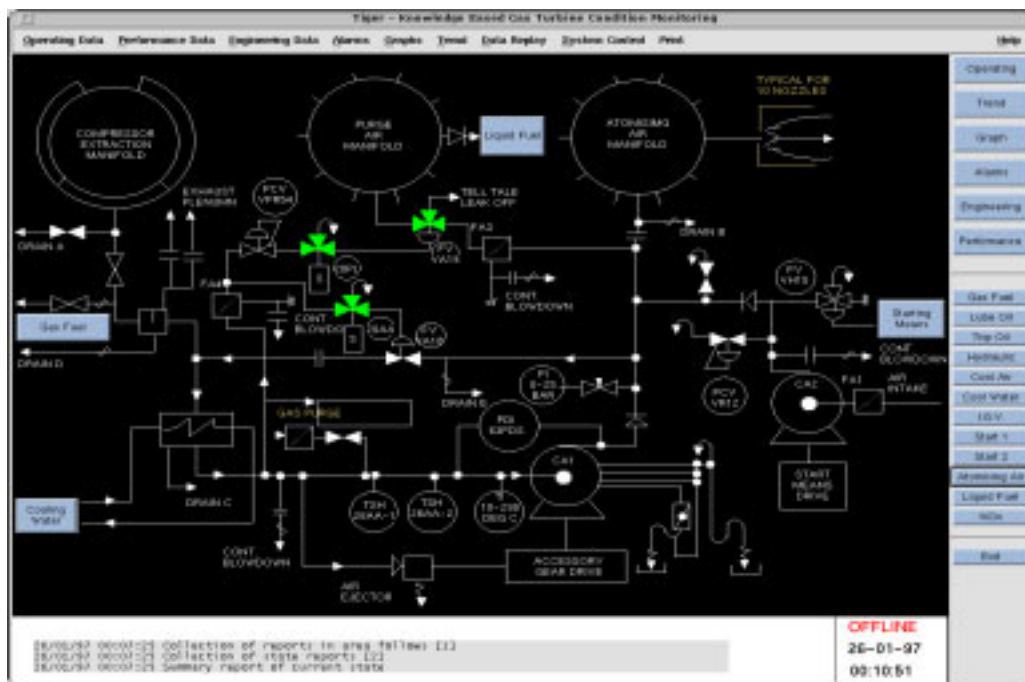


Figure 2: An Electronic Description of a Complex Plant

Transforming a model in a given form into another form which is more adequate for solving the task at hand has also deserved a lot of attention in the last few years. Just to mention a few of them, causal ordering techniques allow one to derive the causal structure of a model given as a set of algebraic and differential equations (Iwasaki and Simon, 1994) (Travé-Massuyès and Pons, 1997). The causal structure is then highly valuable for explanation or diagnosis purposes. It has been shown that automata models can be used to generate chronicles representing faulty or normal situations (Bibas et al., 1996), the chronicles can then be used as reference in a chronicle recognition approach (Dousson et al., 1993).

#### 4.1.3 Problems With The Integration Of Our Systems Within A Whole Industrial Software Environment

A good integration of model based techniques with existing software environments is very important. But there are major problems in that many existing software environments are not easy to integrate with. This is particularly true for systems that are using large custom developed software which was developed by a third party. For example, the software used by technicians in an automotive garage might be developed by a company different than the automotive company, and so the integration is more complex.

Another problem is that companies might use particular specialised databases or storage systems that require specialised interfaces to the model based system (Travé-Massuyès and Milne, 1997).

These issues are not unique to model based systems but are standard problems of any integration of additional software into existing environments. However, they are major problems in the process of integrating model based systems.

#### ***4.1.4 The Limitations And Boundaries Of Our Approach And Technology Are Not Well Assessed And Characterised***

As with any other approach, ours has limitations with respect to some practical issues. These limitations need to be assessed and accepted if one wants to provide better solutions. (*Travé-Massuyès and Milne 1996*) However, it should be emphasised that there are no absolute limitations. Limitations are relative to the problem to be solved and the application domain. For example, imprecision propagation in qualitative/interval dynamic models may be prohibitive for behavior prediction purposes, i.e; applied to simulation algorithms whereas it may be considered as quite acceptable for fault detection and/or isolation purposes which just requires prediction a few temporal steps ahead.

Having in mind the above comment, let's point out a number of commonly referred to limitations:

- the branching problem of qualitative simulation;
- imprecision propagation and spurious behaviors;
- non loop-free model structures;
- non context-free models and the modelling ontology;
- the combinatorial exposure and computation complexity; etc.

As a matter of fact, the properties of modelling systems need to be intensively studied with respect to the decidability, algorithmic complexity and approximation issues.

These problems may be prohibitive in numerous application domains in which complementary techniques are necessary. This underlines the importance of several currently very active research topics:

- methods proposing focusing strategies;
- multi-model reasoning, i.e. using models implementing different view points (functional, behavioural, structural, topological, etc.);
- Collective co-operative architectures.

## **4.2 Human Gaps**

### ***4.2.1 Problems With The Integration Of Our Systems Within A Whole Human Environment***

Most of our systems are not intended to run in closed loop; they are rather presented as an aid to the human operators (See Figure 3). This raises the problem of how to get the systems accepted and really used by the human operators and comes back to the human-machine co-operation issue. It hence points out obvious links with the cognitive science community, and particularly with the research human factors.

In practice, these links have been rather weak so far. The original motivations of QR are definitively cognitive and they have led to psychologically intuitive reasoning formalisms but the MB & QR community has most often than not tackled the problems from a technical view point. This is different for the cognitive community which indeed considers the human being as the central object.

As a matter of fact, the contributions of each community should be assembled, each of them providing solutions from the two ends of the problem. Take for instance the example of process supervision: MB & QR researchers provide systems which are able to assess the situation of the process and run fault detection and isolation procedures supported by psychologically plausible models of the physical phenomena. On the other hand, psychologists work on the problem of assessing human operators reasoning in dynamic environments and ergonomics draw out the

features of well-adapted interfaces. Integrating our systems to their interfaces might definitively be a way to touch the Industry.



Figure 3: A Typical Control Room

From another point of view, it might be interesting to consider putting our systems in use in operators training courses. A good environment for introducing new technologies into industry is indeed through the training environment, and yet very little discussion takes place currently, of using AI and model based systems in this way. The community might penetrate industrial applications better if they targeted training systems more carefully.

#### ***4.2.2 Operative People Have No Modelling Background***

There is often a difference of skills on project teams. The people that know about the operation of the system generally know nothing about aspects of modelling and how to build appropriate models. At the same time, very often, the researchers do not know the end user systems and so this lack of common knowledge creates difficulties. This is not surprising, since each area requires considerable training, and one cannot train in all areas. There are methodologies to address these difficulties, but they still cause barriers.

The outlook for this is getting better. More and more, companies are working in teams, each member having a particular speciality. Also the role of research for R&D groups is changing. Traditional research groups are working more and more on development and learning more about how the products of their company. This is slowly closing this gap, but careful management of the teams is still needed to ensure success.

#### ***4.2.3 Our Techniques Have Not Been Compared To The Techniques Of Other Communities Concerned With The Same Tasks - A Clear Picture Of What Is Available Is Needed***

After about 15 years of vertical investigations, it is now the time to work more deeply along the horizontal axis, i.e. taking as a starting point the tasks for which MB and QR techniques provide solutions.

One can unfortunately notice that there is considerable misunderstanding and misuse of terminology in other areas when they discuss model based reasoning. People that are only partly familiar with the field also understand a number of past problems and limitations that may not be issues currently. The best approach to this is to work in a co-operative way to show how the techniques fit together to identify the common misconceptions and try to clarify these.



For example, for the diagnosis task, it is becoming increasingly clear that there is an overlap between the techniques used by the AI, the control and the statistics community. This overlap is beneficial technically, but can be confusing to end users who do not understand whether these techniques are competing or complementing each other. It needs to be made more clear how the techniques can work together, what they have technically in common, and what is available to address specific problems.

It is now clear that there are a variety of techniques each one very capable in a specific area, but not one technique doing everything. In addition, different techniques require different types of information. For a large scale system it is unlikely that only one type of information and one approach will be adequate for the solution. Hence, a further step is to work for providing systems which associate several methods.

#### ***4.2.4 Model Based Demo Systems Are Missing For A Company To Get Started***

In the area of neural networks if someone wants to experiment, it is very easy to find a free neural network environment to rapidly set it up and do some examples of neural network applications. The same is not true in the model based area. Modelling and simulation packages may be useful to build the models but there are no easy to use demonstration packages of MB environments where one can rapidly build up an interesting demo and see the concepts. Even if the demo system doesn't solve a real problem, it is needed to demonstrate the concepts.

Unfortunately, there are not easy to use beginners tools for these technologies. The tools that are commonly used require programming skills and an understanding of the technology. The tools are not robust or designed to be used with other systems. More importantly, they are not commercially supported.

Although the research community has a number of development tools such as QSIM or GDE, these are not designed to let people experiment with model based reasoning at low cost and not directly available and suitable for industry.

There are several European developed tools such as Ca~En and SQUALE, but these are not freely available. Europe has produced at least 2 commercial products, but these are not available for small scale trials, or free play about sessions. Unlike the Neural networks area, there is very little in the way of promotional demonstration material. This is made difficult because the tool is different for every different task; just the concept of being supported by models is common. What is needed is a range of simple to use introductory tools with tutorials that can be made freely and available on the Web.

#### ***4.2.5 Helping With Safety Critical Problems***

Model based approaches offer a great attraction because of the automated analysis of completeness for safety critical systems that could be very useful. However, to date there are no applications that demonstrate to others that this has been accomplished. A potential benefit of any new technology is to reduce the number of operators needed to control a plant. However, most companies prefer to use systems based on new technologies as advisory system, with an operator making the final decision. This means that the cost savings are reduced and hence the motivation for the user company. The potential for these technologies to contribute to this area is still strong, but more application demonstrations are needed.

#### ***4.2.6 MB&QR Approaches Are Not Well-Integrated Into Engineering Lectures***

A much greater number of students —and hence potential future users— would be exposed to qualitative and model based reasoning if presentations on this subject could be made in a wide variety of lectures. For this to be achieved, teaching material needs to be prepared so that a lecturer not familiar with these technologies can still make a competent presentation.

### **4.3 Economical Gaps**

#### ***4.3.1 Presentation Of Our Methods And Expertise To The Industry Is Not Based On Marketing Issues : How Much Money Do Our Systems Save? Which New Problems Do They Solve?***

It is a fact that up until now, most of the work in the model based and qualitative reasoning communities have been by technical people who are interested in the technical aspects and how they can technically solve the problems.

In order to have an increased uptake within industry of the model based techniques, the presentations have to be on the financial and benefits side. (*Milne 1994a*) More work is needed to close this gap. This is a common problem in many sectors and with many technologies. The way forward is to have more people understand the industrial needs AND the capabilities of the technology well. This process is well understood and can be managed. People who understand industrial needs in specific sectors need to learn more what the technology can do. At the same time, those that understand the technology need to understand well specific industrial sectors. From this ‘market research’ the needs that can be addressed in the short term can be best identified.

#### ***4.3.2 There Are Very Few Model-Based Systems Of Any Kind Used In Regular Use***

Although the technologies have matured, there are very few real model based reasoning systems in regular use in industry. (*Milne 1991*) In the diagnosis domain for instance, the systems that are in use are generally based on very simple and conservative principles, like associating fixed alarm thresholds to critical variables. Neither the AI nor the control model-based technologies are really in use. This reduces the number of case studies and the examples for new industrial companies of what can be accomplished. Steadily this problem will be reduced, but today it is an issue that there are few real applications to give confidence to other industrial companies.

#### ***4.3.3 Care For Maintenance Should Be Put In Our Models And Our Systems - Models Must Be Easy To Evolve***

It can take considerable effort to build the initial model based system, but once the main systems evolve, if the model based system can not be evolved rapidly, it will not be used further. Many projects focus only on the development of the models but proper planning should be put in place to update the model based system as the primary system evolves. What is ideally required is a method to automatically update the models periodically both as the characteristics of the system change and the components of the system change. The current state of the art is not adequate to give industry good reassurance on this.

Many systems age or reduce their efficiency over time. Mechanisms need to be in place so that the model based system changes appropriately to anticipate and respond to this, otherwise it will no longer be accurate and will be rejected.

## 5. SUMMARY

In this paper we have provided a summary of the main gaps and issues between the technical state of the art for model based and qualitative reasoning as it exists in the research community and the need of industry to begin using these technologies seriously.

It is hoped that by making these gaps more explicit, ways can be found to close them.

A lot of work in the past has been focused on technical engineering systems such as electronics, automotive or process industries. However, it should be noted that there is considerable potential for model based techniques in many other areas:

- important non-engineering domains such as the medical and ecology areas;
- the software debugging, verification, and validation area, in which modularity and completeness are critical issues.

This paper has outlined the gaps that exist focusing on technical domain. Now, the needs in other domains might be slightly different. Although we believe the technical gaps remain the same, human and economical factors are radically different and would require a deeper analysis for exhibiting the gaps at these levels.

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