# FINAL PROJECT REPORT
## Progress and Evaluation

**KUN, all**

Revised version October 2006

# AMETIST DELIVERABLE 0.1.6

Project acronym: AMETIST
Project full title: Advanced Methods for Timed Systems
Project no.: IST-2001-35304
Project Co-ordinator: Frits Vaandrager
Project Start Date: 1 April 02
Duration: 39 months
Project home page: http://ametist.cs.utwente.nl/

## Consortium

| *No* | *Name* | *Short name* | *Country* |
|---|---|---|---|
| 1 | Katholieke Universiteit Nijmegen | KUN | NL |
| 2 | Robert Bosch GmbH | Bosch | D |
| 3 | Cybernetix Recherche | CYR | F |
| 4 | Axxom Software AG | Axxom | D |
| 5 | Terma A/S | Terma | DK |
| 6 | Aalborg University | AAU | DK |
| 7 | Universität Dortmund | Uni DO | D |
| 8 | VERIMAG | VERIMAG | F |
| 9 | Weizmann Institute of Science | WIS | IL |
| 10 | Laboratoire d'Informatique Fondamentale de Marseille | LIF | F |
| 11 | University of Twente | UT | NL |

# Contents

# 1 Industrial Objectives and Strategic Aspects

The following description of the objectives of AMETIST has been taken from the Technical Annex.

AMETIST intends to contribute to solutions for the growing industrial need to design reliable and efficient time dependent systems. In particular, it intends to provide theory and tools for error-detection, control and optimisation of real-time distributed systems. Its approach will be based on translating state-of-the-art academic research into methods and tools that can be a basis for an industrial design practice of such systems.

In addition to its technological contributions, AMETIST invests actively in knowledge transfer to the European industry of computer-aided timing analysis and design. Moreover, it is expected that the academic dissemination of the AMETIST research results will influence and advance the field of timed systems research, and (indirectly) contribute to the education of future generations of system engineers.

Whereas timed automata and the tools for their analysis are widely accepted in academia and are being used at hundreds of universities and research laboratories all around the world, they have yet to find their way into industry. The aim of AMETIST is to advance and mature the related models, tools, and methods to allow this situation to change.

The need for automatic tools that allow reasoning about time is evident. Beyond manufacturing, telecommunication and hardware, it is of essential importance for the growing market of embedded systems (from car electronics to home automation). However, there are several obstacles that seem to hinder the use of timed automata technology in industry at this time:

- Scalability: Currently, tools based on timed automata do not allow to handle big examples. There are industrial scale examples that have been treated with these tools but only after tedious manual simplification involving a lot of work in each case.
- Convenience: Current timed automata tools are stand-alone programs and their input formalisms lack important features for convenient specification in an industrial setting.
- Accessibility: To make optimal use of the currently available tools requires quite some sophistication on the user's part, which makes them practically inaccessible even to well-trained engineers.

AMETIST aims at the (at least partial) elimination of these obstacles. The project moves towards this goal along several tracks. One is the treatment of real-life case studies from some candidate application domains to see if, indeed, the proposed models, tools and methodology are suited for them. Indeed much of the project's resources are being spent on case studies. A second direction aims to improve the situation regarding scalability, by introducing better algorithms and data-structures to model and manipulate large systems, in particular in the area of real-time controller synthesis, planning and scheduling. Moreover, the project aims at tool interaction to allow the interfacing of different tools, which can help to improve usability/convenience. The third track aims at synthesizing the accumulated results in order to assess the applicability of the project's vision and modify it according to feedback from the field.

# 2 Achievements

Scheduling and resource allocation problems occur in many different domains, for instance (1) scheduling of production lines in factories to optimize costs and delays, (2) scheduling of computer programs in (real-time) operating systems to meet deadline constraints, (3) scheduling of micro instructions inside a processor with a bounded number of registers and processing units, (4) scheduling of trains (or airplanes) over limited quantities of railway tracks and crossroads, and (5) mission planning for autonomous robots on spacecrafts. Typically, in each of these domain problems are solved using different approaches and mathematical tools. The AMETIST project has provided the foundations for a unifying framework for time-dependent behavior and dynamic resource allocation that crosses the boundaries of application domains.

In the AMETIST approach, components of a system are modeled as *dynamical systems* with a state space and a well-defined dynamics. All that can happen in a system is expressed in terms of *behaviors* that can be generated by the dynamical systems; these constitute the semantics of the problem. Verification, optimization, synthesis and other design activities explore and modify system structure so that the resulting behaviors are correct, optimal, etc. Preferably, the limitations of currently known computational solutions should not influence modeling too much: only after the semantics of a problem is properly understood, abstractions and specialization due to computational considerations can intervene. In such situations, the soundness of abstractions should ideally also be proved, either via deductive verification or model checking. AMETIST has shown that this approach, which underlies the successful domain of *formal verification*, can be extended to resource allocation, scheduling and other time-related problems.

AMETIST has made major advances in the area of (timed automata based) tools. Several (new versions) of tools were released, implementing algorithmic ideas that have been developed during the first two years of the project. Tight connections and interfaces between all of these tools exist or are currently being developed. Figure1 presents an overview of the tools that have been developed (or used) within AMETIST (we refer to Deliverable D2.5.b [47] for a more detailled overview of their functionality). We have classified these tools along two dimensions: (1) the total number of AMETIST PM's spent on their development during the whole lifetime of the project, and (2) the "maturity" of the tool on a scale of 0 (academic prototype, minimal user interface, for internal use only), to 1 (industrial, commercial, good support, widely used). All numbers are rough estimates. Assessing maturity, of course, is a difficult exercise anyhow.

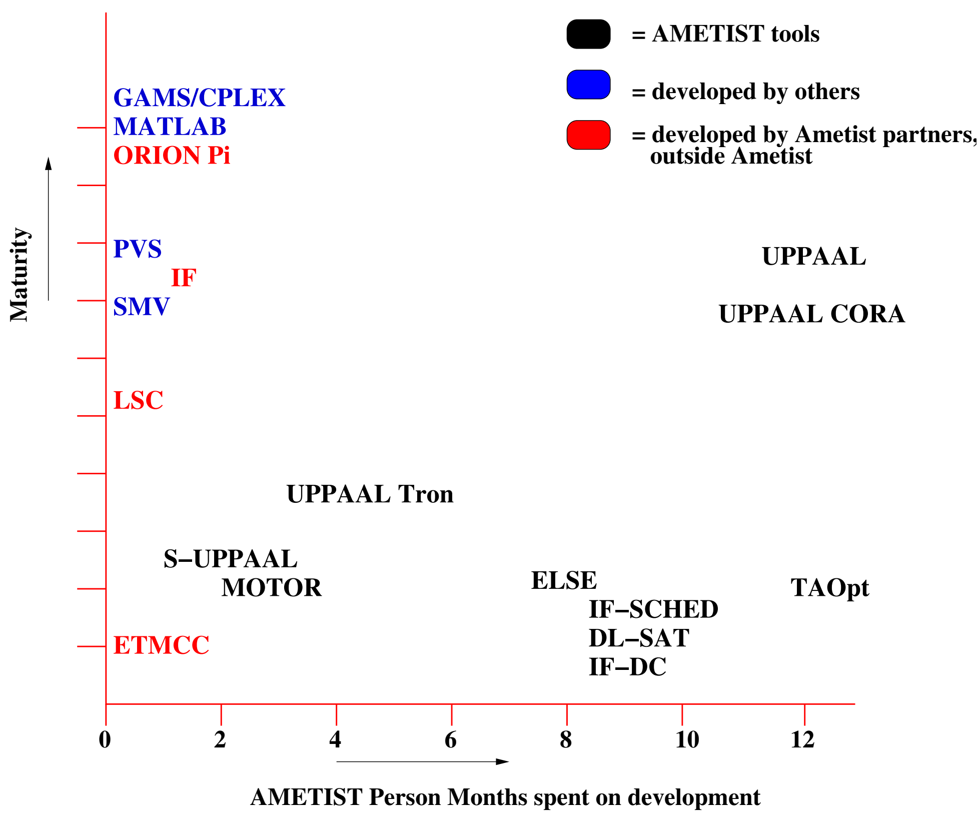


Figure 1: Overview of the tools developed/used by AMETIST.

As becomes clear from the figure, there is a spectrum ranging from tools such as UPPAAL, which have a very nice GUI, are easy to use, and although academic have almost industrial quality, to highly experimental tools such as ELSE which helped us to test the viability of some new verification approaches (partial order reduction, symmetry, model checking via constraint solving,..).

If we compare the current capabilities of these tools with what existed at the start of AMETIST, then it is fair to say that indeed we have moved the state-of-the-art to a new level of maturity (one of the main objectives of the project). At the start of the project, only UPPAAL existed and some precursors of UPPAAL CORA and IF-SCHED. In terms of scalability, convenience and accessibility UPPAAL was much less mature (it was about as mature as UPPAAL Tron is right now). The performance of UPPAAL has improved several orders of magnitude.[1] Also the convenience of using the tool has been greatly improved due to the enriched expressiveness of the input language and connections with other tools. Nowadays even high school students find it easy to modify and build timed automata models using the improved GUI. Through the website and new tutorial papers (such as [92]) the tool has become very easily accessible.

Profiting from the new tools, the AMETIST consortium has tackled more than 20 industrial sized case studies which were provided by our industrial partners (Bosch, CYR, Axxom, Terma) or obtained from other sources. The general conclusion is that using our new methods we can handle bigger problems faster and in a much more routine manner than at the start of the project. Using UPPAAL CORA, for instance, we succeeded to derive schedules that are competitive with those that were provided by industrial partner Axxom using its own tool Orion-Pi. Our experience with the AXXOM case study shows the application of model checking techniques for scheduling is promising. Still, timed automata are not yet a push-button technology to be applied without problem specific modeling and solution strategies. But the generation of libraries of templates for typical configurations seems promising and appears as a path towards to more widespread and easier application for non-TA-specialist users. Considerable further work on modelling methods, reusebility of modelling patterns, identification and evaluation of heuristics, compasison with alternative approaches, all in the context of case studies of greater orders of magnitude, is needed to develop it into a readily applicable standard technique for scheduling.

# 3 Recommendations by the Experts

In this section, we discuss the recommendations from the Technical Evaluation Report based on the Third Review (i.e., report from December 8, 2004, based on the review meeting that took place November 23, 2004).

### Recommendation 1

> *Focus most of the work around two of the case studies: the Axxom case study and the Cybernetix case study. The experts urge the consortium to devote major effort on these two case studies while strongly limiting the effort for the Terma, Bosch and miscellaneous case studies.*
>
> *The consorium is encouraged to concentrate about 60% of the effort on these two case studies and relevant benchmarking. The Bosch and Terma case studies shall be consid-*

[1] The following major changes (not easily quantifiable as a single number) in particular boosted the performance:

- New extrapolations: Several orders of magnitude for some models (e.g. Fischer).
- New internal representation of states: Approximately factor 3 memory reduction.
- Liveness checker and deadlock checker: Speedup of factor 2-4.
- Remodeling with extended subset of C: Depending on the model this may provide a speedup of factor 2.
- Optimizations for handling models with a huge number of concurrent components and optimizations for handling systems with a huge number of deadlocks: if applicable, one order of magnitude.

For CORA the change in how the infimum operation is computed gave about one order of magnitude, and other CORA specific optimizations have provided another speedup with a factor 2-4 (depending on the model).

> *ered as stopped or treated as "miscellaneous" case studies, requiring only a very small portion of the resources in the third period, i.e., less than 2 person months per study.*

Since the 3rd review, major effort has been invested in relevant benchmarking, and preparing publications and the final deliverable for the Axxom case study (the equivalent of 5 to 6 persons full-time). The effort invested in the Cybernetix case study during the final period has been very small and only partner LIF has worked on it during the final period. The effort on the Bosch case study since the 3rd review has also been very small (about 2 weeks by one person from KUN). Also, partners KUN and UT each spent about 1 PM to finalize publications reporting on miscellaneous case studies. Following the 3rd review, effectively no AMETIST resources were invested in the Terma case study.

**Recommendation 2**

> *The final deliverables on technologies and tools (D2.x.y) shall provide qualitative and quantitative assessment on the progress made as part of the* AMETIST *project, on the "scalability", "convenience", and "accessibility" dimensions. As suggested by the consortium, an integration graph, showing the connections between the different tools, shal appear as part of D2.5.b. For each tool, a summary of the improvements made to the tool during the course of the project shall be provided.*

A qualitative discussion of the progress made by AMETIST has been included in all final deliverables on analysis and tools (D2.x.y). Quantitave evaluation of the tools UPPAAL CORA, ORION-Pi, Moebius, IF and TAopt on the Axxom case study is provided in deliverable D3.4.4 [49]. In D2.5.b [47] a summary of the improvements made to each tool during the course of the project is provided.

**Recommendation 3**

> *The final deliverables on case studies (D3.x.y) shall provide qualitative and quantitative assessment about how technology and tools developed as part of* AMETIST *help in representing and solving the problems under consideration. This is particularly important for deliverables D3.1.4 (Cybernetix case study), D3.4.4 (Axxom case study) and D3.5.3 (miscellaneous). We suggest that deliverable D3.5.3 includes a summary table showing for each application the advantages provided by the technology developed in* AMETIST.

This has been done.

**Recommendation 4**

> *Concerning the future strategy on tool integration, the consortium should limit its efforts in terms of research, development, promotion, dissemination activities, solely to those tools out of which consolidation and validation is feasible within the lifetime of the project.*

During the last year, partner AAU seriously invested in the development of UPPAAL and UPPAAL CORA. For both tools, consolidated versions have been made publically available on the web. Only a small fraction of the development work on Uppaal Tron, IF-DC, MoDeST and MoToR was funded by AMETIST. During the last year, partners AAU and KUN made a very limited investment (< 1PM) to prepare the integration of S-UPPAAL in the main version of UPPAAL. (Due to lack of time this integration has only taken place after AMETIST has ended.) No major effort was invested in IF-SCHED during the final year of the project. The development on ELSE, TAopt, and the DLSAT solver for difference logic is the main goal of three PhD theses which are (have been) written in the context of AMETIST. Even though these prototype tools will not be consolidated/validated within the lifetime of the project, practically it was impossible to change the course of these PhD project at this point. Scientifically, we believe the results from these three theses are very interesting.

**Recommendation 5**

> *Identify joint activities and synergies to use the results of the project in future strategic research projects and as part of the HYCON and Artist2 Networks of Excellence. The consortium is asked to prepare a two page document explaining the possible joint activities with the NoEs identified.*

Done, see Section 7.3.

**Recommendation 6**

> *Resubmit the midterm progress report D0.1.5 making it consistent with what has been discussed during the review and adding the table for resource allocation for the period m25-m39.*

This has been done.

**Recommendation 7**

> *The consortium should finalise the technical work by m36 while devoting the last 3 months of the project, i.e. months 37-39 solely to documentation, dissemination and exploitation, in particular to prepare the final Ametist conference in June 2005.*

By and large this is what we did. However, in research it is virtually impossible to completely separate technical work from documentation.

**Recommendation 8**

> *To plan the exploitation routes, the consortium is strongly advised to establish and sign a consortium agreement that discusses and clarifies among the partners the Intellectual Property Rights (IPRs) issues.*

All partners have signed in a letter in which they delare "Hereby all partners within the EU IST project AMETIST certify that — as the research within AMETIST is (and has been) of a precompetitive nature — there are no IPRs issues that need to be clarified/settled via a consortium agreement."

**Recommendation 9**

> *The consortium should inform the Commission of its participation in future conferences, events and any publications prior to its submission or acceptance (obviously only if costs are going to be charged to the project).*

As previously agreed with the project officer (see Deliverable D0.1.4 [39]), the Commission has been informed in advance if partnes asked for re-funcing of travel expenses uitside the EU and for dissemination activities.

# 4 Key Events During Reporting Period

During the reporting period two regular project meetings as well as the first review meeting took place:

- On May 10, 2004, the second review meeting took place in Brussels.

- The new case study proposed by Bosch was presented and discussed during a special project meeting in Nijmegen on June 9, 2004. This meeting was attended by 10 persons from Bosch, KUN and UT.
- On September 20-21, 2004, a project meeting was held in Grenoble, France, organised by VERIMAG. This meeting was attended by 25 persons.
- On September 22-24, 2004, the second FORMATS workshop took place in Grenoble, sponsored by AMETIST. Out of 69 submission, 24 papers were selected for presentation. There were 55 participants, including a substantial number of students. We had participants from Esterel Technologies, Honeywell, Sun Microsystems, SRI International and NASA.
- Partner UTorganized the highly successful first edition on the QEST (Quantitative Evaluation of Systems) international conference at the University of Twente in September 2004. The proceeding are published in the IEEE CS series [156].
- On November 23, 2004, the third review meeting took place in Brussels.
- On January 13-14, 2005, a project meeting was held at the University of Twente, organised by partner UT, which was attended by 24 persons.
- On April 11, 2005, a meeting was organised in Nijmegen to fix the different verification benchmarks for the Axxom case study. Representatives of Axxom, KUN, UT, and Uni DO were present at this meeting.

The agendas and (most of) the slides for the above meetings are available on-line at `http://ametist.cs.utwente.nl/INTERNAL/MEETINGS/Meetings.htm`.

In addition to these meetings, several bi- and trilateral visits between partners took place. AMETIST members attended many conferences where they presented the results of the project.

# 5 List of Deliverables

| No | Description | Due Date | Delivery | Status | Resp Partner |
|---|---|---|---|---|---|
| 4.4 | AMETIST Website | May 02 | May 02 | accepted | UT, all |
| 0.1.1 | Project Rep. - Progress & Evaluation | Oct 02 | Nov 02 | accepted | KUN, all |
| 3.1.1 | Case Study 1: Prel. Description | Oct 02 | May 02 | accepted | LIF, CYR |
| 3.2.1 | Case Study 2: Prel. Description | Oct 02 | Apr 02 | accepted | AAU, Terma |
| 3.3.1 | Case Study 3: Prel. Description | Oct 02 | Sep 02 | accepted | Uni DO, Bosch |
| 3.4.1 | Case Study 4: Prel. Description | Oct 02 | Oct 02 | accepted | Uni DO, Axxom |
| **4** | Dissemination and Use Plan | Oct 02 | Oct 02 | accepted (qual.) | VERIMAG, all |
| 4.1.1 | AMETIST Workshop | Oct 02 | Apr 02 | accepted | VERIMAG |
| 0.1.2 | Project Rep. - Progress & Evaluation | Apr 03 | Jun 03 | accepted | KUN, all |
| 0.2.1 | Framework Report (v1) | Apr 03 | Jun 03 | accepted | VERIMAG, all |
| 0.3.1 | Financial Review | Apr 03 | Jun 03 | accepted | KUN, all |
| 1.5 | Modeling: Controller Synthesis | Apr 03 | Apr 03 | accepted | VERIMAG |
| 2.3.a | A & T: State Space Representations | Apr 03 | Jun 03 | accepted | LIF |
| 3.1.2 | Case Study 1: Model | Apr 03 | Jun 03 | accepted | LIF, CYR |
| 3.2.2 | Case Study 2: Model | Apr 03 | May 03 | accepted | AAU, Terma |
| 3.3.2 | Case Study 3: Model | Apr 03 | Jun 03 | accepted | Uni DO, Bosch |
| 3.4.2 | Case Study 4: Model | Apr 03 | Jun 03 | accepted | Uni DO, Axxom |
| 3.5.1 | Misc. Case Studies: First Year Report | Apr 03 | May 03 | accepted | UT, all CRs |
| 0.1.3 | Project Rep. - Progress & Evaluation | Oct 03 | Apr 04 | accepted | KUN, all |
| 0.1.4 | Mid Term Assessment Report | Apr 04 | May 04 | accepted | KUN, all |
| 0.2.2 | Framework Report (v2) | Apr 04 | May 04 | accepted | VERIMAG, all |
| 0.3.2 | Financial Review | Apr 04 | June 04 | submitted | KUN, all |
| **1.2** | Modelling: Model Composition | Apr 04 | May 04 | accepted (qual.) | KUN |
| 1.3 | Modelling: Quantitative Modelling | Apr 04 | May 04 | accepted | UT |
| 1.4 | Modelling: Scheduling and Planning | Apr 04 | May 04 | accepted | Uni DO |
| 2.1.1 | A & T: Abstraction and Compositionality | Apr 04 | May 04 | accepted | KUN |
| 2.2.1 | A & T: Control Synthesis Algorithms | Apr 04 | May 04 | accepted | VERIMAG |
| 2.3.b | A & T: State Space Representations (v2) | Apr 04 | May 04 | accepted (qual.) | LIF |
| 2.4.a | A & T: Stochastic Analysis (v1) | Apr 04 | May 04 | accepted | UT |
| 2.5.a | A & T: Tool Interaction (v1) | Apr 04 | May 04 | accepted | AAU |
| 3.1.3 | Case Study 1: Optimisation | Apr 04 | May 04 | accepted | LIF, CYR |
| 3.2.3 | Case Study 2: Optimisation | Apr 04 | May 04 | accepted | AAU, Terma |
| 3.3.3 | Case Study 3: Optimisation | Apr 04 | May 04 | accepted | Uni DO, Bosch |
| 3.4.3 | Case Study 4: Optimisation | Apr 04 | May 04 | accepted | Uni DO, Axxom |
| 3.5.2 | Misc. Case Studies: Second Year Report | Apr 04 | Apr 04 | accepted | UT, all CRs |
| 0.1.5 | Project Rep. - Progress & Evaluation | Oct 04 | May 05 | accepted | KUN, all |
| **0.1.6** | Final Project Rep. - Progress & Evaluation | Apr 05 | Oct 06 | submitted | KUN, all |
| **0.2.3** | Framework Report (final) | Apr 05 | May 06 | submitted | VERIMAG, all |
| **0.3.3** | Financial Review | Aug 05 | Oct 05 | submitted | KUN, all |
| **1.1** | Modelling: Model Classification | Apr 05 | May 06 | submitted | VERIMAG |
| 2.1.2 | A & T: Structure Exploitation | Apr 05 | Jun 05 | accepted | KUN |
| **2.2.2** | A & T: Scheduling and Planning Algorithms | Apr 05 | May 06 | submitted | VERIMAG |
| **2.3.c** | A & T: State Space Representations (v3) | Apr 05 | May 06 | submitted | LIF |
| 2.4.b | A & T: Stochastic Analysis (v2) | Apr 05 | May 05 | accepted | UT |
| **2.5.b** | A & T: Tools and Tool Interaction (v2) | Apr 05 | Oct 06 | submitted | AAU |
| **3.1.4** | Case Study 1: Final Report | Apr 05 | May 06 | submitted | LIF |
| 3.2.4 | Case Study 2: Final Report | Apr 05 | May 05 | accepted | AAU, Terma |
| 3.3.4 | Case Study 3: Final Report | Apr 05 | May 05 | accepted | KUN, Bosch |
| 3.4.4 | Case Study 4: Final Report | Apr 05 | Jun 05 | accepted | Uni DO, Axxom |
| **3.5.3** | Misc. Case Studies: Final Report | Apr 05 | Jun 05 | accepted (qual) | UT, all CRs |
| 4.1.2 | AMETIST Conference | Apr 05 | Jun 05 | accepted | VERIMAG |

# 6 Scientific and Technical Performance

For an overview of the scientific and technical results obtained by the project, we refer to the final deliverables of the various tasks in the three technical work packages, as listed in the table below.

| *Task* | *Name* | *Deliverable* |
|---|---|---|
| | **WP1 Modelling** | |
| 1.1 | Model Classification | D1.1 [53] |
| 1.2 | Model Composition | D1.2 [36] |
| 1.3 | Quantitative Modelling | D1.3 [38] |
| 1.4 | Scheduling and Planning | D1.4 [37] |
| 1.5 | Control Synthesis | D1.5 [25] |
| | **WP2 Analysis and Tools** | |
| 2.1 | Abstraction, Compositionality and Structure Exploitation | D2.1.1 [27] & D2.1.2 [46] |
| 2.2 | Control Synthesis and Scheduling Algorithms | D2.2.1 [28] & D2.2.2 [43] |
| 2.3 | State Space Representations | D2.3.c [44] |
| 2.4 | Stochastic Techniques | D2.4.b [45] |
| 2.5 | Tool Interaction | D2.5.b [47] |
| | **WP3 Case Studies** | |
| 3.1 | Cybernetix Case Study | D3.1.4 [50] |
| 3.2 | Terma Case Study | D3.2.4 [55] |
| 3.3 | Bosch Case Study | D3.3.4 [48] |
| 3.4 | Axxom Case Study | D3.4.4 [49] |
| 3.5 | Miscellaneous Case Studies | D3.5.3 [52] |

# 7 Dissemination

## 7.1 End-User Panel

The AMETIST project views its end-user-panel as an important means for interaction with the industry at large. The panel serves both as a dissemination channel for the project results and as a provider of feed-back on the development of the project. Panel members participate in discussions on future directions within the project and are kept informed about the developments as well as the technological perspective of the work.

The panel consists of representatives of companies that have expressed an interest in AMETIST and have committed to participate. In principle, the panel is an open forum and it is intended to attract more participants in the course of the project. Currently, eight companies and research labs participate in our panel:

- ASML (Rick van Lierop and Barend van de Nieuwelaar), Veldhoven, `www.asml.com`
- Philips Research (Lex Heerink), Eindhoven, `www.philips.com`
- National Aerospace Laboratory NLR (Ernst Kesseler), Amsterdam, `www.nlr.nl`
- Thales Naval (Ronald Lutje Spelberg), Hengelo, `www.thales-naval.nl`
- BMW AG (Heinz Treseler), Muenchen, `www.bmw.com`
- Kern Delta Systems (Mr Eberhard), Aachen, `www.delta-systems.de`
- Degussa AG (Markus Schulz), Hanau, `www.degussa.com`
- Carmen Consulting (Niklas Kohl), Copenhagen, `www.carmenconsulting.com`

Members of the end-user-panel were present at the project meetings in Munich, Nijmegen (Berg en Dal) and Cassis and provided useful feedback and some new case studies (both during and after the meeting). Just as an example to illustrate that transfer to industry has taken place. Last month partner KUN was contacted by ASML. On its own initiative, ASML had used UPPAAL to model kinematic calibration sequencing and to compute optimal calibaration sequences. Machines manufacturing at nanometer accuracy (high-precision machines) have to correct for all kinds of geometric imperfections. Many kinematic chain-based approaches have been described to correct for imperfections in the machine hardware. People at ASML were quite excited about the ability of Uppaal to deal with the degradation of geometric imperfections and to find the fastest calibration sequence.

## 7.2 Workshops and Conferences

The Ametist project was one of the main initiators and sponsors of the First International Workshop on Formal Modeling and Analysis of Timed Systems (FORMATS 2003) held as satellite event of CONCUR 2003 in Marseille, France, September 6-7, 2003. FORMATS and CONCUR were hosted by the *Université de Provence* and partner LIF. The proceedings have been published in the Lecture Notes in Computer Science series of Springer-Verlag [212].

FORMATS aims to be a major annual event dedicated to the study of Timed Systems, uniting three independently started workshop series related to the topic: MTCS (held as satellite event of CONCUR'00-02), RT-TOOLS (held as satellite event of CONCUR'01 and FLoC'02) and TPTS (at ETAPS'02), with a total in 2002 of around 100 individual participants.

The Ametist consortium plans to establish this workshop as a major vehicle for advancing a unified timing technology. Both Kim Larsen and Oded Maler participate in the Steering Committee of FORMATS.

In September 2004, the second FORMATS workshop took place in conjunction with FTRTFT in Grenoble, France, where it was organized by partner VERIMAG. The 3rd FORMATS will be held in Uppsala, Sweden, September 26 - 28, 2005 in conjunction with ARTIST2 summer school on Component Modelling, Testing and Verification, and Static analysis of embedded systems.

## 7.3 Collaboration with other EU Projects and NoE

A formal collaboration was set up between Ametist and the EU IST project Hybridge focusing on the compositional specification and analysis of real-time stochastic systems.

Three partners from Ametist (VERIMAG, KUN, WIS) also participated in the EU IST project OMEGA, which led to close links between the two projects, in particular within Task 1.2. Paper [205] is an example of a joint paper of Ametist and OMEGA. We also maintained close links with the EU IST project CC. The synthesis paper [230] is an example of a publication that was prepared in collaboration with the project CC.

Partners UT, AAU and VERIMAG participate in ARTIST2, the EU FP6 network of excellence on Embedded Systems. Partners Uni DO and UT participate in HYCON, the EU FP6 Network of Excellence on Hybrid Systems. Below we elaborate on the relationship between Ametist and these NoEs.

### 7.3.1 ARTIST2

The objective of the ARTIST2 Network of Excellence is to strengthen European research in Embedded Systems Design, and to promote the emergence of this new multi-disciplinary area.

ARTIST2 implements an international and interdisciplinary fusion of effort to create a unique European virtual centre of excellence on Embedded Systems Design. This interdisciplinary effort in research is mandatory to establish Embedded Systems Design as a discipline combining competencies from electrical engineering, computer science, applied mathematics, and control theory.

ARTIST2 addresses the full range of challenges related to Embedded Systems Design, covering all aspects, ranging from theory through to applications. The ambition is to compete on the same level as equivalent centres in the USA (Berkeley, Stanford, MIT, Carnegie Mellon), for both the production and transfer of knowledge and competencies, and for the impact on industrial innovation.

One of the main objectives of the ARTIST2 Network of Excellence is to gather together the best European teams from the composing disciplines, and to forge a scientific community. This objective will be achieved by integration around a Joint Programme of Research Activities, aiming to create critical mass from selected European teams.

One Joint Programme of Research Activity of ARTIST2 is devoted to Verification and Testing of Real-time Properties. AAU and UTare the leading ARTIST2 core partners of this activity (Kim Larsen cluster leader, Ed Brinksma Quantitative Testing and Verification programme leader), with KUN as an Associated Partner. In the JPRA there is a direct link with the work done in AMETIST, and activities to incorporate and extend AMETIST technology in different directions, e.g.:

- The advances made on efficient scheduling and planning with AMETIST will be applied both in deriving new and more efficient test-case generation techniques for real-time systems but also in guiding a verification effort in order to increase the likelyhood of detecting errors as fast as possible. Some preliminary work has already been done in AMETIST.
- The work in AMETIST on scheduling under uncertainty will be directly incorporated in work in ARTIST2 on controller synthesis and in development of game-based testing strategies.
- The stochastic extensions and the application of timed technology to the field of testing are being addressed.

Also, several of the results obtained within AMETIST will be disseminated through ARTIST2 activities. In particular, the ARTIST2 Summer School on Component Modelling, Testing & Verification, and Statical Analysis of Embedded Systems, Uppsala, Sept 29 - Oct 2, 2005, will feature a number of invited presentations given by current AMETIST participants and contributors (Ed Brinksma, Gerd Behrmann, Patricia Bouyer, Holger Hermanns, Joost-Pieter Katoen, Brian Nielsen, Stavros Tripakis).

#### 7.3.2 HYCON

HYCON is a European Network of Excellence in the Area of Hybrid Control, i.e. the modelling, simulation, analysis and synthesis of control systems where in the closed loop continuous and discrete dynamics interact, e.g. a physical process (usually termed “plant” in the control terminology) is controlled by a logic controller that reads and writes binary signals (indicators whether a physical variable exceeds a threshold or not, on/off switches or valves). The continuous part of the closed-loop system is usually described by a system of differential and algebraic equations which can become quite complex if a faithful model of the physical reality is required, while for the discrete part a large number of formalisms exist and are used.

Besides aiming at the establishment of a European Institute of Hybrid Systems, work in HYCON is divided into platform functions (benchmarking, tool integration), prototype applications in the areas of energy systems, automotive controls, industrial processes, and communications, and knowledge systematisation and dissemination. Resource scheduling which is in the focus of AMETIST is not considered in HYCON thus far. Tools and theory for timed systems (timed automata) that are developed in AMETIST are of importance for HYCON because abstractions of the continuous dynamics lead to timed models that can be used in the analysis of hybrid control systems. E.g. in previous and current work on the verification of logic controllers by the group in Dortmund, the tool UPPAAL is used for the analysis of the interaction of a formal model of the logic controller and an abstracted model of the continuous plant dynamics. The tools for reachability analysis of timed automata that have been developed in AMETIST therefore will be considered in the tool integration and benchmarking workpackages of HYCON and will be applied in the applications case studies.

From the partners of AMETIST, Uni DO currently is also a node of HYCON, coordinating the workpackages on tool integration and industrial controls. This will guarantee the integration of the tools from AMETIST in HYCON. Also UT is involved in HYCON where – amongst others – it brings in the work of Brinksma, Langerak et al on hybrid systems that has also been presented within Ametist. VERIMAG may in the future also become involved with HYCON.

## 7.4 Other Dissemination Activities

Members of the Ametist consortium were involved in numerous other dissemination activities. We mention some highlights, without striving for completeness.

(Also) during the third year of AMETIST the UPPAAL and UPPAAL Cora tools have been presented at several PhD schools and at tutorials. A new UPPAAL tutorial note fully compatible with version 3.4 has been written as a contribution to a summer school on Formal Methods for Real-Time Systems (Bertinoro September 2004) [92]. We mention:

- Formal Methods for the Design of Computer, Communication and Software Systems: Real Time, 13-18 September, 2004, Bertionoro University Residential Center, Italy.
- Third international symposium on Formal Methods for Components and Objects (FMCO 2004), Leiden, The Netherlands, November 2-5, 2004.
- PRISE: Principles of Software Engineering, Buenos Aires, Argentina, November 22-27,2004.
- MOVEP'04: Modeling and Verifying Parallel Processes, Brussels, Belgium, 13-17 December 2004.
- GVD'05: German Verification Day, Oldenburg, Germany, March, 2005.
- Belgian seminar on Computer Aided Verification, Centre Fédéré en Vérification, Brussels, November 2004.

Members of Ametist made efforts to push the timed automaton vision to relevant communities. In several studies Priced Timed Automata, the underlying model of UPPAAL CORA have proven to be a very natural formalism for modeling a number of optimal scheduling and planning problems ranging from cost-optimal task-graph scheduling, air-craft landing to vehicle routing problems. In [89, 90] we present the methodology of UPPAAL Cora to two different research communities, namely (a) Performance Analysis and (b) Planning and Scheduling. O. Maler and Y. Abdeddaim have presented the results of [6, 1, 3] in affiliated workshops of ICAPS'02 in Toulouse, and a year later O. Maler gave a one-day tutorial in ICAPS'03 in Trento about timed automata and scheduling. At this year's ICAPS Kim G. Larsen has been invited to give a key-note lecture on UPPAAL Cora in particular and the findings of AMETIST in general. The work on the NASA K9 Rover case-study [94] has demonstrated the applicability of timed automata for space application, and led to a discussion with labs such as LAAS, Toulouse about closer collaboration between the AI planning crowd and the timed automaton community. As an opening toward the OR community, preparations for a new Dagstuhl seminar on different approaches to scheduling under uncertainty, by R. Mohring and O. Maler have started. The unifying model for controller synthesis, planning and scheduling [230] has been presented to a variety of communities such as those of discrete-event systems (WODES) and control (CC project).

# 8 Management

## 8.1 Project Co-ordination and Management Activities/Issues

The AMETIST project is managed by coordinating partner KUN, with help of VERIMAG (scientific coordination) and UT (website, publication database). For an overview of the organization structure of AMETIST, we refer to the webpage http://ametist.cs.utwente.nl/PROJECT/organisation.htm.

A practical difficulty encountered during the final year of the project was that, due to a coincidental piling up of both personal and professional reasons, several PCC members could invest less time in the project than foreseen originally. In particular:

- Ed Brinksma (UT) accepted the position of Scientific Director of the Embedded Systems Institute (ESI) in Eindhoven (http://www.esi.nl). ESI is a public/private initiative of the three Dutch universities of technology and a number of industrial partners, including Philips, ASML, and Oce.
- Kim Larsen (AAU) was appointed as Director of the newly started Danish Center for Embedded Software Systems CISS (http://www.ciss.dk/).
- Sebastian Engell (Uni DO) is a Vice-Rector of the University of Dortmund.
- Thomas Hune (Terma) got a new job as section leader with focus on new and uniform development methodologies to be used throughout the company. Thus he is no longer in the Radar division (which is the division that we have been collaborating with).

In fact, most of the other PCC members also experienced some scheduling problems. This combination of circumstances certainly complicated the project management during the last year of the project and caused some delays:

- Organization of the final AMETIST workshop started late.
- There has been no coordinated effort to work on the CYR case study during the final months of the project (as suggested by the reviewers).
- Deliverables D0.2.3 (Framework Report, VERIMAG), D1.1 (Model Classification, VERIMAG), D2.3.c (State Space Representations, LIF) and D3.1.4 (Final Report on Cybernetix Case Study, LIF) were not ready at the time of the final review.
- Consequently, also the final project report (D0.1.6) was provided late.

Having said this, it is important to note that during the last year at all sites the technical progress and productivity has been excellent, as it has been throughout the entire lifetime of the project.

## 8.2 Project Workplan and Proposed Changes

Due to the turbulent situation at CYR, this partner was not able to invest much time in the project during m25-m39. In fact, following the discussion during the review, CYR decided it will declare no costs in its final cost statement. There were no further major (>10%) deviations from the workplan for any of the partners or any of the workpackages during the reporting period, apart from the delays in deliverable production mentioned in Section 8.1, and the issues that were discussed already in Del 0.1.5:

- The reallocation of money from partner Terma to other partners.
- The allocation of money from the central coordination budget to support additional person months for 5 partners.

- The extension of the project with 3 months.
- Partners Axxom, KUN, AAU, UT and Uni DO invested more than planned in the Axxom case study during the final year.
- Since the hourly rates were somewhat lower than planned, the total number of PMs at WIS turned out somewhat higher than planned.
- Partners VERIMAG and UT have invested more in the project than promissed. In fact, VERIMAG and UT invested more PMs in AMETIST in the first 2 years than planned originally for 3 years, and also invested seriously in the project during the third year.

## 8.3 List of Items to be Amended in Contract incl. Annex 1

During the last year, two amendments were made to the Contract. The first amendment concerned the modification of the principal contractor's name (into Radboud University Nijmegen), the second amendment concerned extension of the contract with 3 months.

## 8.4 Effort Consumption

All figures in the table below denote persons months (PMs). All PMs figures correspond to the additional PMs as mentioned in the CPFs; the own contributions of partners that work under the AC model are not included. Ideally, for each partner the sum of the resources used over the full project should equal what has been planned, i.e., the sum of the number of PMs in the Annex and the number of PMs that has been reallocated according to the proposal in Deliverable D0.1.5 [54]. Due to the reasons listed above, the two sums are not always equal, as becomes apparent from the last column ("Deviation"), which lists for each partner the difference between the two sums.

| | *Used in Yr 1+2* | *Used in Yr 3+* | *Result Reallocation* | *Total Planned (Annex 1)* | *Deviation* |
|---|---|---|---|---|---|
| KUN | 37.6 | 36.7 | 4.0 | 65.0 | 5.3 |
| Bosch | 1.9 | 1.2 | 0 | 3.0 | 0.1 |
| CYR | 15.5 | 0 | 0 | 28.9 | -13.4 |
| Axxom | 7.5 | 6.5 | 0 | 11.3 | 2.7 |
| Terma | 0.9 | 0.1 | -5.5 | 6.7 | -0.2 |
| AAU | 20.2 | 21.7 | 4.0 | 42.4 | -4.5 |
| Uni DO | 24.0 | 15.0 | 1.0 | 36.0 | 2.0 |
| VERIMAG | 85.0 | 18.7 | 6.0 | 78.0 | 19.7 |
| WIS | 27.7 | 9.4 | 0.0 | 30.6 | 6.5 |
| LIF | 45.7 | 23.3 | 0 | 63.0 | 6.0 |
| UT | 40.4 | 9.8 | 4.0 | 39.9 | 6.3 |
| *Total* | 306.4 | 142.4 | 13.5 | 404.8 | 30.5 |

The table below exhibits resources per partner per work package for the final period of the project, i.e., m25 - m39.

| | *WP0* | *WP1* | *WP2* | *WP3* | *WP4* | *Used in Period* | *Total Used Yr 1+2* | *Total Planned (Annex 1)* |
|---|---|---|---|---|---|---|---|---|
| KUN | 6.0 | 6.0 | 6.0 | 17.0 | 1.7 | 36.7 | 37.6 | 65.0 |
| Bosch | 0.2 | 0 | 0 | 1.0 | 0 | 1.2 | 1.9 | 3.0 |
| CYR | 0 | 0 | 0 | 0 | 0 | 0 | 15.5 | 28.9 |
| Axxom | 0.1 | 0 | 0 | 6.3 | 0.1 | 6.5 | 7.5 | 11.3 |
| Terma | 0.1 | 0 | 0 | 0 | 0 | 0.1 | 0.9 | 6.7 |
| AAU | 1.0 | 1.0 | 12.0 | 6.0 | 1.7 | 21.7 | 20.2 | 42.4 |
| Uni DO | 1.0 | 2.0 | 6.0 | 5.0 | 1.0 | 15.0 | 24.0 | 36.0 |
| VERIMAG | 3.0 | 3.0 | 8.7 | 1.0 | 3.0 | 18.7 | 85.0 | 78.0 |
| WIS | 0.1 | 3.0 | 3.1 | 3.0 | 0.2 | 9.4 | 27.7 | 30.6 |
| LIF | 2.0 | 1.0 | 17.0 | 3.0 | 0.3 | 23.3 | 45.7 | 63.0 |
| UT | 2.0 | 1.0 | 1.0 | 3.8 | 2.0 | 9.8 | 40.4 | 39.9 |
| *Used in Period* | 15.5 | 17.0 | 53.8 | 46.1 | 10.0 | 142.4 | | |
| *Total Used Yr 1+2* | 19.8 | 62.9 | 132.2 | 85.5 | 6.0 | | 306.4 | |
| *Total Planned (Annex 1)* | 33.0 | 72.3 | 175.9 | 107.6 | 16.0 | | | 404.8 |

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