PROJECT PERIODIC REPORT

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[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm ; logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

Declaration by the scientific representative of the project coordinator[1]

I, as scientific representative of the coordinator[1] of this project and in line with the obligations as stated in Article II.2.3 of the Grant Agreement declare that:

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period;
- The project (tick as appropriate):

  X has fully achieved its objectives and technical goals for the period;

  ☐ has achieved most of its objectives and technical goals for the period with relatively minor deviations[3];

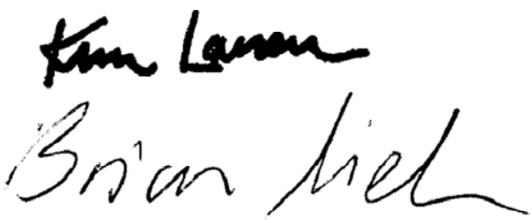
  ☐ has failed to achieve critical objectives and/or is not at all on schedule[4].

- The public website is up to date, if applicable.
- To my best knowledge, the financial statements which are being submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project (section 6) and if applicable with the certificate on financial statement.
- All beneficiaries, in particular non-profit public bodies, secondary and higher education establishments, research organisations and SMEs, have declared to have verified their legal status. Any changes have been reported under section 5 (Project Management) in accordance with Article II.3.f of the Grant Agreement.

Name of scientific representative of the Coordinator[1]: Kim G. Larsen & Brian Nielsen

Date: 28/06/2011.

Signature of scientific representative of the Coordinator[1]:



1.1

3 If either of these boxes is ticked, the report should reflect these and any remedial actions taken.

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Contents

2. Publishable summary

The objective of the Quasimodo project is to develop theory, techniques and tool components for handling quantitative constraints in model-driven development of real-time embedded systems. These real-time, hybrid and stochastic constraints involve the resources that a system may use (computation resources, power consumption, memory usage, communication bandwidth, costs, etc.), assumptions about the environment in which it operates (arrival rates, hybrid behaviour), and requirements on the services that the system has to provide (timing constraints, QoS, availability, fault tolerance, etc.).

More specifically, the project aims at:

1. Improving the modelling of diverse quantitative aspects of embedded systems.
2. Providing a wide range of powerful techniques for analysing models with quantitative information and for establishing abstraction relations between them.
3. Generating predictable code from quantitative models.
4. Improving the overall quality of testing by using suitable quantitative models as the basis for generating sound and correct test cases.
5. Applying the techniques to real-life case-studies and disseminating the results to industry.

By enabling early and automated analysis, design, and test of embedded systems with quantitative constraints, the results of Quasimodo will increase the competitiveness of European embedded systems industry and will help establish Europe as a leader in design of complex embedded systems.

Quasimodo applies and evaluates its research ideas and tools on the following challenging case studies:

1. The Accumulator Charge Controller (provided by HYDAC),
2. The self-balancing scooter (provided by CHESS),
3. A Wireless Sensor Network (provided by CHESS), and
4. The attitude and orbit control software for the satellites Hershel and Planck (provided by TERMA).
5. Adaptive data-paths in photocopiers/printers (provided Océ)
6. Design space exploration for motion control applications implemented on packet switched multi-processor platforms (provided by ASML).

Significant work has been made on all case studies. In particular, the HYDAC Controller and the CHESS WSN cases have served as the basis for model-based testing activities. In all cases the benefits of applying model-based testing was clearly demonstrated. In addition to the original four case studies, the project has worked on a broad selection of case studies which address almost all of the Quasimodo methods, techniques, and tools, and which have provided interesting feedback for Quasimodo as well as for the systems being analyzed. We have shown that the methods, techniques, and tools are applicable, useful, and do provide benefits, but also that scalability (e.g., state-space explosion) and usability (the methods and tools were mostly used by Quasimodo experts and are still difficult to use for industrial engineers) remain critical issues.

During the third year we have also worked extensively on reduction and abstraction techniques for quantitative models, in particular for probabilistic automata and for extremely large Markov chains. Also, during the third year we have developed complete and compositional specification frameworks for probabilistic automata, timed systems, and weighted systems. In addition the probabilistic and timed frameworks are tool supported. For the most expressive quantitative formalisms and properties – e.g. time-bounded reachability in CTMDP and parameter synthesis for MDP – approximate algorithms have been devised.

During the third year of our project, we have made substantial progresses in algorithmic methods for the synthesis with bounded resources and in particular multi-energy and multi-mean-payoff games. The challenge of ensuring robustness of timed automata – in order to enable transfer of properties established on abstract models into concrete implementations – has been subject to significant research. Finally, the HYDAC case has been generalized into a systematic method for linking UPPAAL Tiga and SIMULINK, thus allowing for simulation, validation and automatic code-generation of winning strategies obtained from timed games.

Enormous progress has been made on the work-package on testing during Year 3. We have focused on test generation for hybrid and probabilistic systems, and symbolic testing, and their combinations --- even though various contributions to the timed setting have also been made. Moreover, we have also gained good results on test coverage measures. We have extended our testing theory and methods with specific procedures for handling uncertainty in the timed case, and in the adaptor component in the test tools. Moreover, we have made important contributions on the topic of model construction, which is the most expensive, and perhaps most important, part when applying MBT in practice.

Several new tool components have been developed, and several new features have been added to existing tools, e.g. statistical model checking in UPPAAL, improved usability of JTorX and UPPAAL Tron. On integration of tools, support for the model exchange between UPPAAL and Modest has been implemented, and the integrations of UPPAAL Tiga/Tron and Simulink have been systematized. We believe that we have made significant steps towards improving state-of-the-art in terms of useful tool environments for model-based analysis, implementation, and testing of quantitative system properties.

The work is also reported in a very large number of scientific publications. Overall the project has made significant scientific progress. Also, substantial effort has been made on disseminating the results of Quasimodo, including special Quasimodo sessions at a number of conferences and the undertaking of the Quasimodo Handbook.

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Quantitative System Properties in Model-Driven-Design of Embedded Systems

3. Project Achievements

3.1 *Project objectives for the period*

The overall third year objective is to finalize development tool components for quantitative analysis, synthesis and testing, and to integrate these in tool chains, and to perform a final application of these to case studies. A special objective is on dissemination with focus on completing the industrial handbook.

The objectives are detailed through the description of milestones M6, and M7.

Milestone M6 is to be verified though the availability of: 1) Final version of tool components, Well documented APIs and XML exchange formats for all tool components available, 2) Case studies completed including modeling, analysis, testing and code generation using developed tool components integrated with industrial tool chains.

Milestone M7 is to be verified though the availability of: 1) Final reports evaluating case studies, tool components and their integration and applicability, and 2) Dissemination of results of the project via tool demonstrators and the ”Quasimodo Handbook”.

Reaching these objectives will advance the techniques and tools available for quantitative analysis for embedded systems, provide a good foundation for wider dissemination and exploitation of the results by European Researchers and Embedded Systems Industries.

The next section details how we have reached these objectives. Section 3.3.8 gives a summary comparing with the milestones and these objectives.

3.2 *Work Progress and achievements*

3.2.1 WP1: Modelling and Specification

Wp1 aims at improving modelling and specification of quantitative properties of embedded systems.

Our work in **T1.1 (Model Process improvement)** aims at developing methods for obtaining adequate and faithful models of embedded systems. The aim of **T1.2 (Modelling of Quantitative System Aspects)** is to integrate timed, hybrid and stochastic aspects of models. According to the work plan, these tasks ended by the end of the second reporting period, and hence no activities have been planned, and no further progress have been reported.

Our work on **T1.3 (Design Notations and Tools)** aims at describing quantitative aspects syntactically in design notations for embedded systems with accompanying tool support.

The nuances underlying mathematical models (e.g. semi Markov chains, Markov decision processes, or probabilistic timed automata) for combined probabilistic, real-time and cost features that are manipulated by Quasimodo tools, are too fine-grained to be directly used as specification means by an embedded systems designer.

Developing a quantitative notation that is intuitive to use for designers, that has a precise semantics, that allows it to be preserved when transformed into the formalisms supported by current analysis tools is a quite challenging task, but important results are:

- A plugin for STATEMATE for design time evaluation of dependability properties through a compositional augmentation with probabilistic timing information.
- Our experience indicate that the more mature QUASIMODO notations and tools, like Uppaal-timed automata, can be applied in industrial practise, and has potential to become accepted as an industrial notation. (e.g one company has abandoned the use of using UML and UML tools for test model specifications, and rather than translating these to Uppaal, they are now directly specified in the Uppaal tool).
- We have used Quasimodo tools and notations as background tools for (domain specific) industrial notations and tools suites. In the context of the Architecture Analysis and Design Language (AADL) we have formalized a significant subset of AADL, incorporating its recent Error Model Annex for modelling faults and repairs, enabling a component based and precise description of nominal hardware and software operations, hybrid (and timing) aspects, as well as probabilistic faults and their propagation and recovery. Further, we have added support for automated analysis of these aspects via MRCM. Also a domain specific language for design-space exploration of large parameter sets has been mapped to Uppaal.
- We have indicated a tool chain for Simulink for controller synthesis based on Uppaal-TiGa models, and have enabled co-simulation with Simulink and Uppaal-TRON.
- We have proposed Live Sequence Charts as an easier means for industrial engineers to specify systems and properties to be checked in Uppaal.

Whilst the envisioned overarching notation and tool has not fully materialized, we have demonstrated several links to industrial notations and tools that shows the practical applicability of the underlying Quasimodo notations and tools. Hence, Quasimodo has much to offer to future developments of general purpose and domain specific notations.

3.2.2 WP2: Analysis

The overall ambition of WP2 is to provide a wide range of powerful techniques for analysing models with (possibly multiple) quantitative information.

T2.1 (State space representation and model checking)
In T2.1 (State space representation and model checking) the main focus in the last year has been on two things: a continuous-time version of Segala's probabilistic automata (PA), and static reduction techniques for Markov decision processes that incorporate data.

The variant of Segala's model, baptized Markov automata, incorporates labeled transitions that yield a probability distribution over states, as well as transitions labeled with parameters of exponential distributions (i.e., randomly timed transitions) that yield states as their target. The central question has not been to define the model, but instead to come up with a notion of weak bi-simulation that fulfills a number of criteria such as: (a) congruence property wrt. parallel composition, enabling component-wise reduction, (b) backward compatibility with weak bi-simulation on IMCs and PA, both sub-models of Markov automata, and (c) an equivalence satisfying some natural laws.

The reduction techniques for MDPs with data are focused on syntactic transformations that are aimed at reducing the state space before generating it while preserving their functional and quantitative properties. An intermediate format has been defined, and efficient transformations that map parallel processes to such format. The format allows for several optimisations that may yield state space optimisations of up to 95%. This has been complemented by confluence reduction techniques, an approach akin to partial-order reduction, which preserves (branching) probabilistic bi-simulation. Reductions obtained in this manner exceed those by partial-order reduction. In addition, bi-simulations have been linked to compositional proof systems for a general class of continuous-time continuous-space models.

T2.2 (Abstraction, Refinement, and Compositionality)

Like in the previous year, in T2.2 (Abstraction, Refinement, and Compositionality), major progress has been made (see the list of significant results below). Complementary abstraction techniques have been fully developed using predicate abstraction, an approach that has been proven quite successful for software model checking, and the framework of three-valued abstraction in traditional model checking has been combined with that of modal transition systems and successfully applied to Segala's probabilistic automata. The latter results in a complete specification framework for PA. Similar work has been done for timed systems, which is combined with new on-the-fly algorithms for checking Büchi objectives of two-player timed games using zones as symbolic representation. Modal transitions systems have also been used for weighted systems, resulting in a completed specification framework for weighted transition systems.

The theoretical framework of three-valued abstraction of continuous-time Markov chains has been realised in a prototypical tool, and used for experimentations on case studies from classical queueing theory. In particular, it has been shown that by adequate abstraction of the state space, transient probabilities in so-called tree-based quasi birth-death processes (a continuous variant of probabilistic pushdown automata) can be obtained for extremely large state spaces, upto 10^{400} states by accurate abstraction of about 500.000 states. Such results clearly show the potential of this approach.

Finally, progress has been made on the verification of safety properties of probabilistic hybrid automata using aggressive abstraction techniques.

T2.3 (Approximate Analysis Techniques)

In the last year, work in T2.3 (Approximate Analysis Techniques) has been boosted significantly. Approximate parameter synthesis techniques have been developed for parametric MDPs and PCTL formulas. By means of this technique, a hyper-rectangle is approximated such that all MDPs obtained by instantiating with parameter values inside this shape satisfy a given PCTL formula. Secondly, major progress has made towards the approximate verification of time-bounded reachability probabilities in CTMDPs, a continuous-time version of MDPs. This is a long-standing open problem in probabilistic model checking. Two approaches have been developed that yield promising results.

In addition, statistical model checking algorithms have been developed and implemented for networks of stochastic timed networks, an automata-based algorithm for CSL model checking has been designed, and PCTL model checking of discrete-time stochastic hybrid systems is tackled by an approximation yielding DTMCs, such that error bounds on the satisfaction of reachability probabilities can be given.

Significant results (in arbitrary order of relevance):

1. A syntactic powerful reduction technique for probabilistic automata.

2. A combination of probabilistic automata and interactive Markov chains equipped with a useful notion of weak bi-simulation.

3. A complete specification framework for probabilistic automata, timed systems, and weighted systems.

4. Analysis of extremely large Markov chains using abstraction yielding the transient analysis of the largest tree-based queuing network ever.

5. Significant progress in the verification of stochastic hybrid systems.

6. Statistical model-checking for networks of timed automata.

7. Approximate algorithms for time-bounded reachability in CTMDPs.

8. Approximate parameter synthesis algorithms for MDP verification.

There are no deviations from the original planning. In fact, more results in WP2 have been achieved so far than originally planned.

3.2.3 WP3: Implementation

The main research objectives of WP3 are twofold. First, within task T3.1, our objective is to improve the understanding of synthesis problems defined on rich models suited for the modeling of embedded systems. Second, within task T3.2, our objective is to study the transfer of properties established on abstract models into concrete implementations automatically, and the process of automatically generating executable codes from high-level mathematical models.

Task 3.1 (Controller Synthesis and Scheduling)

In Task 3.1 (Controller Synthesis and Scheduling) we study models suited for modeling quantitative aspects of embedded systems and algorithms to reason on those models. In particular, we want to study synthesis problems for models where quantitative aspects of those systems can be modeled adequately. For example, models should allow us to specify and solve algorithmically scheduling problems and optimal resource usage problems. For that purpose, we are studying synthesis problems on finite state game structure, timed game structures defined timed automata, automata models extended with probabilities, and automata models extended with costs, etc. During the third year of our project, we have made substantial progresses in algorithmic methods for the synthesis with bounded resources and in particular multi-energy and multi-mean-payoff games. The main results in this line of research are as follows:

- **Generalized Energy and Mean-Payoff Games**. In mean-payoff games, the objective of the protagonist is to ensure that the limit average of an infinite sequence of numeric weights is nonnegative. In energy games, the objective is to ensure that the running sum of weights is always nonnegative. Generalized mean-payoff and energy games replace individual weights by tuples, and the limit average (resp. running sum) of each coordinate must be (resp. remain) nonnegative. These games have applications in the synthesis of resource-bounded processes with multiple resources. We have proven the finite-memory determinacy of generalized energy games and show the inter-reducibility of generalized mean-payoff and energy games for finite-memory strategies. We have also improved the computational complexity for solving both classes of games with finite-memory strategies: while the previously best known upper bound was EXPSPACE, and no lower bound was known, we give an optimal coNP-complete bound. For memoryless strategies, we have shown that the problem of deciding the existence of a winning strategy for the protagonist is NP-complete.

- **Energy games in multi-weighted automata**. This work is closely related to the previous one but consider richer models where upper-bounds on energy can be specified. Energy games have recently attracted a lot of attention. These are games played on finite weighted automata and concern the existence of infinite runs subject to boundary constraints (not only lower bounds as in the work above) on the accumulated weight, allowing e.g. only for behaviors where a resource is always available (nonnegative accumulated weight), yet does not exceed a given maximum capacity. We extend energy games to a multi-weighted and parameterized setting, allowing us to model systems with multiple quantitative aspects. We present reductions between Petri nets and multi-weighted automata and among different types of multi-weighted automata and identify new complexity and (un)decidability results for both one- and two-player games. We also investigate the tractability of an extension of multi-weighted energy games in the setting of timed automata.

- **ATL with Strategy Contexts: Expressiveness and Model Checking.** We have studied the alternating-time temporal logics ATL and ATL* extended with *strategy contexts*: these make agents *commit to their strategies* during the evaluation of formulas, contrary to plain ATL and ATL* where strategy quantifiers *reset* previously selected strategies. We illustrate the important expressive power of strategy contexts by proving that they make the extended logics, namely ATL_{sc} and ATL^*_{sc}, equally expressive: any formula in ATL^*_{sc} can be translated into an equivalent, linear-size ATL_{sc} formula. Despite the high expressiveness of these logics, we prove that their model-checking problems remain decidable by designing a tree-automata-based algorithm for model-checking ATL^*_{sc} on the full class of n-player concurrent game structures.

Task T3.2 (Implementability and Code Generation)

Second, within Task T3.2 (Implementability and Code Generation), our objective is to study the transfer of properties established on abstract models into concrete implementations automatically. This problem is particularly challenging for timed models. Indeed, in timed models time elapsing is measured using real-valued variables while in implementations, time elapsing is measure by counting ticks of a discrete clock with finite precision. The theoretical background has been developed by several teams of the QUASIMODO project. Theoretical progresses have been made last years and reported into deliverable D3.1 (year 2008). During 2009, a practical algorithm based on the zone data-structure for analysis behaviuor of timed automata has been developed. During 2010, refinements of the previous results on robustness have been obtained, in particular:

- **Quantitative robustness analysis of flat timed automata**. Recently, several works have studied a parametric semantics of timed automata related to implementability: if the specification is met for some positive value of the parameter, then there exists a correct implementation. In addition, the value of the parameter gives lower bounds on sufficient resources for the implementation. In this work, we present a symbolic algorithm for the computation of the parametric reachability set under this semantics for flat timed automata. As a consequence, we can compute the largest value of the parameter for a timed automaton to be safe.

- **Timed automata can always be made implementable**. Timed automata follow a mathematical semantics, which assumes perfect precision and synchrony of clocks. Since this hypothesis does not hold in digital systems, properties proven formally on a timed automaton may be lost at implementation. In order to ensure implementability, several approaches have been considered, corresponding to different hypotheses on the implementation platform. An existing prominent approach, for verifying the behavior of real-time programs executed on CPUs, is robust model-checking. It consists in studying the enlarged semantics of the timed automaton, where all the constraints are enlarged by a small (positive) perturbation Δ, in order to model the imprecisions of the clock. In some cases, this may allow new behaviors in the system, regardless of Δ. Such automata are said to be none-robust with respect to small perturbations. On the other hand, if no new behavior is added to the system, that is, if the system is robust, then implementability on a fast-enough CPU will be ensured. In [1], we show that timed automata can always be made implementable. More precisely it is shown, that from any timed automaton A, we build a timed automaton A that exhibits the same behavior as A, and moreover A is both robust and samplable by construction.

Those results and their related publications are summarized in the deliverable D3.7. The objectives that were identified in our research proposal for year 3 have been met.

Third within task 3.2, we also study how to generate codes from high-level mathematical models. In particular, we want to generate code from timed automata. In Deliverable D3.7, we report on executable code generation from timed games via strategies. Here is a summary:

- **From UppAal-Tiga winning strategies to Simulink in the Hydac case study**. UppAal-Tiga is a tool for the automatic synthesis of winning strategies in timed games. The framework of timed game automata is well adapted for modeling control problems and it offers algorithms for automatically solving those problems.

Within the Quasimodo project, we have shown that those techniques can be applied to non-trivial problems. In particular, we have show how to automatically generate correct by construction, near optimal and robust controllers for an industrially relevant application: the Hydac case study problem (see Deliverable D5.7). In this case study, we have produced automatically Simulink S-functions from UppAal-Tiga winning strategies. Those S-functions have been used a.o. to simulate the controller within a stochastic model of noise which allowed us to evaluate the performances of the automatically generated controller.

- **From Timed Games via Strategies to Executable Code.** Recently, we have generalized this successful application into a systematic method for linking UPPAAL-TIGA and SIMULINK. In particular given a user defined timed game model in UPPAAL-TIGA, a winning strategy can be automatically imported to SIMULINK as an S-function for simulation, validation and automatic generation of executable code. For demonstration purposes, we have applied the methodology to a small two-tank example. The framework requires that two models of the control problem are provided: an abstract model in terms of a timed game and a complete, dynamic model of the environment in terms of a hybrid system. Given the abstract (timed game) model together with logically formulated control and guiding objectives, UPPAAL-TIGA automatically synthesizes a strategy that is directly compiled into an S-function. This enables evaluation of the performance of the control strategy on the given environment by simulation in SIMULINK. Also, by choosing different control objectives for the synthesis problem in UPPAAL-TIGA, we can easily obtain and evaluated alternative controllers. Generation of final executable code is possible through the SIMULINK real-time workbench.

3.2.4 WP4: Testing

Software becomes more and more complex, making thorough testing an indispensable part of the development process. The U.S. National Institute of Standards and Technology has assessed that software faults cost the American economy almost sixty billion dollars annually. More than a third of these costs could be eliminated if testing occurred earlier in the development process.

During Year 3, we have made enormous progress in WP4. This was actually projected, since 4 out of 6 WP3 deliverables were due in Year 3, even though the foundations have been laid in Year 1 and 2.

Task 4.1: Test Generation

Task 4.1 (Test Generation) is concerned with provably sound and complete test case generation for systems with quantitative aspects. In Years 1 and 2 we have made tremendous progress in defining conformance relations for timed systems (tioco) and in developing online and offline test generation methods for timed system, for instance using games.

During Year 3, we have focussed on test generation for hybrid, probabilistic and symbolic testing, and their combinations --- even though various contributions to the timed setting have also been made. Moreover, we have also gained excellent results on test coverage measures. In particular, our achievements have been the following.

Hybrid testing. UPPAAL has recently been extended with so-called stopwatches. These are continuous clock variables that can be stopped (by setting its derivative to zero) and resumed (setting its derivative back to one), thus providing a means for integration over time. UPPAAL is able to perform an (over-approximate) reachability analysis for such timed automata with stopwatches. Earlier work has shown that reachability analysis of linear hybrid automata can be reduced (via a translation) to reachability analysis of timed automata with stop watches. Since, we have incorporated stopwatches in UPPAAL-TRON, (resulting in a slightly over approximated state-set) this gives a path to testing linear hybrid automata with the existing tool.

Other interesting and relevant results have been obtained by using UPPAAL TRON for hybrid testing. UPPAAL TRON does not support continuous variables, but integer variables can be updated at certain time intervals defined by the clock variables. In this way, continuous variables can be emulated. These techniques turn out to work well in many cases.

Probabilistic Testing. A probabilistic model contains information that express with what probability the system executes a given transition; this may by an input given to the system, an output delivered by the system, or an internal computation step. Thus it may express information about distributions of both expected uses and expected responses. We have worked on probabilistic testing theories that support the follwing several applications in model-based testing, including (1) Operational Usage profile testing/statistical usage testing, where test input sequences are generated in correspondence with the distributions of the model such that they reflect the expected use of the system. This is the basis for performance evaluation and reliability estimation. (2) Guiding: Guiding either towards an area in the model that is of particular interest or is particularly critical, or to increase coverage of the model (utilizing information of likely outputs) and (3) Statistical hypothesis testing: Here the goal is to estimate the probability of conformance. Techniques used here are embeddings of the resulting mathematical objects into partially observable Markov decision processes (POMDPs).

Combinations. An very important topic is the integration of the testing frameworks above. Serious progress has been made in this direction: symbolic methods have been explored for timed testing, probabilistic methods have been combined with timed testing in the context of statistical real-time model checking, and time, symbolic and probabilistic features come together in the MoDeST language.

An important milestone is the integration of UPPAAL TRON with external tools. Simulink is one of the most widely used system design tools, and Phaver/SpaceEx is a state-of-the-art model checker for hybrid systems. The integration with Simulink and Phaver enables extensive co-simulation of hybrid systems, and of system aspects that are not supported by UPPAAL TRON. Since these results are very promising, connecting to external tools with specific strengths seems a viable way to go.

It should however be noted that dealing with one quantitative modality (real-time, quantitative data, probability) is already extremely challenging. Hence, full integration of the developed framework is foreseen in the (near) future.

Test selection and test coverage. Testing is inherently incomplete, since complete testing requires infinitely many scenarios. Therefore, it is of vital importance to come up with efficient test suites that have high impact. The test coverage measures we have developed for quantitative systems are instrumental here: they assess which parts of the SUT and/or system specification have been examined by the test suite. A very important topic we tackled concerns risk-based testing. Here, we give a notion of coverage in a probabilistic setting, and we quantify the probability (and their impact) of remaining faults in a SUT that passed a given test suite.

Also, we have developed test generation methods for timed automata with complete edge coverage, and subject to several optimization criteria. Finally, we assessed the impact of coverage criteria in practice, and compared the impact of three well-known whitebox coverage measures in three software projects for a software development company.

Symbolic test case generation for timed automata. Conformance relations were defined already defined for timed systems and for symbolic systems, but not yet for a combination of both. This gap has now been filled, where a conformance relations for Symbolic Timed Automata (a combination of Timed Automata and Symbolic Transition Systems) is introduced.

How to derive timed test cases for a complex system? The bigger the system, the more difficult it is to design an effective and efficient test suite. Ideally, these tests are generated automatically from a model, executed against an implementation-under-test and evaluated according to some conformance relation. However, it is not always easy to obtain a test, especially not in a setting with real time. We developed a UPPAAL-based tool for deriving test cases based on timed automata. It allows the user to make a model in UPPAAL, and then generate a test suite with complete edge coverage based on several test generation algorithms. Either the test suite is generated based on a reachability question or an optimization strategy, by targeting single edges, or just randomly (to support these techniques, two model transformations are performed). To generate an actual executable test suite, the user can annotate the model to denote in what way inputs have to be provided and observations have to be made.

Task 4.2: Approximate Testing

Task 4.2 (Approximate Testing) is concerned with dealing the imprecisions that come into play when handling quantitative information from a continuous domain (time, physical quantities, continuous data). For instance, the observed timing of the events may not coincide with the actual timing of the occurrence of the events. The Goals of Task 4.2 are to develop a testing framework that is able to cope with these issues.

A general quantitative testing theory with test case derivation, execution and evaluation for systems with measurement imprecisions had established in Year 1. In Year 3 we have extended our work with specific procedures for handling uncertainty in the timed case, and in the adaptor component in the test tool, which connects between the system under test (SUT) and the testing tool. Moreover, we have made important contributions on the topic of model construction, which is the most expensive, and perhaps most important, parts when applying MBT technology in practice.

In more details, our contributions are the following.

Uncertainty in the connection between SUT and test tool. An important source of approximativity in the ioco-approach to conformance testing is rooted in the communication between the testing tool and the SUT: the synchronicity assumed by the testing theories can only be approximated by a asynchronous communications. The handling of these aspects is the task of the Adaptor. But although a crucial component, there is no systematic method of obtaining one. We have made created a more generic Adaptor, facilitating communication with a new SUT in the future. This is done
in the context of a LEGO bricks sorting machine.

Timed Testing under uncertainty. In a real-time setting, the MBT testing machinery often interacts with the system under test (SUT) on the basis of discretized values. At the same time, it must evaluate the timeliness of the SUT. To account for these complications, the testing process needs to be made adaptive to uncertainty in the implementation's responses, but in a sound and effective manner. We have developed a variety of techniques developed, like time over-approximation and value over-approximation to approximate the uncertainty and imprecision properly and effectively. These have been incorporated in the UPPAAL TRON testing environment.

Approximative learning. MBT relies on the existence of a model of the SUT. Since this model is not always available (especially for legacy software), Quasimodo has embarked on concerted efforts to turn the MBT testing technology into an automata learning technology. The original approaches to automata learning relies – as a crucial component – on a component that is able to decide language equivalence queries. This is approximated in the automata learning approach by an MBT testing tool that feeds the SUT with long test sequences, thereby approximating the original question.
Furthermore, MBT technology can also be used to approximatively learn probabilistic specifications. For complex systems that are only partially observable via their interactions with the user, it might be unrealistic to assume that an adequate deterministic model exists.
We finally report on efforts to learn probabilistic quantitative models of a system's observable (and possibly non-deterministic) behaviour. The data we require for learning only consists of previously observed system behaviours that are obtainable through active or passive testing.

All in all, we can conclude that WP4 has been a success: we have accomplished all results stipulated by the Description of Work: Indeed, we have made solid gains to overall quality and effectiveness of testing by using suitable quantitative models as the basis for generating sound and correct test cases.

We have developed strong tool components for testing control, real-time, complex data, and stochastic models. However, they are not fully integrated in the since that one tool component supports all aspects. Handling time, data intensive, hybrid, costs and stochastics integrated into the same algorithmic core is challenging, it is an important question for future research whether a more feasible approach would be to integrate specialized tool components via a a common “test tool bridge” that would enable integration of Simulink, UPPAAL-TRON, TORXAKIS, and JTorX.

3.2.5 WP5: Case Studies, Tools, Dissemination and Exploitation

Work package WP5 is concerned with case studies (T5.1), tools (T5.2), and dissemination and exploitation (T5.3).

Task 5.1: Case Studies

In T5.1 (case studies), Quasimodo has worked on a series of case studies, provided by the industrial partners in Quasimodo and by some external collaborators. In these case studies various modeling formalisms were used for (quantitative) analysis, model checking, simulation, and model-based testing. The case studies served as testbed, as motivation, and to demonstrate and challenge the usefulness of the developed methods and tools, and to assess their strengths and weaknesses. The case studies that were selected are close in spirit to products that are under development by the industrial partners.

Four case studies were initially identified and provided by the Quasimodo industrial partners:

1. the Accumulator Charge Controller (ACC), provided by HYDAC;
2. the Self-Balancing Scooter, provided by CHESS;
3. a Wireless Sensor Network (WSN), provided by CHESS;
4. Attitude and orbit control software for satellites Hershel and Planck, provided by TERMA.

In addition, two case studies were selected from external industrial collaborators in other projects:

5. adaptive scheduling of data paths , provided by OCE;
6. a Rapid Input-Output (RIO) packet switch, provided by ASML.

During Year 3 the Quasimodo methods, techniques, and tools were also applied to a number of smaller case studies, mostly in cooperation with related research projects. These case studies are also described below.

Details about the case studies are reported in the deliverables:

D5.2: "Preliminary description of case studies";
D5.5: "Case studies: Models",
D5.7: “Case studies: validation”;
D5.10: “Final Report: Case Studies and Tool Integration”.

1. Accumulator Charge Controller (HYDAC)

In Years 1 and 2 we have successfully shown how to use quantitative models for synthesis, analysis, and simulation of the HYDAC Controller. These results have been reported in Deliverables D5.5 and D5.7, and at various tutorials, conferences, and seminars. HYDAC is currently investigating how to incorporate these results into their product. A Quasimodo Book chapter explaining the controller synthesis results has been written.

In Year 3 we have been working on model-based testing of the ACC controller, in particular to test for safety properties. A Matlab/Simulink implementation of the controller was tested against a formal model derived from the earlier formal analysis work. A test environment was developed that connects the model-based tester developed in Java to the Matlab/Simulink implementation. A few design flaws and bugs in the controller were detected and reported to HYDAC. The benefits of automatic model-based testing were clearly demonstrated.

2. Self-Balancing Scooter (CHESS)

During Years 1 and 2 a high-level model of the behavior of the self-balancing scooter was developed in Uppaal. This model was of great help in increasing understanding of this supposedly simple system, and in making the specification more precise. These results are presented in a Quasimodo Book chapter. Since there are not that many quantitative aspects, we decided not to continue this case study in Year 3.

3. Wireless Sensor Network (CHESS)

The Wireless Sensor Network (WSN) case study provided by CHESS is one of the larger case studies, for which different aspects have been analyzed. In Years 1 and 2 we analyzed the clock synchronization protocol by means of model checking with Uppaal; see D5.7. Flaws have been detected, and improvement have been proposes. A chapter in the Quasimodo Book and a demonstrator are results from this activity.

Quantitative analysis by means of stochastic discrete-event simulation with MoDeST and Möbius was used to analyze energy consumption, collision rates and effectiveness of the collision detection mechanism, radio communication mechanisms, and message propagation speed. Interesting, yet not completely unequivocal results were obtained; see D5.10.

During Year 3 we have worked on model-based testing (MBT) for WSN. A protocol conformance test of the gMAC protocol layer of a single WSN node was performed using three Quasimodo MBT tools: Uppaal Tron, JTorX, and TorXakis. This test was performed on the gMAC production code in a host environment in simulated real-time. For MBT, first a model of the required gMAC protocol behavior has to be developed. This turned out to be difficult, due to lack of documentation. Consequently, we started with a very abstract model, and then tried to refine this model based on observations made during the test with the abstract model, i.e., a kind of ad-hoc ‘model learning’. At the end a reasonably precise model was obtained with which may long test were executed. This learning and testing process helped the testers as well as the gMAC developers to understand the intricacies of the gMAC protocol behavior, and to detect some unexpected behavior. Moreover, it triggered, and provided practical input to, the research on model learning; see D4.4: ‘Approximate Testing’. A Quasimodo Book chapter is written based on the WSN MBT experience.

A practical case study showed the suitability of the CHESS WSN for real-time applications. A wireless bike braking system was designed, modeled, simulated, verified, constructed, deployed, and (manually) tested. Analysis showed some critical safety issues (amount of delay before braking) which were confirmed by experiments on the bike.

4. *Attitude and orbit control software (TERMA)*

Within the Herschel and Planck satellite systems the ACC ASW software is responsible for satellite attitude and orbit control. During year 2, work was performed on schedulability analysis using Uppaal, which TERMA has so far performed using classical worst-case response-time analysis. The conclusion is that Uppaal takes more details about tasks and therefore is able to produce more realistic response times. Most importantly, it shows that the system is indeed schedulable in contrast to a negative result from the classical response time analysis, which has never been observed in neither stress testing nor deployment. This case study shows that the UPPAAL model checker can be applied for schedulability analysis. These experiences resulted in a chapter for the Quasimodo Book.

In Year 3 a model-based testing (MBT) activity has started to test the software components responsible for the communication link between the satellites and the earth via telemetry commands. Models of this behavior have been developed for use with the MBT tool Uppaal Tron.

5. *Adaptive scheduling of data paths (OCE)*

The OCE case study, which was added to our selection of cases at the end of the first year, is performed in close cooperation with the Octopus project in which, among others, OCE, ESI/RU, and ESI participate. It concerns the data path of a printer/copier encompassing the complete path of the image data (the bit stream) from source (e.g., the network) to target (the imaging unit). Due to its complexity, it provides an excellent challenge for the new analysis and synthesis techniques that are being developed within Quasimodo.

Using Uppaal, the worst case latency was analyzed of scan jobs with uncertain arrival times in a setting where the printer is concurrently processing a stream of print jobs. It was shown that Uppaal can handle the complexity of dynamic memory bus behavior in a realistic model of a complex industrial application.

6. *Rapid Input-Output packet switch (ASML)*

Another case study that was added to the set of case studies is a Rapid Input-Output packet switch provided by ASML in the context of the ESI project WINGS. The project concerns a multi-processor platform where processors are interconnected by Rapid Input-Output (RIO) packet switches. The main challenge is how to map a specific application on the platform such that periodic timing constraints (all packets are delivered in time) are met. The first model in the language POOSL developed in WINGS was used for functional and performance analysis with simulation based techniques leading to approximate results for worst-case and average case latencies. However, because of the criticality also formal verification of worst-case latencies as well as functional logics was desired by ASML. For this, we transformed the model to a network of Timed Automata for Uppaal. With this Uppaal model we formally verified some functional behaviors such as deadlock freedom as well as worst–case packet latencies. Although the approach works in principle, there remain scalability issues, despite applying heuristics and improving abstractions in Uppaal. Moreover, initial experiments were started to check the correctness of the Uppaal model with respect to the POOSL model by means of model-based testing (MBT) of the POOSL model (as SUT) against the Uppaal model (as specification model). Results look very promising but more work is needed to make this a completely viable way of checking models in different languages with respect to each other.

7. Additional Case Studies

A number of additional smaller case studies, mostly in close cooperation with other projects, were performed. In these case studies the Quasimodo methods and tools were applied, providing valuable feedback about tools and methods. Details about these case studies can be found in D5.10.

Model-based testing of electronic passports. The access protocols for the new, Dutch biometric electronic passport were tested using the model-based testing tool TorXakis. Long test runs, upto 1,000,000 test events, were executed, showing the feasibility of the MBT approach for this kind of systems. This project was performed together with the Digital Security group of the Radboud University and the Dutch Ministry of Internal Affairs.

Model-based testing of a software bus at Neopost. A software bus was modeled, verified, and the resulting implementation tested with JTorX, in cooperation with the company Neopost. It was shown that a model-based approach pays off.

Formal specification and analysis of Zeroconf using Uppaal. In this case study, a model of the IP Zeroconf protocol was developed and subsequently analyzed using a combination of manual abstraction an model checking using Uppaal.

The impact of GSM-R on railway capacity. The impact of the new GSM-R communication system on line capacity was analyzed using stochastic modeling.

Testing automated trust anchor updating in Autotrust. Together with the Dutch company InternNLnet an implementation of the IP protocol DNSsec was model-based tested using Uppaal Tron.

Testing a printer controller. In cooperation with OCE, model-based testing was applied to their printer controllers. This was done in two separate projects: one addressing the reactive, stateful job handling task, and one handling the stateless job processing task. The former was done using the tools ToRXakis, Gast, JTorX, and a home-made Python tool. The latter used Boolean predicates and combinatorial (pair-wise) testing.

During year 3 WP5 has worked on a broad selection of case studies which address almost all of the Quasimodo methods, techniques, and tools, and which have provided interesting feedback for Quasimodo as well as for the systems being analyzed. We have shown that the methods, techniques, and tools are applicable, useful, and do provide benefits, but also that scalability (e.g., state-space explosion) and usability (the methods and tools were mostly used by Quasimodo experts and are still difficult to use for industrial engineers) remain critical issues.

Task 5.2: Tools

For tools (T5.2), the ambition is to develop tools, tool-plug-ins and tool-chain integration between tools developed by partners and external and industrially applied tools. Last year's deliverable D5.8: "Tool Components" left the following remaining tasks with respect to for development of tools as:

- Some five components should be developed in order to complete the envisaged set of tool components.
- Frameworks for integration and more easy accessibility of the testing tools of Quasimodo (JTorX and UPPAAL Tron).
- Support for exchange of models between the real-time and probabilistic families of tools (e.g. UPPAAL XX and MODEST). This work is complicated by the differences in the synchronization principles applied (CSP versus CCS) as well the difference in dealing with updates of discrete variables (concurrent versus sequential).
- Work towards linking Quasimodo Tools with Simulink was initiated and should be completed.

During the third year four new tools have been put forward by the Quasimodo partners, three of which supports probabilistic analysis of various sorts, and one offering a prototype tool platform.

- The tool CoDeMOC is a model checker for Continuous-time Markov Chains (CTMC) against linear specifications described using deterministic timed automata. The tool support bisimulation minimization and parallelization.
- The tool UPPAAL SMC extends the UPPAAL toolset with the ability to perform statistical model checking of networks of timed automata (with a stochastic semantics obtained in terms of races between components). The tool monitors several runs of the system, and then supports estimation (using Monte Carlo simulation) and sequential hypothesis testing (of Wald) to estimate the correctness of the system with respect to probabilistic guarantees of time- and cost-bounded properties.
- The tool SCOOP offers a symbolic approach to reduce the state space of probabilistic models with data, by minimizing state spaces prior to their generation by means of syntactic transformations. For this a probabilistic process-algebraic language prCRL is developed extending that of the muCRL language.
- The OPAAL tool allows for a wide range of abstractions useful for model checking large (or even infinite) state systems to be specified through user-defined lattices that are part of the model.

As detailed in the Deliverable D5.9 all components promised of the Tool Component framework has been achieved. The Quasimodo testing tools have been improved in terms of usability during the third year:

- JTorX has been connected with the STSimulator through a defined XML exchange format. The STSimulator is a prototype Java library allowing to simulate Symbolic Transition Systems, allowing for explicit notions of data, and data-dependent control flow (somewhat similar to UML state machines).
- Uppaal-TRON has hitherto functioned as a stand-alone command-line based tool. To make it more accessible and easier to use we have developed a GUI and plugged this into the Uppaal GUI to create an integrated environment for modelling, simulation, verification as well as testing.

In terms of integration between tools a number of links was already developed during the first two years between probabilistic tools of Quasimodo and PRISM. During the third year the ability to exchange models between UPPAAL and Modest has been implemented - by suitable extensions of the two formalisms and their engines to overcome differences in synchronizations and evaluation-order of updates. We expect that exchange of models will primarily exploit the stochastic semantics of timed automata given by UPPAAL SMC and the support of probabilistic timed automata (PTA) in Modest.

For linking to Matlab/Simulink two directions has been completed:

- A tool chains has been implemented which – given a user defined timed game model in UPPAAL Tiga – allow for winning strategies to be automatically imported to Simulink as an S-finction allowing for simulation, validation and automatic generation of code.
- A framework allowing for linking UPPAAL Tron and Simulink models has been implemented. The framework can be used in several ways: a) in testing conformance of a real-time system with respect to a timed automata model one may augment the model with dynamic behavior using co-simulation by Simulink for environment emulation purposes; b) the framework can be used to test conformance of Simulink models against timed automata specifications.

The significant development of tools, tool components and tool integration made during year 3 are described in detail in Deliverable D5.9. Summarizing, we have worked on a development of new tools, improvement of usability of existing tools, completion of the envisaged set of tool components, and completion of integration between tools (probabilistic tools and integration with Simulink). We believe that we have made significant steps towards the improving state-of-the-art in terms of useful tool environments for model-based analysis, implementation, and testing of quantitative system properties.

Task 5.3: Dissemination and Exploitation

The activities that Quasimodo organized in the context of dissemination and exploitation are described in Deliverable D5.11: "Final Report on Dissemination and Exploitation". Many different activities have been organized in this respect. The following remarks can be made:

1. A final Quasimodo symposium was planned but not organized since the attendance at the first Quasimodo workshop was a little disappointing. Instead, special

Quasimodo sessions were organized at a number of conferences, such as the Embedded Systems Week in Phoenix, FMCO (Formal Methods for Objects and Components) in Graz, and ETAPS in Saarbrücken.

2. Work on writing a "Handbook on Quantitative Model-Driven Development for Embedded Systems" is progressing but is a little delayed. Almost all chapters are available but some chapters are still being reviewed. We expect to finalize this book around the summer.

3.3 *Management*

3.3.1 Consortium management tasks and achievements;

The day-to-day management of Quasimodo is handled by the management team, which consists of the Coordinator, Co-coordinator and Administrative Project Manager. The agreed procedures have been followed thus securing efficient day-to-day support of the consortium members.

During the third project period, the main management tasks have included:

- Organization of four project meetings, Paris 24-26 February, Saarbrücken, June 10-11 2010, Saarbrücken February 3-4 2011, in Haarlem October 30, NL, and finally Copenhagen June 15+16 2010.
- Organization and conduction of General Assemblies in conjunction with the project meetings.
- Follow-up on project review.
- Completion of amendment (extension of the duration of the project), including e.g. producing an updated DOW and submitting it on the NEF.
- Organization of Quasimodo dissemination events at ES Week in Arizone, ETAPS in Saarbrücken, at FMCO in Graz, and in Copenhagen
- The research in the work packages have been coordinated primarily via mail and telephone, in addition to the project working meetings; the communication within and between work packages works well.
- Continuous update and development of the Quasimodo project website.
- Ensuring efficient communication within the consortium.
- Conducting distribution of payment to all partners
- Updating contact information
- Project reporting, monitoring and review.
- Continuous update and development of the Quasimodo project website.
- Esben Ahlmann Hjuler has taken over the administrative project leader task as Marlene Kræmmer Sparre is on maturnity leave
- Marielle Stoelinga (ESI/Twente University) has resumed lead of WP4 after maternity leave.

Moreover, the management team endeavours to assist the consortium on day-to-day management issues and to communicate information and guidelines from the EC.

Finally, it is the impression of the management team that the consortium performs well, and the individual WPs interacts satisfactorily and in general the progress is according to schedule.

The last reporting period included two review meetings: A regular review and a follow-up meeting. The conclusion from the Y2 review meeting was that the project has excellent progress. The reviewers made some recommendations to the consortium:

From the regular review:

> Recommendation 1: We would like to suggest to the Consortium again that they would be more effective in integrating the project results if they provide support for the industrial take-up of their techniques and tools by means of (a) a systematic description for how to select a suitable notation and analysis/synthesis approach and (b) providing guidance for how to systematically apply the techniques when starting from different industrial modelling approaches (UML, Matlab/Simulink, ...). We think the deliverable D5.9, and in particular the planned industrial handbook, would be the ideal place to disseminate this additional information.

The industrial handbook focuses on two notations, the Uppaal-timed automata and Modest languages, and explain these very thoroughly. The subclasses of Modest and what analysis support tools are available in the stochastic domain are discussed in Chapter 10 on “Probabilistic Analysis of Embedded Systems”. Hence the problem of choosing among the zoo of Quasimodo formal models is reduced. Starting from existing industrial notations is currently less addressed, but should be discussed in the introduction.

> Recommendation 2: The Recommendation 2 from the last review “From the industry perspective, we would like you to consider how to involve the architectural modelling perspective, in addition to the behavioural aspects” seems not covered to the full extent that has been intended by the suggestion. The clarification request concerning the coverage of architectural concepts of AADL and the received feedback appears to indicate that applicability of the project results could be improved by better reflecting the component-based nature of the system also in the modelling and analysis approach. Currently, the presented material does not demonstrate very clearly how this linkage can be exploited (e.g., does the same component-based decomposition work for the design as well as analysis models? does the reuse of software or hardware components lead to reuse opportunities for the analysis models?).

The architectural aspect is admittedly implicit in much of our work, and is given through the communication of its constituent processes (component behaviour). We have however addressed the behavioural annex of AADL.

> Recommendation 3: The presented results for code-generation of untimed models provided in deliverable D3.6 entitled “Code generation from untimed specifications” seem to be rather decoupled from the rest of the project. The source language (Promela) is not used by any of the tools of the project, and the output language Java does not seem well suited to the real-time setting of the project. However, the consortium was able to explain this discrepancy and outlined a convincing plan for the forthcoming work for code-generation of timed models. We want to emphasize in the recommendation that in the case of code-generation of timed models proper linkage to the different analysis models is of major importance and should thus be well documented.

Quasimodo has developed synthesis of control strategies using Uppaal-Tiga. Via an export to Matlab/Simulink, further simulation and code generation is possible. Further we have extensively studied the issue of robustness/implementability of timed automata models. Here a major result is that any timed automaton may be transformed into an equivalent robust/implementable one.

> Recommendation 4: The planned Industrial Handbook (D5.12) has potential to be a very useful deliverable. We really appreciate the decision of the consortium to have such a handbook. We only recommend adjusting the planned handbook according to points (a) and (b) of Recommendation 1, and ensuring that the perspective of industrial needs is prominent, instead of the handbook being presented as a series of disjoint descriptions of available techniques. Further, the handbook should be drafted early in the period to allow for identifying and addressing concerns that may emerge while harmonizing project results.

The handbook is targeted towards an industrial audience and written in a tutorial style with modelling and analysis from first principles. Our first experiences in teaching (external industrial engineers seeking a masters degree) based on selected chapters are encouraging as they have been able to produce better models and more sophisticated analysis than in previous courses. The obtained experiences are being fed back to the authors of the relevant chapters. The organization of the handbook with introductory chapters and their advanced applications to case studies should appeal to practitioners, and inspire them to try out the techniques and seek further information. Further external review will be conducted before final print. The architectural aspect has yet to be addressed.

> Recommendation 5: In the last review we criticized the writing style of the reports. We acknowledge that the reports this time have been very clear and informative for the academic expert. However, there is still the shortcoming that sufficient background and explanations of terms necessary for most real-time experts without academic background in the specific field of the project is missing. As the industrial handbook planned for the 3rd period should also be used to make project results available to external stakeholders and to facilitate involvement of stakeholders outside the consortium, the above observation is probably even more relevant since a similar situation could substantially reduce the value of the handbook for industrial users.

Management have emphasized to authors that deliverables should be self contained and explanatory, but we acknowledge that it is a significant challenge to balance their informativeness towards different audiences with their length and required writing effort; in particular some of the hardcore research results requires significant technical insights to be fully appreciated. It is also evident from the deliverables that most results are disseminated by additional means; through papers (and handbook), tools, and academic and industrial seminars, in addition to the deliverables.

The additional interim review meeting also made a number of smaller recommendations:

> Recommendation: Outline the specific application more clearly (the hydraulic subsystem not the whole machine) and also discuss the benefits and its implications from the user perspective (What were the challenges, what are the savings, why cannot conventional control match formal methods, etc.)
>
> Experience from Novo Nordic was reported, where UPPAAL Tron is used for testing, cutting product cycles down to days. Recommendation: Cover this industrial experience in the Quasimodo material.
>
> The project results build on a large set of tools. Recommendation: Be clear which tools are intended as front-end modelling tools, and which are back-end analysis tools.

The two first two and other experiences will be highlighted in the final report. The Novo technique is described in D4.3. A chapter in the handbook is dedicated to the Hydac Case, and possibly, a short discussion relating to ”conventional control” will be added. The third recommendation is passed on to each partner. However, the distinction is not always easy to make as several tools functions as both (eg. Uppaal is both used as both).

> Recommendations: Clarify the budget situation for CNRS and verify that they can continue working in the project in spite of an exhausted budget.
> Explore lightweight approaches for integration (e.g., limit the support to dedicated block sets) and cover the necessary steps to get from a MATLAB/Simulink to the analysis tools and back in the industrial handbook (e.g., by the case studies where it applies).

CNRS, CHESS and Terma, all with low remaining budget were made aware of the situation. However, they have agreed to continue their remaining duties in the project.

We have developed several tool integrations with Matlab/Simulink, but no explicit guide for translating (semi-automatic or manual) has so far been made. A process for making good models is contained in the handbook. A key point here is that modes should be made with a particular purpose in mind, and existing models are typically not made with the same purpose as Quasimodo models would serve; and hence a direct translation is not recommended. Some indication of a mapping will be provided in introduction of the handbook. Positive
experiences in teaching this material exists already.

> Recommendation Provide some general guideline that demonstrate how typical architectural models such as UML components, AADL, AUTOSAR or EAST-ADL can be captured in your models for analysis. Clarify how in the case that models for different components exists that have been described by different analysis modelling languages, these models can be conceptually integrated using the MODEST language.

See comments regarding architectural modelling above.

> The recommendations for the industrial handbook were discussed and it was noted that in the last review, early access to a draft of the book had been requested. All participants of the meeting agreed that the reviewers may provide feedback and that the consortium will try to provide a draft as soon as possible (taking into account the constraints due the publication by Springer).

A draft version of the handbook was made available to reviewers in late may 2011. Although this is not as early as originally envisioned there is time for additional feedback from the reviewers and other external reviewers. Feedback is welcome.

> Recommendations: Maybe parts or subsections can be used to reduce the number of chapters and thus improve the structuring of the book. Property verification may deserve a separate chapter to be analogous with the other techniques such as schedulability analysis, test generation, etc. The initial modelling introduction should also take care of the link to architecture modelling.

As explained we consider property checking an integrated part of making sound models, and have presented it that way in the handbook. Any model should be checked before applications for testing and code generation, otherwise the derived artefacts may not reflect the intentions of the engineer, and a vital part of doing early analysis and defect detection could be lost. This point will be stressed in the handbook.

The consortium requested an extension of 4 months to be able to get the full potential fro the consortium. Recommendation: An extension seems appropriate, but a motivation and updated plan is required.

A motivation and an updated DOW was prepared and accepted by the Project Officer. This was subsequently accepted.

3.3.2 Problems and solutions

Writing the Industrial Handbook has been a major undertaking in the third reporting period, and has consumed significant time from several senior Quasimodo researchers. Whilst some chapters were drafted and reviewed on time, others were not. Given the potentials of this deliverable, it has been a management decision to push for completion of the individual technical chapters in priority of writing the technical deliverables (to a large extend to be written by the same staff). The consequence was some of the deliverables were submitted later than planned, and also had a cascading effect on the periodic progress report, final report and financial reporting.

Besides this there have been no major problems in the period.

3.3.3 Changes to the consortium

Since the beginning of the project all parties have changed their administrative contact person. In relation to the amendment just completed, the contact information has been updated in the Grant Preparation Forms.

In year 3, Esben Ahlmann Hjuler has replaced Marlene Kræmmer Sparre as the projects administrative manager as she is on Maternity leave.

Furthermore, Mariëlle Stoelinga (ESI/Twente) has resumed work after a maternity leave, and has also recently resumed the task of leader of WP4.

3.3.4 Project meetings

In this Y3 reporting period three regular Quasimodo workshops have been arranged, in addition to a dedicated WP4 meeting, and the 4 dedicated dissemination events. Also a regular review was held in conjunction with meeting 5, and an additional interim review was organized in Brussels in September 2, due to travel problems of the project officer at the ordinary review.

Meeting 5 was held in Paris 24+26 of February 2010 and organized by CNRS. The workshop featured 13 technical/scientific presentations related to the work packages. 45 international researchers associated with the partners were present showing an enormous interest in the Quasimodo project. Also, a management board meeting took place. Minutes and slides from the meeting and general assembly are available at the internal Quasimodo website. Ramine Nikoukhah was invited to present the SciLab alternative to Simulink.

Meeting 6 was held in Saarbrücken, on June 10-11, 2010 organized by Saarland University. The workshop featured 13 scientific presentations related to the work packages, of which most focused on tools and case-studies. About 45 participants were present. Also, a management board meeting took place. Minutes and slides from the meeting and general assembly are available at the internal Quasimodo website.

Meeting 7 was also held in Saarbrücken, on February 3-4, 2011, but this time organized and hosted by Hydac. The workshop featured 12 scientific presentations related to the work packages, a demonstration of the Hydac demonstrator, and a tour of the development and production facilities of Hydac. Nearly 30 participants were present. Also, a management board meeting took place. Minutes and slides from the meeting and general assembly are available at the internal Quasimodo website.

A **dedicated meeting for WP4** was held in Haarlem, NL, arranged and hosted by Chess, on September 30 to October 1, 2010. 17 participated. Presentation and discussions focused on theory, tools, and case-studies of model-based testing, and on planning work for the remaining short period. Also, the participants were guided on a tour in the Chess facilities.

The meeting attendance has thus continued to be very high, showing a steady high interest in topics addressed by Quasimodo, and its results.

3.3.5 Project planning and status;

Quasimodo has submitted all required deliverables, and met its main mile stones, and work has in several areas progressing beyond the plan. A remaining task is completion and printing of the industrial handbook.

3.3.6 Use of foreground and dissemination

A detailed list of the dissemination activities appears in Deliverable 5.11 (dissemination and exploitation). We refer to this for details.

In the Year 3 period, Quasimodo staff personnel are very active in disseminating the research results. In the reporting period they have been involved in organizing more than 23 local and international workshops, summer-schools, events, and courses related to Quasimodo work.

We remark that also industrial partners have arranged internal training seminars to disseminate results internally.

Further, dedicated Quasimodo events included a half day tutorial on “Quantitative System Validation in Model Driven Design” were arranged and given at the Embedded Systems Week in Arizona October 2010, a session at FMCO 2010, a session at the Rocks symposium at ETAPS 2011, and a final dissemination event on “From Model-Driven Development to System Engineering Science” (with the DaNeS project) in Copenhagen, 2011.


Quasimodo Tutorial Presenters at ES Week in Arizona

In addition to numerous (unlisted) regular scientific paper presentations, more than 65 invited and keynote talks related to Quasimodo work has been given.

The several demonstrators developed by Quasimodo, and especially the Industrial Handbook, will serve as vehicle for future exploitation and dissemination.

Quasimodo very actively collaborates with several other national (including more than 10 industrial projects) and international projects. Especially, we remark the EC projects ARTIST Design NoE, MOAN (Strep), Multiform (Strep), Genesys (Strep), Destecs (Strep), GASSICS (ESF).

The research in Quasimodo has for year 2010 (and known to appear in 2011) resulted in more than 125 refereed scientific (conference or journal) publications. The accumulated bibliography (sorted per work package per year) is listed in Section 9. A browsable version is available online at the Quasimodo webpage http://www.quasimodo.aau.dk/publications.html

3.3.7 **Use of Resources**

The following table shows the planned and real (actual) staff (person month) usage per work package per partner for ***staff being paid*** from the Quasimodo budget. P=planned, R=real person months. Remark that much more effort is put into the project than reflected in this table.

Year 3

	WP0		WP1		WP2		WP3		WP4		WP5		Total	
Partner	P	R	P	R	P	R	P	R	P	R	P	R	P	R
AAU	6	4	0	0	0	9	1	0	2	7	11	16	20	36
ESI	0	0	4	5	2	4	1	1	7	10	9	18	23	38
CNRS	0	0	0	0	2	3	2	5	0	0	3	2	7	10
RWTH	0	0	0	1	2	3	0	1	0	2	4	6	6	13
SU	0	0	1	0	3	4	0	0	4	4	4	7	12	15
CFV	0	0	0	0	1	0	2	17	0	0	2	0	5	17
Terma	0	0	1	0	0	0	0	0	0	0	2	1	3	1
Chess	0	0	0	0	0	0	0	0	0	0	3	2	3	2
Hydac	0	0	0	1	0	0	0	0	0	3	2	1	2	5
Total Y3	6	4	6	7	10	23	6	24	13	26	40	53	81	137
Total Y1	6	5	12	5	20	15	20	9	3	9	28	25	89	68
Total Y2	6	4	15	14	24	24	19	23	13	5	22	28	99	98

Total all periods (months 0-40).

	WP0		WP1		WP2		WP3		WP4		WP5		Total		Remain
Partner	P	R	P	R	P	R	P	R	P	R	P	R	P	R	
AAU	18	13	2	2	6	13	6	6	6	9	14	20	52	63*	-11*
ESI	0	0	16	11	11	8	6	3	14	19	25	35	72	76	-4
CNRS	0	0	0	0	8	14	13	17	0	0	7	4	28	35	-7
RWTH	0	0	4	4	14	14	0	2	0	4	10	10	28	34	-6
SU	0	0	5	5	11	13	0	0	4	4	11	14	31	34	-5
CFV	0	0	0	0	4	0	20	28	0	0	4	0	28	28	0
Terma	0	0	2	0	0	0	0	0	3	1	5	8	10	9	1
Chess	0	0	2	2	0	0	0	0	0	0	8	11	10	13	-3
Hydac	0	0	2	2	0	0	0	0	2	3	6	4	10	9	1
Total	18	13	33	26	54	62	45	56	29	40	90	106	269	301	-34
Total Yr	18	13	33	26	54	62	45	56	29	40	90	106	269	301	
Remain	5		7		-8		-11		-11		-16		-34		

For the 3rd reporting period a total of 135 person months have been delivered compared with an originally planning of 81. In part, this compensates for the less-than-planned effort delivered in the first year, but also overall during the whole project more effort (about 30 person months) than initially estimated.

We remark that significantly more effort than planned has been delivered to all work packages (except WP0 management). An exception is WP1 (modelling). This is explained by the fact that this plan was made prior to project launch, and hence prior to the departure of partner Inchron. Hence, less efforts for working on modelling notations for Inchron's tool suite (see deliverable D1.4) has been required. Still the WP1 has met its overall objectives. The extra efforts in WP2 to WP5 are well in line with the strong scientific results, case-studies and dissemination activities.

Remark that this table (and the underlying yearly reports) is maintained and reported in whole person months; accumulation of rounding errors may therefore result in a small deviation (0-2 person months) between actual effort and the tabulated overall sum. E.g, for AAU (labelled *) the tabulated sum is nearly 2 pm higher than the actual effort.

Several partners have been able to deliver more person months for RTD work that originally estimated. A large part of the explanation is that the budget were made based on average cost of staff, but the partners have been able to hire staff with less costs (e.g PhD Students and Post Docs). Many young researchers have been involved in Quasimodo. However, such more inexperienced staff may take longer to complete a task than more senior personnel, so none of the effort could have been removed without impacting the performance of the project.

It has been necessary for CNRS and Chess to make a budget deficit to deliver the required work; CNRS has been highly involved in the successful work on controller synthesis, and CHESS extremely involved with much work on their case studies.

AAU in particular has delivered more on RTD than originally estimated (nearly 50 versus the estimated 32). This is in part because of hiring of staff (PhD students and Post Docs) that was cheaper than originally budgeted, and in part because some of the budget for "other direct costs" has been used to hire staff, rather than travel. Also the "other direct cost" included resources available to the coordinator for inviting external researchers and experts on tool integration (esp. Matlab/Simulink). However, the required expertise was found internally. Also less effort for management than planned has been paid by Quasimodo (13 versus 18 person months). During the project it was discovered that the original budget for management were being depleted (since management is carried out by senior permanently hired staff with above average personnel cost used in the budget). Rather than overspending too much on management, the coordinator decided to do the work in his own time without charging the project, and maintain RTD resources as much as possible.

In total about 300 person months have been delivered in Quasimodo has been delivered by Quasimodo. The deliverables, milestones and overall objectives have all been met.
The project meetings have had a very high attendance rate (30-50 researchers). Thus the support by the EC has produced a lot of good quality research on quantitative system properties, and the project has thus made effective use of the resources at its disposal.

3.3.8 Summary of Milestones

The overall third year objective is to finalize development tool components for quantitative analysis, synthesis and testing, and to integrate these in tool chains, and to perform a final application of these to case studies. A special objective is on dissemination with focus on completing the industrial handbook.

Quasimodo has developed a large set of unique tool-components. They are described in deliverable 5.8 and 5.9, and are available via the Quasimodo web-page. All tools are based on a precise model with a formally defined syntax and semantics. The tool components vary in maturity from research prototypes to more mature. As a consequence also the amount of documentation varies.

For all major tool components, the format of the languages and input files is well documented as part of the tool documentation. Admittedly, not all input and output files are yet XML based, but where beneficial many are (e.g. Uppaal timed automata, Torx GraphML, XML format for symbolic transition systems, Uppaal-TRON configurations). The API for creating Uppaal-Tron adaptors is extensively documented in its manual.

As elaborated in Deliverable 5.9, there are many links between Quasimodo tools. Exchange of probabilistic models is to a large extent enabled via imports/exports to the Prism language. For the timed automata based tools, the Uppaal language is widely used. The possibilities for exchanging models between the timed automata based tools and Modest based probabilistic tools is being bridged through implementation of new synchronization operators and semantics, and the new statistical model-checker for Uppaal.

Further, significant progress has been made in linking and integrating these with industrial notations and tool-chain, e.g., STATEMATE, Simulink, AADL analysis. Obviously, this is the beginning of wider deployment and much can be done in the future.

In the project we have applied our techniques to 6 larger Quasimodo industrial case studies, in addition to a large collection of additional case studies. The applications range across several typical development activities from modelling, analysis, synthesis and testing; in most cases the techniques have successfully solved aspects of these case study. In several cases we have found defects in the systems being investigated that potentially could have been avoided using Quasimodo techniques. In the Hydac case we have obtained a breakthrough in how optimal controllers may be engineered in the future using automated controller synthesis.

The handbook is in very good progress. A full text internally reviewed draft version exists of most chapters, and the remaining ones are ready for internal review. The book will be released for further external review and commenting in the near future. Although the finalization and external review and printing takes place later than expected, a high quality handbook will appear.

The objectives of Y3 are detailed through the description of milestones M6, and M7.

> Milestone M6 is to be verified though the availability of: 1) Final version of tool components, Well documented APIs and XML exchange formats for all tool

components available, 2) Case studies completed including modeling, analysis, testing and code generation using developed tool components integrated with industrial tool chains.

Milestone M7 is to be verified though the availability of: 1) Final reports evaluating case studies, tool components and their integration and applicability, and 2) Dissemination of results of the project via tool demonstrators and the ”Quasimodo Handbook”.

Quasimodo has submitted all contractual deliverables, and based on the discussion above we believe that we in all essential aspects have met these milestones.

4. Deliverables and milestones tables

Deliverables (excluding the periodic and final reports)

Year 3 deliverables are highlighted using a bold-faced font.

TABLE 1. DELIVERABLES[5]

Del. no.	Deliverable name	WP no.	Lead beneficiary	Nature	Dissemination level	Delivery date from Annex I (proj month)	Delivered Yes/No	Actual / Forecast delivery date	Comments
D1.1	Modeling quantitative system aspects	1	ESI/RU	R	PU	12	Y	12	
D1.2a	Design Notations	1	SU	R	PU	12	Y	12	1)
D1.2b	Design Notations	1	SU	R	PU	12	Y	24	
D1.3	Model process improvement	1	ESI/RU	R	PU	24	Y	24	
D1.4	Modeling tools	**1**	**ESI/ESI**	**R+P**	**PU**	**39**	**Y**	**41**	**P)**
D2.1	Model checking real-time probabilistic models	2	AAU	R+P	PU	12	Y	12	P)
D2.2	Symbolic data structures and analysis of models with multiple quantitative aspects	2	CNRS	R+P	PU	18	Y	24	2) P)
D2.3	Abstraction	2	RWTH	R	PU	24	Y	24	
D2.4	Abstraction-refinement	**2**	**ESI/RU**	**R+P**	**PU**	**30**	**Y**	**41**	**2) P**
D2.5	Approximate Analysis	**2**	**SU**	**R+P**	**PU**	**39**	**Y**	**41**	**P**
D3.1	Transfer of correctness properties from model to implementation	3	ULB	R	PU	12	Y	12	

[5] For Security Projects the template for the deliverables list in Annex A1 has to be used.

D3.2	Tool for implementability checking	3	ULB	P	PU	18	Y	24	2) P)
D3.3	Model checking of controllability properties	3	ULB	R+P	PU	12	Y	12	4)
D3.4	Synthesizing controllers with bounded resources	3	CNRS	R+P	PU	24	Y	24	P)
D3.5	Extended timed automata for scheduling	3	CNRS	R+P	PU	18	Y	24	2) P)
D3.6	Code generation from untimed specifications	3	ESI/TW	R+P	PU	24	Y	24	P)
D3.7	Code generation from timed specifications	**3**	**AAU**	**R+P**	**PU**	**39**	**Y**	**41**	
D4.1	Quantitative Testing Theory	4	ESI/TW	R	PU	12	Y	12	
D4.2	Algorithms for off- and online quantitative testing	4	AAU	R+P	PU	24	Y	24	P)
D4.3	Test selection and coverage	**4**	**AAU**	**R+P**	**PU**	**30**	**Y**	**41**	2) P)
D4.4	Approximate testing	**4**	**ESI/TW**	**R**	**PU**	**30**	**Y**	**41**	2)
D4.5	Final Algorithms and evaluation	**4**	**ESI/TW**	**R**	**PU**	**39**	**Y**	**41**	
D4.6	Online hybrid/stochastic testing	**4**	**ESI/TW**	**R+P**	**PU**	**30**	**Y**	**41**	2) P
D5.1	Quasimodo Website	0	AAU	O	PU/CO	1	Y	1	
D5.2	Preliminary description of case	5	SU	R	PU/CO	6	Y	12	2)
D5.3	Dissemination and use plan	5	ESI	R	PU	6	Y	12	2)
D5.4	Plan for integration of tool components	5	AAU	R	PU	12	Y	12	
D5.5	Case Studies: models	5	RWTH	R	PU	12	Y	12	
D5.6	Dissemination and Exploitation	5	ESI/ESI	R+D	PU	24	Y	24	D)
D5.7	Case studies: validation	5	SU	R	PU/CO	24	Y	24	
D5.8	Tool components	5	AAU	R+P	PU/CO	24	Y	24	P)
D5.9	Tool components and tool integration	**5**	**AAU**	**R+P**	**PU**	**30**	**Y**	**41**	**2)**
D5.10	Final report on case studies and tool integration	**5**	**RWTH+SU**	**R+P**	**PU/CO**	**39**	**Y**	**41**	

D5.11	Final report on Dissemination and Exploitation	**5**	**ESI/ESI**	**R**	**PU**	**39**			
D5.12a	Industrial Handbook vers. 1	5	ESI/ESI	R	PU	24	Y	24	
D5.12b	Industrial Handbook final	**5**	**ESI/ESI**	**R+D**	**PU**	**39**	**Y**	**41**	**D)**

1) Concerning D2.1 on design notations which we find only partially completed due to the uncertainty of the partner replacement, we propose to write an updated version by month 24. This will be reflected in our proposal for an updated Description of Work.
2) These deliverables were submitted to the commission by the end of the reporting period (M40) in agreement with the project officer

D) Demonstrator is the handbook with its examples.

P) A prototype tool component is delivered with this deliverable as described in the following table

Deliverable	Description	Availability by
D1.4	Stochastic plug-in for STATEMATE for checking dependability properties.	Contacting the developers (Holger Hermanns hermanns@cs.uni-saarland.de).
D2.4	SCOOP is a tool for optimising analysis of probabilistic processes with complex data. ProHVer is a tool for computing the unbounded reachability probability for a very general class of probabilistic hybrid automata. PASS: We have developed PASS (implementing predicate abstraction and abstraction refinement.) a tool that analyzes concurrent probabilistic programs, which map to potentially infinite Markov decision processes.	SCOOP, including the web-based interface, can be found at http://fmt.cs.utwente.nl/˜timmer/scoop/ http://depend.cs.uni-sb.de/tools/prohver/ PASS is available at http://depend.cs.uni-sb.de/tools/pass/
D2.5	Uppaal-SMC is a statistical model-checker for networks of priced timed automata.	Uppaal-SMC is to be released as part of the Uppaal tool suite Q3 2011 www.uppaal.com
D3.7	Ruby script for translatating for Uppaal-Tiga Strategies to Matlab/Simulink S-functions	Available by contact to developers Alexandre David (adavid@cs.aau.dk)
D4.3	The coverage optimizing offline test generation (using agent based search strategy) tool Upaal-Ygdrasil.	Contact developers for the latest versionof Yggdrasil: K. G. Larsen (kgl@cs.aau.dk).
D4.6	Plugin for co-simulating Uppaal-TRON with Matlab/Simulink and virtual clock framework.	The described extension and virtual clock framework of uppaal-TRON is implemented in the latest release. The Simulink plugin is available by contacting the developers (Marius Mikucionis marius@cs.aau.dk)

D5.9	A large set of tool components supporting formal analysis and synthesis, testing of probabilistic, timed, priced, timed probabilistic systems have been developed. In particular SCOOP, JTorx, MoDeCo, Uppaal-SMC and Opaal have been developed in Y3; further previous delivered components have been further developed and refined.	The Quasimodo Website maintains a list of available (currently more than 20) Quasimodo tool compontents http://www.quasimodo.aau.dk/tools.html

Milestones

TABLE 2. MILESTONES

Milestone no.	Milestone name	Work package no	Lead beneficiary	Delivery date from Annex I	Achieved Yes/No	Actual / Forecast achievement date	Comments
M1	Project Start	All	AAU	M1	Yes	15+16 Jan'08	Kickoff meeting
M2	Definition Phase	All	ESI	M6	Yes	M8	
M3	Modelling Formalisms	All	SU	M12	Yes	M12	
M4	Algorithm Design	All	CNRS	M18	Yes	M18	
M5	Tool Components	All	RWTH	M24	Yes	M24	
M6	**Tool Integration and case studies**	**All**	**ESI**	**M30**			
M7	**Project Closure**	**All**	**AAU**	**M36**			

1. Milestone M1 is to be verified through a kick-off meeting. The Quasimodo kick-off meeting was held 15+16 january 2008 at Aalborg University, Denmark.
2. Milestone M2 is to be verified through availability of 1) a precise descriptions of case studies, 2) a plan for tool components and their integration in industrial tool chain.
3. Milestone M3 is to be verified through the availability of 1) a semantic foundation of quantitative models in terms of labelled transition systems including semantics of composition of models, refinements between models, 2) a formal definition of conformance and robustness between quantitative models and implementations, 3) first models of case studies, and 4) quantitative extensions identified by the needs of case studies.
4. Milestone M4 is to be verified though the availability of 1) implemented data-structures for symbolic representation and manipulation of state spaces for quantitative models, and 2) verified algorithms and experimental implementation for quantitative analysis, abstraction/refinement, controller synthesis and testing.
5. Milestone M5 is to be verified though the availability of 1) first implementation of tool components, 2) first tool trial: integration of selected tool components with industrial tool chains and application to case studies.
6. Milestone M6 is to be verified though the availability of: 1) final version of tool components, Well documented APIs and XML exchange formats for all tool components available, 2) Case studies completed including modeling, analysis, testing and code generation using developed tool components integrated with industrial tool chains.
7. Milestone M7 is to be verified though the availability of: 1) Final reports evaluating case studies, tool components and their integration and applicability, and 2) Dissemination of results of the project via tool demonstrators and the ”Quasimodo Handbook”.

We believe that we have reached these milestones M6-M7 as discussed in Section 3.3.8.

5. Explanation of the use of the resources

Beneficiary 1 AAU			
Work Package	Item description	Amount	Explanations
WP0-5	Personnel costs	165.519 €	Salery for: 4 post docs (aug10-apr11) 2 research assistants (feb-apr10, apr11) 1 ph.d. student (aug10-apr11) 3 associate proffessors (okt10-apr11), 2 project managers
	Subcontracting	6.034 €	PWC Audit- Jun2011
WP0-5	Travel	20.636 €	Jacob I Rasmussen (Paris) 23/2 2010 cancelled/weather situation - non refundable expences Shuhao Li (Dresden) 8/3 2010 presenting paper at DATE'2010 conference Brian Nielsen project meeting and review (Paris) 23-27/2 2010 Alexandre David - review Paris 24.-26.2.10 Kim G. Larsen - review Paris 23.-26.2.10 Alexandre David - project meeting Saarbrucken 9-11/6 2010 Brian Nielsen - project meeting Saarbrucken 9-11/6 2010 Marius Mikucionis - project meeting Saarbrucken 9-11/6 2010 Brian Nielsen - Interim review meeting - Brussels 2-3/9-2010 Brian Nielsen - WP4 meeting - Haarlem (NL) 29/9-1/10-2010 Marius Mikucionis - WP4 meeting - Haarlem (NL) 29/9-1/10-2010 Kim G.Larsen/Brian Nielsen - Hotel - Interim review meeting 2-3/9-2010 Kim G Larsen - review - Brussel 2-3/9 2010 Brian Nielsen, session at FMCO - Graz 29/11-2/12 2010 Brian Nielsen, work meeting Eindhoven 16-20/11 2010 Kim G Larsen - MFCS-CSL 2010 Czech Republic 27-29/8 2010 Kim G Larsen - CSMD 2010 Paris 27-29/10 2010 BN - 201085596 - Partnermøde Dusseldorf (D) 15-16/12 2010 Kim G Larsen Workshop fee Saarbrücken (D) 10-11/6 2010 Kim G Larsen - Partner meeting Dusseldorf (D) 15/12 2010 Kim G Larsen - 201083395 - Marktoberdorf (D) 3-14/8 2010 Brian Nielsen - Project meeting Saarbrücken 2-4/2 2011 Marius Mikucionis presentation Salzburg 9-10/4 2011 Kim G Larsen - Project meeting Saarbrücken 2-4/2 2011 Kim G Larsen - Coop. Meeting J.F. Rasking - Brussels 9-10/3 2011 Alexandre David - Final review meeting, Copenhagen 15-16/6 2011 Brian Nielsen - Final review meeting, Copenhagen 15-16/6 2011 MKK review, Paris rejse Kim G Larsen - Final review meeting, Copenhagen 14-17/6 2011
	Other	1.887 €	DOD - Research Review Geodis Wilson, Amendment til EC (Jan) Geodis Wilson (jun.) Geodis Wilson (okt.) Bank transfer fees
	Remaining direct costs		
TOTAL DIRECT COSTS*		194.075 €	

Beneficiary 2 ESI			
Work Package	**Item description**	**Amount**	**Explanations**
	Personnel costs	170.117 €	B.R.H.M. Haverkort: 0,32 pm (person months) G.J. Tretmans: 4,34 pm L. Frantzen: 4,71 pm F. Aarts: 11,61 pm F.I. Berg: 1,83 pm J. Xing: 12 pm G. Angyal: 0,57 pm E. Pater: 1,79 pm
	Subcontracting	3.948 €	KPMG Audit
	Traveling	25.488 €	Traveling
	Remaining direct costs		
TOTAL DIRECT COSTS*		199.553 €	

Beneficiary 3 CNRS			
Work Package	**Item description**	**Amount**	**Explanations**
2,3,5	Personnel costs	87.062 €	Salaries of 3 CNRS researchers and 2 ENS-Cachan researchers, for the time they spent on the project
	Subcontracting		
2,3,5	Major cost item "X"	10.968 €	Travel costs
	Major cost item "Y"		
	Remaining direct costs		
TOTAL DIRECT COSTS*		98.030 €	

Beneficiary 4 RWTH			
Work Package	Item description	Amount	Explanations
1, 2, 5	Personnel costs	€47.504	Hours of PD and Prof. working on project
	Subcontracting	€0	
	Major cost item "X"		
	Major cost item "Y"		
	Remaining direct costs	€4.373	Travel costs
TOTAL DIRECT COSTS*		€51.877	

Beneficiary 5 SU (UDS) – Total RTD + demo			
Work Package	**Item description**	**Amount**	**Explanations**
2,4,5	Personnel costs	69.242 €	Salaries of participating personnel in Quasimodo
	Remaining direct costs	2.605 €	Travel costs
TOTAL DIRECT COSTS*		71.847 €	

Beneficiary 6 CFV			
Work Package	**Item description**	**Amount**	**Explanations**
	Personnel costs	100.468 €	1 post-doc student during 2010 - 20% salary of senior researcher (rd and demonstration) - 3 months of doctoral student for demonstration - All activities have been delivered in the context of WP3.
	Subcontracting		
	Major cost item "Travel"	4.854 €	Travel to Quasimodo meetings and conferences for dissemination
	Remaining direct costs		
TOTAL DIRECT COSTS*		105.322 €	

Beneficiary 7 TERMA			
Work Package	**Item description**	**Amount**	**Explanations**
5	Personnel costs	7.538 €	
	Subcontracting		
	Major cost item "X"		
	Major cost item "Y"		
	Remaining direct costs	178 €	
TOTAL DIRECT COSTS*		7.716 €	

Beneficiary 8 CHESS			
Work Package	**Item description**	**Amount**	**Explanations**
	Personnel costs	7.698 €	work on WP5 case studies (model based testing) + hosting WP4 test meeting + book chapter authoring and review
	Subcontracting	0 €	
	Remaining direct costs	1.360 €	travel and organisation cost Quasimodo meetings in Paris (02-10), Saarbrucken (06-10) and Haarlem (10-10)
TOTAL DIRECT COSTS*		9.058 €	

Beneficiary 9 HYDAC			
Work Package	**Item description**	**Amount**	**Explanations**
1,4,5	Personnel costs	35.873 €	
	Travel Costs	1.234 €	Travel expenses
4,5	Demonstration machine	7.090 €	hydraulic parts
4,5	Demonstration machine	1.762 €	electric parts
1,4,5	Matlab Licence	8.000 €	contains Matlab, Simulink and Stateflow
	Meeting costs	951 €	
TOTAL DIRECT COSTS*		54.910 €	

Cost-budget follow-up

The following table shows the cost-budget follow-up for Quasimodo (the actual and percentual) spending of the total budget (not EC contribution) for Quasimodo. Most partners have spent and even exceeded their budget. Especially CNRS has exceeded their allocated part; however, they have delivered more person months than initially projected, but have been necessary to accomplish its goals. We remark that ESI has surplus in the budget (and RWTH a small one). The discrepancy is explained by differences between estimated and actual personnel cost.

Cost Budget Follow-up Table		total budget figures - not EC funding									
Contract no.	214755	Acronym:	Quasimodo			Date:	16-jun-11				
			Actual costs (EUR)				Pct. Spent				
Participants	Type of expenditure (as defined in budget)	Budget	Year 1	Year 2	Year 3	Total	Year 1	Year 2	Year 3	Total	Remaining budget (EUR)
		e	a1	b1	c1	d1	a1/e	b1/e	c1/e	a1/e+b1/e+c1/e	e-d1
Partner 01											
AAU	Personnel costs	237.372,33	63.022	50.587	165.518,74	279.128	27%	21%	70%	118%	(41.755)
	Subcontracting	1.500,00	0		6.034	6.034	0%	0%	402%	402%	(4.534)
	Other direct costs	82.947,00	6.231	16.921	22.523	45.675	8%	20%	27%	55%	37.272
	Indirect costs	192.191,59	41.551	40.504	112.825	194.880	22%	21%	59%	101%	(2.688)
	Total costs	514.010,92	110.804	108.012	306.901	525.717	22%	21%	60%	102%	(11.706)
Partner 02											
ESI	Personnel costs	379.340,03	67.535	111.836	170.117	349.488	18%	29%	45%	92%	29.852
	Subcontracting	4.500,00	0		3.948	3.948	0%	0%	88%	88%	552
	Other direct costs	36.000,00	7.856	9.191	25.488	42.535	22%	26%	71%	118%	(6.535)
	Indirect costs	249.204,02	45.234	72.616	117.363	235.213	18%	29%	47%	94%	13.991
	Total costs	669.044,05	120.625	193.643	316.916	631.184	18%	29%	47%	94%	37.860
Partner 03											
CNRS	Personnel costs	97.500,50	45.094	106.133	61.942	213.169	46%	109%	64%	219%	(115.669)
	Subcontracting	78.356,00	0			0	0%	0%	0%	0%	78.356
	Other direct costs	11.072,00	500	13.583	11.908	25.991	5%	123%	108%	235%	(14.919)
	Indirect costs	65.143,50	27.356	71.828	42.806	141.990	42%	110%	66%	218%	(76.846)
	Total costs	252.072,00	72.950	191.544	116.656	381.150	29%	76%	46%	151%	(129.078)

Partner 04											
RWTH	Personnel costs	159.761,52	61.902	47.816	47.504	157.222	39%	30%	30%	98%	2.540
	Subcontracting	1.500,00				-	0%	0%	0%	0%	1.500
	Other direct costs	12.090,56	4.831	3.656	4.373	12.860	40%	30%	36%	106%	(769)
	Indirect costs	103.111,24	40.039	30.883	31.126	102.048	39%	30%	30%	99%	1.063
	Total costs	276.463,32	106.772	82.355	83.003	272.130	39%	30%	30%	98%	4.333
Partner 05											
USAAR	Personnel costs	177.042,02	42.418	70.838	69.242	182.498	24%	40%	39%	103%	(5.456)
	Subcontracting	1.500,00	0			0	0%	0%	0%	0%	1.500
	Other direct costs	12.090,56	1.106	5.044	2.605	8.755	9%	42%	22%	72%	3.336
	Indirect costs	113.479,54	26.114	45.529	43.108	114.751	23%	40%	38%	101%	(1.271)
	Total costs	304.112,12	69.638	121.411	114.955	306.004	23%	40%	38%	101%	(1.891)
Partner 06											
ULB	Personnel costs	144.532,02	0	55.759	100.468	156.227	0%	39%	70%	108%	(11.695)
	Subcontracting	1.500,00	0			0	0%	0%	0%	0%	1.500
	Other direct costs	12.075,45	1.696	1.132	4.854	7.682	14%	9%	40%	64%	4.393
	Indirect costs	93.964,48	1.017	34.135	63.193	98.345	1%	36%	67%	105%	(4.381)
	Total costs	252.071,95	2.713	91.026	163.661	257.400	1%	36%	65%	102%	(5.328)
Partner 07											
Terma	Personnel costs	71.853,25	6.934	63.400	7.538	77.872	10%	88%	10%	108%	(6.019)
	Subcontracting	1.500,00	0			0	0%	0%	0%	0%	1.500
	Other direct costs	10.500,00	1.219	7.734	178	9.131	12%	74%	2%	87%	1.369
	Indirect costs	71.134,72	7.831	66.162	7.251	81.244	11%	93%	10%	114%	(10.109)
	Total costs	154.987,97	15.984	137.296	14.967	168.247	10%	89%	10%	109%	(13.259)

Partner 08											
CHESS	Personnel costs	62.568,07	46.441	23.088	7.698	77.227	74%	37%	12%	123%	(14.659)
	Subcontracting	1.500,00	0			0	0%	0%	0%	0%	1.500
	Other direct costs	10.500,00	2.787	1.556	1.360	5.703	27%	15%	13%	54%	4.797
	Indirect costs	43.840,84	29.537	13.853	5.435	48.825	67%	32%	12%	111%	(4.984)
	Total costs	118.408,91	78.765	38.497	14.493	131.755	67%	33%	12%	111%	(13.346)
Partner 10											
HYDAC	Personnel costs	70.859,79	20.948	7.662	35.873	64.483	30%	11%	51%	91%	6.377
	Subcontracting	1.500,00			8.852	8.852	0%	0%	590%	590%	(7.352)
	Other direct costs	10.500,00	761	841	10.185	11.787	7%	8%	97%	112%	
	Indirect costs	72.128,18	21.323	7.799	36.515	65.637	30%	11%	51%	91%	6.491
	Total costs	154.987,98	43.032	16.302	91.425	150.759	28%	11%	59%	97%	4.229
Total											
	Personnel costs	1.400.829,53	354.294	537.119	603.959	1.557.314	25%	38%	43%	107%	(156.484)
	Subcontracting	93.356,00	-	-	18.834	18.834	0%	0%	20%	20%	74.522
	Other direct costs	197.775,57	26.987	59.658	83.474	170.119	14%	30%	42%	86%	27.657
	Indirect costs	1.004.198,11	240.002	383.309	459.622	1.082.933	24%	38%	46%	108%	(78.735)
	Total costs	2.696.159,21	621.283	980.086	1.165.889	2.824.346	23%	36%	43%	103%	(128.186)

6. Quasimodo Publications (as of June, 2011)

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2010

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WP1: Modelling and Specification

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