Probabilistically Analyzable Real-Time Systems

D5.6 Period 2 Project Activity Report Version 3.0

Funding Scheme: Collaborative Project (STREP)
Date of latest version of Annex I
against which the assessment will be made: 14/11/2011
Period covered: from 01/02/2010 to 31/04/2011
Scientific representative of the Coordinator: Francisco J. Cazorla Almeida (BSC)
Tel: +34 93.413.7173
E-mail: francisco.cazorla@bsc.es

Document Information

Contract Number	249100
Project Website	www.proartis-project.eu
Contractual Deadline	M27
Dissemination Level	Public
Nature	Report
Author	Francisco J. Cazorla / Xavier Salazar / Ian Broster
Contributors	Eduardo Quiñones (BSC), Ian Broster (RAPITA), Liliana Cucu (INRIA), Tullio Vardanega (UNIPD), Franck Wartel (AFS)
Reviewer	Tullio Vardanega (UNIPD) - All, Ian Broster (RAPITA) – Dissemination, Francisco Cazorla (BSC) – Management
Keywords	Activity Report, Technical Progress, Management Progress, Dissemination Progress, Financial Progress

Notices:
The research leading to these results has received funding from the European Community's Seventh Framework Programme [FP7/2007-2013] under grant agreement n° 249100.

Declaration by the scientific representative of the project coordinator

I, as scientific representative of the coordinator 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):

  ■ 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[1];

  ☐ has failed to achieve critical objectives and/or is not at all on schedule[2].

- 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: Francisco J. Cazorla Almeida

Date: 18/07/2012

Signature of scientific representative of the Coordinator:

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

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

Change Log

Version	Description of Change
v1.0	Initial version released to the European Commission. This version is marked DRAFT as several minor financial issues remain pending. These financial issues do not impact the general financial assessment of the project; however, the Coordinator would like to ensure their accuracy for the final version.
v1.1	Second version including reviewers' comments. Updated Teleconferences and Face-to-face Meetings (Table 3) in Communication section (5.1.1), and Explanation of the use of the resources chapter (7) including final numbers and detailed explanations.
v2.0	Proof-reviewed version
v2.1	Final version including project and financial officers' feedback. Updated chapter 7 Explanation of use of resources to accommodate their comments including: Updated tables 4 and 5 on personnel effort and related figures 3 and 4. Updated UNPD and added AFS P1 Adjustment tables (Table 11 and 15).
v3.0	Proof-reviewed version

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1 Publishable summary

1.1 Motivation

The demand for both new functionality and reduced development and production costs for Critical Real-Time Embedded (CRTE) systems continues to rise rapidly. For instance, modern cars can have software components consisting of up to 100 million lines of code, and each car contains up to 70 ECUs (Electric Control Units), which accounts for roughly 40% of the total production cost.

Unlike conventional systems, developers of CRTE systems (whether safety critical, mission critical, or business critical) require to demonstrate to the customer or certification authorities the correctness of the system in both the functional and the extra functional dimensions, the latter of which includes the temporal behaviour. Whereas most contemporary CRTE systems are deployed on comparatively simple and old processor technologies whose temporal behaviour is relatively easy to understand, even the most comprehensive static analysis and testing efforts yield results that are far from perfect. In fact, these incorrect operations cost EU industries billions of Euros annually in warranty claims and post-production costs.

Market demands for the next decade will require increased functionality which can only be delivered by introducing more complex software that is supported by aggressive performance hardware acceleration features like deep memory hierarchies and multicore CPUs. However, this increased complexity will also make systems much more difficult to analyze for their temporal behaviour and will lead to a major negative impact on the quality and reliability of the resulting products. This is due to the fact that current timing analysis techniques and testing processes will not be able to scale up to the challenge.

The aim of the PROARTIS project is to define new hardware and software architecture paradigms that, by design, exhibit a timing behaviour that can be effectively analysed with probabilistic techniques. The hypothesis of the PROARTIS project is that:

> *New advanced hardware features can be used and analysed effectively in embedded real-time systems when designs move towards more truly randomized behaviour which probabilistically reduces the risk of temporal pathological cases to quantifiably negligible levels. This approach enables probabilistic timing analysis techniques that can be used effectively in the verification of Critical Real-Time Embedded Systems.*

1.2 Project Objectives

PROARTIS defines three main scientific / technological outcomes:

1. Define a set of hardware and software design guidelines that will allow CRTE system designers to benefit from randomization properties.
2. Define a new analysis paradigm based on the randomization properties of the architecture defined in (1). These new probabilistic approaches will enable analysis of high performance hardware features as well as more complex software systems.
3. Develop a case study with real avionic applications based on the outcomes of (1) and (2) in order to demonstrate and quantify the approach. These outcomes will

facilitate the production of analyzable CRTE systems on advanced hardware platforms.

PROARTIS brings us closer to realizing these high level goals via clear progress against the following specific objectives:

- *O1: Develop randomization techniques in hardware designs.* Inventing and implementing new hardware mechanisms that exploit randomization.
- *O2: Develop randomization techniques for low level software.* Implementing and evaluating randomization mechanisms at the hardware-dependent software level. In particular investigating issues of real-time operating system (RTOS) device driver software and schedulability. Moreover, investigation of randomization mechanisms at the compiler and run-time library level in support of O1.
- *O3: Develop new architectural software designs that support analyzability.* Implementing and evaluating high level programming paradigms, patterns and styles that can and should be followed (and those that must be avoided) to enable probabilistic timing analysis.
- *O4: Apply novel probabilistic and statistical analysis techniques to the problem of timing analysis.* Invention of new techniques to precisely model the new paradigms developed in the project.
- *O5: Provide arguments and evidence to support the certification process.* Development of new probabilistically based arguments of the temporal correctness of the systems that can be used in a certification process.
- *O6: Develop simulation tools to perform architectural design exploration.* Development of architectural simulation tools for at least one Instruction Set Architecture ISA (TriCore, PowerPC or SPARC) to perform automatic design exploration of the hardware and software proposals developed in PROARTIS.
- *O7: Develop new probabilistic timing analysis tools.* Development of a new probabilistic worst-case execution time (WCET) timing analysis tool based on the RapiTime toolset. Development of a probabilistic schedulability analysis tool. Implementation of the mathematical models on standard statistical tools.
- *O8: Validate the results on an industrial case study.* Requirements capture of industrial size hard real-time systems in the avionics domain. Evaluation of the techniques proposed in the project on benchmark code and on industrial systems provided by the industrial partner AFS. The evaluation of the case studies will demonstrate the suitability of the techniques and methods developed in the project. The results of the comparison will not only be based on timing estimations, but also on support for certification.

1.3 Technical Work Performed and Main results

The main objectives for Period 2 (m6-m27) of the project were to carry out a complete first iteration of the PROARTIS technology for single-core architectures. The main objective and sub-objectives for this period are summarized by Milestone (MS2). The work performed during this period aimed at obtaining this main objective. The work can be broken down into the following activities.

We identified the requirements on the platform, which includes hardware and system software and on which our probabilistic timing analysis (PTA) approach. This was done for all three analysis methods developed during this period and summarized below. We contrast our work with previous approaches that use probabilistic timing analysis on standard non time-randomised architectures.

We defined a processor core and cache designs that accomplish the PTA requirements. We provide a classification of processor resources based on whether they exhibit response time jitter (variability on their processing time). We show that only resources with high jitter have to be randomized. We show that time-randomized and non time-randomised resources can coexist in the same processor architecture and still accomplish the requirements needed to provide safe probabilistic WCET (pWCET) estimations. We also developed compiler support to reach those objectives as an alternative to using hardware means to achieve time randomisation. In particular we designed the compiler techniques to randomize the location of the stack and the code layout into memory.

We define three probabilistic timing analysis techniques as well as their requirements on the platform: Static Probabilistic Time Analysis (SPTA), Measurement-Based Probabilistic Timing Analysis (MBPTA) and Hybrid Probabilistic Timing Analysis (HyPTA). The first one statically derives a-priori probabilities from a model of the system: we call it Static PTA, SPTA. The second technique is measurement-based and derives probabilities from end-to-end runs on the target hardware of the software under study: we call it MBPTA. The third approach is hybrid as it is based on a combination between MBPTA and RapiTime : HyPTA uses a combination of static structural analysis and execution time measurements of sections of code. For each such approach, we define the mathematical foundations on which PTA is based. We further enumerate and attack the challenges we encounter at hardware and software levels upward the execution stack to pursue our vision. We then show how PTA techniques reduce the amount of knowledge needed to achieve tight WCET estimations. ,

We define the time composability principles of a probabilistic timing analysis approach. With the implementation of the PROARTIS Stack, we achieve time composability at the level of individual processor instructions. This is done by ensuring that the timing behaviour of the processor hardware, as observed at the granularity of processor instructions, must have either no dependence at all on execution history or a dependence that can be characterised probabilistically. While this is an excellent result in itself, PROARTIS also sought time composability between the architectural parts of the software system, hence at a level higher than individual processor instructions, that of program runs at the application level (where the term “program” is used in the classic meaning of timing analysis, that is: unit of analysis, along the control flow graph of the root procedures in the application). We defined the technical means and the mathematical foundations to compose the pWCET estimations of application programs in a PROARTIS system. We paid special attention to IMA-like platforms used as a reference for the study, we define how to achieve time composability with IMA software units: partitions within the system; threads within individual partitions; procedures within threads. We also ensure that the Operating System would be time composable toward the application. This latter objective is achieved in two complementary ways: (i) we redesigned our baseline ARINC compliant kernel (POK) in a manner that causes all of the OS and kernel services that could be invoked – directly or indirectly – by the application software when in steady state (thus outside of initialization and partition switch) to attain jitterless response time; (ii) leveraging the time composability of the

PROARTIS processor, we made sure that the execution of the OS and kernel services would cause no timing perturbation on the application-level upon return from the call; this is achieved by avoiding any tampering on the processor state left by the application at the time of the call.

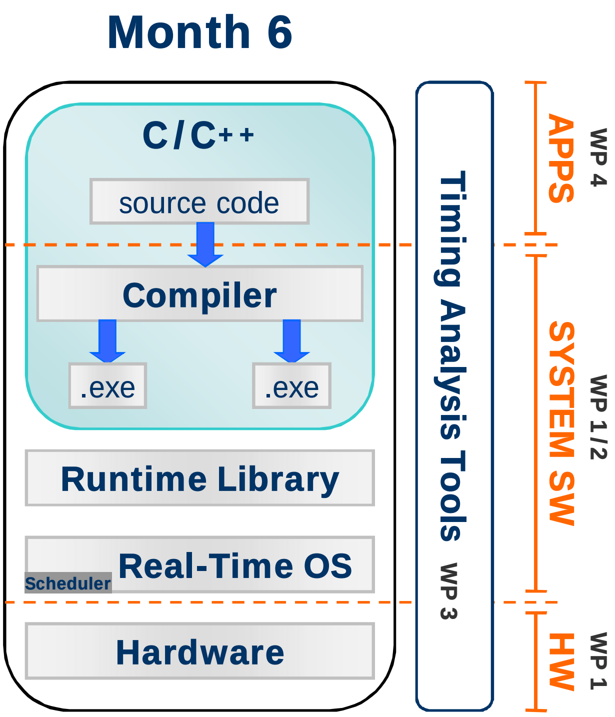
We developed an industrial case study based on an actual avionics application from AFS (FCDC), which has been ported to the PROARTIS processor simulator. We applied and successfully evaluated the PROARTIS approach. We selected a set of different units of software, reflecting the coding patterns commonly used in AFS avionics software, and a set of hardware configurations to evaluate PROARTIS probabilistic WCET estimation and average performance impacts.
Industrial case study experiments approved the good maturity level of the PROARTIS framework, inclusive of the processor simulator and the associated analysis tools. The experiments also provided satisfactory results which show that the PROARTIS approach can withstand industrial-quality software.

The results we obtained with: (1) the AFS case study: (2) a number of standard benchmarks (EEMBC and Mälardalen) and (3) Missile Guidance application provided by Rapita show that the PROARTIS platform meets PTA requirements on which trustworthy statistical tests are based. We also show that the different PTA techniques are able to provide pWCET estimations for both single-path and multipath programs. We analyse the effect of different composition scenarios on those pWCET estimations. Finally, we compared our time-randomised architecture against a deterministic architecture in terms of average performance. We also provided an initial comparison of the pWCET estimation obtained with our PTA techniques against those obtained with STA.

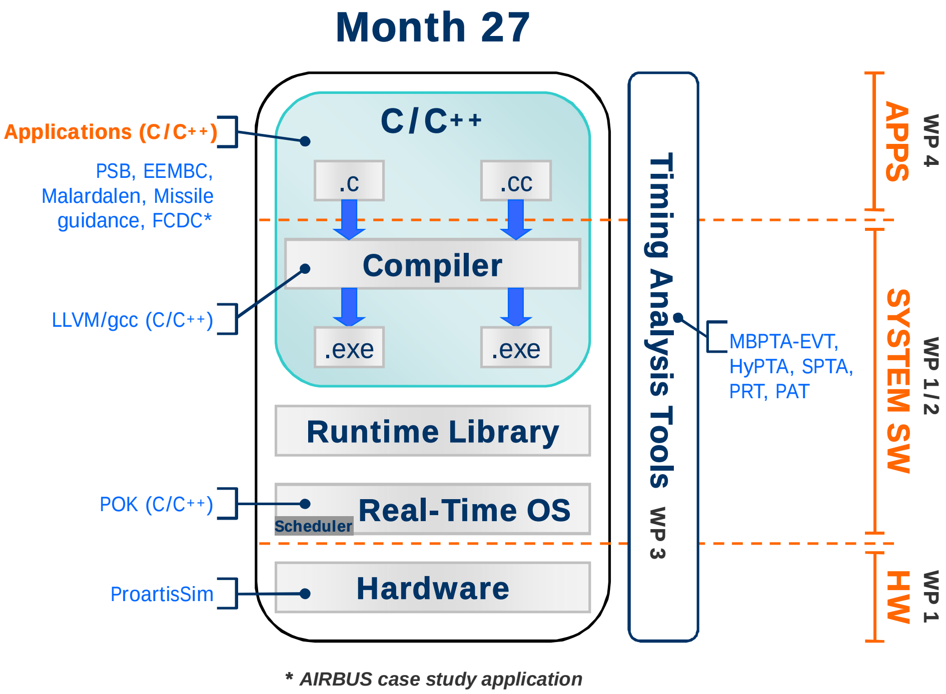
We provided a first release of the certification arguments: The PROARTIS technology requires altering the design of the processor, in particular the timing behaviour and design of the cache, the software production tool-chain, the run-time libraries and the execution time analysis method. This has a number of different impacts on the safety case for a system using the PROARTIS technology. We started exploring the use of explicit argumentation to document the case for using results from the PROARTIS probabilistic timing analysis approach (PTA). The essential elements of the reasoning are presented in this preliminary version.

The work carried out in the PROARTIS Stack (tool-chain) was quite significant. It covers the whole stack from hardware design to application design passing through Operating System, Compiler and Analysis tool design and deals with real applications. This is a great achievement for such a small project like PROARTIS comprising only 5 partners and a EC contribution of 1,8 million euro.
Starting from the complete tool-chain that we defined by MS1 and that we describe in the deliverable D3.2 we carried out all the developments needed to implement the PROARTIS approach. Recall that this tool-chain comprises: a compiler; an ARINC-compliant RTOS, with all the relevant run-time libraries, an architectural simulator emulating the target processor of interest to WP4, and probabilistic/statistic analysis tools. The main changes are listed next. In Figure 1(a) we show the toolchain as it was in m6 and in 1(b) how it is in month 27:

- Hardware simulator: The work in the simulator can be classified in three main activities. (1) We developed the proper cache and processor design on top of which we construct our time-randomised designs. (2) We provide support to the RTOS and Application layers so the case study and the standard benchmarks used in this project can be executed. And (3) we provide support for the generation of statistics in the simulator
- Compiler Support: We developed Stabilizer, a compiler and run-time system that provides the required services at both software component levels to randomly allocate functions and stack frame objects. The Stabilizer compiler pass has been developed within the LLVM compiler. The Stabilizer run-time library is based on DieHard. The code generated by Stabilizer can be executed on top of the hardware simulator and a real PPC-Linux platform.
- Analysis techniques: We developed three flavors of PTA: SPTA, MBPTA and HyPTA. SPTA is presented as some java tools, MBPTA in the form of R-script and HyPTA is an integration of MBPTA within RapiTime.
- Software: A subset of the ARINC653 service functions have been implemented, first a no-interference stubs and then as part of a novel time-composable kernel layer,to enable the execution of the AFS case studies on the PROARTIS platform as described in deliverable D4.2.
- Application: We implemented several cases studies based on IMA-based applications used by partner AFS. The *Missile Guidance* application was integrated in the PROARTIS Stack to carry out the RPT demonstrator. EEMBC and Malardalen were adapted to run in our tool chain.



(a) Tool chain status in month 6



(b) Tool chain status in month 18

Figure 1. Status of the tool chain in MS1 (month 6) and in MS2 (month 12)

Finally, as part of the activities done in this phase of the project we sketched how the PROARTIS principles apply to multicore architectures. Our main focus has been on extending some of the PROARTIS key concepts to multicore environments.

The collaboration between all project partners during the second phase of the project was very strong and effective: we held 2 face-to-face full project technical meetings, 5 Work Package-focused face-to-face meetings, and 24 teleconferences. Weekly teleconferences were also held between the different WPs to progress on the technical side of the project. As a result of that effort, we were able to successfully accomplish the objectives set for the period.

2 Project objectives for the period

The first 27 months comprise the Phase 1 (or Bootstrap Phase) and Phase 2 (or Single-Core phase). The objectives of the first Phase were the identification of the technical requirements, the success criteria and the integration of the tools. During the Phase 2, we focused on making a complete iteration of the PROARTIS technology. This goal is split in the following 4 objectives:

1. Develop the theoretical foundations and the techniques to effectively provide Probabilistic Timing Analysis. This includes the hardware/compiler and software support and the proper analysis techniques.
    a. The foundations include the list of assumptions done for the analysis about the behaviour of the underlying platform. These assumptions of the analysis technique became requirements in the design of hardware. Those assumptions were successfully analysed and the developed platform is shown to accomplish with them, for which the proper statistical tests have been used.
    b. At hardware level, the objective was to define a processor-core and cache hierarchy architecture able to accomplish with analysis technique requirements. This has been successfully achieved for SPTA, MBPTA and HyPTA
    c. At compiler level, the objective was to develop code and stack randomizations able to reach the required randomization level.
    d. At the system software level we focused on ensuring that the Operating System would be time composable toward the application
2. Develop the PROARTIS Stack (tool-chain) so that the PROARTIS technology at timing analysis, hardware, compiler and software was properly evaluated. This includes:
    a. Implement in proartis_sim the theoretical solutions developed in 1.
    b. Develop the proper interfaces to communicate data from proartis_sim to the analysis tools
    c. Develop the tools to provide probabilistic WCET estimations for SPTA, MBPTA and HyPTA.
3. Show evidences of the PROARTIS techniques for multicore platforms.
    a. Adaption of the industrial case study to the PROARTIS platform.
    b. Integration of the RPT application called Missile Guidance used as demonstrator of the use of the PROARTIS technology in RapiTime work flow.
    c. Evaluate the different PROARTIS solutions on EEMBC and Mälardalen.
4. Start exploring the use of explicit argumentation for certification to document the case for using results from the PROARTIS PTA approach.

3 Work progress and achievements during the period

During this period, the work in all the technical work packages focused on making a complete iteration of the PROARTIS technology. The partners collaborated closely to ensure that the requirements listed in D5.3 were satisfactory met, paying special attention to inter-WP requirements. This collaboration converged into several publications done by many PROARTIS members.

In the sections to follow, we describe the progress we did to reach the technical objectives set forth for Milestone MS2 (due by month 27) with special emphasis on the tasks performed during the last 15 months.

3.1 WP1

The activities described next contribute to tasks T1.2 and T1.3 as described in the DoW.

- *T1.2.* This task focused on the development of hardware randomisation mechanisms.
    - We started by identifying the main requirement to be accomplished by a processor architecture to be PTA analyzable. This activity leads to a paper submission to RTSS conference (currently under submission) and a patent process that has been started.
        - *Core architecture*. At the core level we show how time-randomized and deterministic (non-time randomized) can work in a PTA architecture. Deterministic resources include buffers.
        - *Cache architecture.* We design cache placement and replacement algorithms able to provide the requirements needed by PTA. This cache can be combined in an arbitrary way and also support Translation lookaside buffers. This activity leads to a paper submission to CASES conference (currently under submission)
    - *PRNG.* We implement a low-power, low-complexity Pseudo Random Number Generator needed for our random placement and replacement policies.
    - *Support for the RTOS and applications.* Our simulator tool comprises an emulator, in charge of executing the instructions like in a virtual machine, and the timing simulator in which we implemented our proposal. In this activity we devote significant effort to extend the simulator with the features required by the RTOS and the case study applications.
    - *Creation of a Synthetic Benchmark and adaption of standard benchmarks.* We develop a set of PROARTIS synthetic benchmarks (PSB) in order to make initial evaluations of the PROARTIS developments until the standard benchmarks, such as EEMBC or Malardalen, where properly adapted to work in the PROARTIS tool chain. In the case of Malardalen, several input sets were developed in order to properly check the multi-path EVT analysis.

    - *Result generation.* Several tools were generated to filter the results of the simulator and to pass then in the appropriate format to WP3 for their analysis.
- *T1.3.* This task focused on developing compiler techniques to randomise the placement of the stack and global static objects at the data and instruction levels. We carried out the randomisations by the addition of PROARTIS-specific passes to the processing of the standard gcc cross compiler for PowerPC targets. To integrate those specialised passes in the compilation process we use the LLVM compiler infrastructure (cf. http://llvm.org/), whose C and Ada variants integrate with the gcc versions of interest to PROARTIS applications. The main activities were:
    - During the second phase of the project, we have developed *Stabilizer*, a compiler and run-time system that randomly locates function and stack frames objects in memory, forcing deterministic cache design to timing behave as random cache designs:
        - The Stabilizer compiler pass has been developed within the LLVM compiler.
        - The Stabilizer run-time library is based on DieHard.
    - This activity leads to a paper submission to RTSS conference (currently under submission).
- T1.4. At the project proposal time, this task was intended to provide support at RTOS level to support the compiler and hardware techniques developed within tasks 1.2 and 1.3. However, at the end of Phase 1 it was understood that part of the job planned within this task was already performed in task T1.3 and T2.3. At deliverable D5.3 (month 6) the boundaries between WP1 and WP2 were clearly defined: The research carried out by WP1 in the context of run-time libraries was exclusively focused on sequential (single-threaded) execution, while WP2 focuses on concurrent (multi-threaded) execution. Therefore, the run-time memory related run-time library has been integrated within Stabilizer (task 1.3) to provide support to the software randomization approach. Scheduling decisions, instead, have been considered as part of the jitterless services (task 2.3) whose execution causes no perturbation on the processor state for the application after return from the call.

3.2 WP2

The work carried out by WP2 in the Reporting Period concentrated on the pursuit of four main objectives through four tasks designated in the DoW as T2.2, T2.3. T2.4 and T2.5. The four main objectives, presented in their logical precedence order, were:

- T2.4: To perform a critical scrutiny of the capabilities, needs and limitations of the probabilistic timing analysis techniques being defined in WP3 in order to ensure that the design principles, run-time operation and effect on the application, of the Operating System layer of the PROARTIS Stack were fully coherent and consistent with the analysis assumptions and requirements. Massive effort was devoted to this end, with excellent results in terms of technical and scientific alignment, which materialized in a number of joint publications and paper submissions.
- T2.2: Detailed analysis of the way the time randomisation features introduced at level of the processor architecture would impact the application behaviour at run time. At the project proposal time, it was expected that programming paradigms,

patterns and styles should be introduced at the application level for it to better conform to the PTA principles. In the Reporting Period it was instead understood that PTA per se causes no impact on the way the application software is designed and implemented, and requires no other programming styles than those that ease the construction of the control flow graph of the program as with classic timing analysis, whether static or measurement based or hybrid.

- T2.3: The above observation made it also clear that the impact on the application would be further reduced if the Operating System layer could be made time composable. This prompted an effort aimed at the design, implementation and experimental evaluation of a revamped version of the ARINC 653 Operating System that was adopted in the project (POK) whose services have a virtually jitterless response time and whose execution causes no perturbation on the processor state for the application after return from the call. The rationale of the novel design and the experimental results that confirm the intent are described in deliverable report D2.2.
- T2.5: Contribution to the development of arguments that can be used to support certification of an avionic system developed following the PROARTIS method and techniques. The initial leg of this activity, which will continue until the end of the project, assessed the safety aspect of the argument, challenged the correctness of the proof carried by the PROARTIS method, and began to consider the intelligibility and maintainability of the argument. The initial results of these reflections are presented in deliverable report D2.3.

3.3 WP3

As described in the DoW, WP3 focuses on the development of the analytical mathematical models of the mechanisms explored in WP1 and their implementation. The analytical models proposed by WP3 allowed the proposition of new mechanisms into WP1. These analytical models are primarily obtained using standard probabilistic and statistical approaches.

The work carried out by WP3 in the Reporting Period concentrated on the pursuit of four main objectives through four tasks designated in the DoW as T3.2, T3.3, T3.4 and T3.5 and this for the single core case:

- T3.2 This is the main body of work of this Work Package. The approaches collected in task T3.1, are applied analyzing the platform defined in WP1 and WP2. The objectives of T3.2 (to fulfill) were performing WCET and schedulability analysis. We have proposed three probabilistic methods for estimating WCET: SPTA, MBPTA and HyPTA. SPTA inherits the complexity of static methods therefore we proposed techniques to decrease the complexity of obtaining WCET estimates by SPTA. We measure the impact of these techniques on existing schedulability analyses. SPTA is presented in a top-tier journal publication, MBPTA in a top-tier conference publication. The techniques associated to SPTA are presented in a paper currently under submission. We expect HyPTA to be presented as publication before the end of the project.
- T3.3 This task is directly connected to the previous task T3.3, and it is executed during an iterative process. The objectives to fulfil were the evaluation of our techniques using existing tools like R, Xstat and Matlab. The main core of our tests is done on R because this software integrates a package for extreme value

theory. We also used Extremes (package of Matlab) as it contains the existing statistical test ET (for Gumbel fitting). Most of the iid tests were carried out using Xstat, a package of Excel.

- T3.4 Finally, considering the results of tasks T3.3 and T3.4, the selected WCET techniques are prototyped into the measurement based tool, RapiTime. A prototype probabilistic schedulability analysis tool is implemented. This task also includes integration with other standard statistical analysis tools that will be used and evaluated for analytical modelling. The objective of proposing a prototype of the WCET analysis into RapiTime is covered by the proposition of the Rapita demonstrator (HyPTA). HyPTA is a combination between RapiTime and MBPTA, thus it is a hybrid tool. Moreover SPTA and MBPTA associated tools are integrated in the single core tool chain.
- T3.5 The different tools implementing the functionalities required by the MS2 (month 27) have been successfully implemented and integrated. In particular, as described in D3.5, the hardware simulator (proartis_sim) implements those hardware features described in T1.2 for single core. The tool for software randomisation support (T1.3) generates binaries that run on top of proartis_sim. This tool is not fully automated yet and requires some steps to be performed manually. The RTOS layer (T2.3) has been also developed and integrated into the toolchain. Analysis tools described in T3.2, T3.3 and T3.4 have been fully integrated with the hardware/software prototypes. Overall, the whole PROARTIS stack for the single core phase is up and ready and has been proven to work successfully with benchmarks and the AFS case study developed in T4.2 and T4.3.

3.4 WP4

The goal of WP4 is to ensure the applicability of methods and arguments defined by PROARTIS to the case of certified avionics. As stated in the DoW, this industrial case study was initially planned to be performed in incremental steps, from sequential execution of extracts of FCDC to a complete multi partitions environment on top of an A653 compliant Operating System. As explained in *D4.3*, we focused efforts on the Sequential FCDC test case, for which we refined the unit of software of interest and associated hardware configurations to be tested.

The activities performed to reach WP4 goal for MS2 can be decomposed into the following subtasks:

- T4.2 Design experiments. This task designs the concrete experiments useful to WP1, WP2 and WP3, and defines the appropriate experiments setups and measurements to be performed on the selected pieces of software from the ported Airbus application. For MS2, T4.2 covered the single core case and was divided into the following subtasks.
    - *T4.2-1:* Isolation of processes of interest for the experiment.
    - *T4.2-2:* Cross compilation of those extracts.
    - *T4.2-3:* Definition of the test scenario, i.e. definition of the set of external conditions to be simulated.
- T4.3 Execute experiments. This task represents the execution of the experiments from T4.2, offering feedback to all Work Packages, particularly adjusting the certification arguments in T2. This task was divided into the following sub tasks.
    - *T4.3-1*: Execution on top of PROARTIS Simulator (HW from WP1, SW from WP2).
    - *T4.3-2:* Traces analysis to compute the probabilistic WCET (pWCET).

All tasks have been completed for the Sequential FCDC test case. It is important to highlight that we refined during this second phase *(T4.2-1)* to *(T4.2-3)* results against those of initial phase, as we ported the complete FCDC application, executed the complete APPL process, and applied PROARTIS approach on four units of software relevant to AFS, and detailed in *D4.3* deliverable.

Substantial efforts have been made in collaboration with WP1 on PROARTIS simulator and with WP3 for the analysis and pWCET computation, in order to provide sound results from (*T4.3-1*) and (*T4.3-2*).

A653_FCDC software porting tasks *(T4.2-1)* to *(T4.2-3)* have been completed, *(T4.3-1)* and *(T4.3-2)* are partially achieved as *A653 FCDC* is actually running on top of the PROARTIS simulator but not benefits yet from zero disturbance features implemented by WP2. Note that *A653 FCDC* experiments will focus on interaction between avionics application and the OS, in order to validate by experiments based on an actual avionics application, the OS PROARTIS approach. Furthermore we do not expect any additional novel results, but a validation of the results already obtained with WP2 benchmarks for MS2 with an industrial application.
A653 FW related tasks are in progress, and are currently planned to be part of the multicore industrial case study.

Regarding T2.5, "Support for certification", the PROARTIS approach has been presented and discussed with AFS certification experts during a dedicated workshop in AIRBUS premises, in order to elaborate the initial certification arguments detailed in deliverable D2.3

3.5 Results

The results obtained by the PROARTIS team as part of the Technical Deliverables show that the PROARTIS platform achieves the requirements to enable PTA. This PTA-friendly architecture has an average performance difference with respect to a deterministic architecture of less than 20% for the setups used in the Technical Deliverables. The analysis techniques, SPTA, MBPTA and HyPTA, have been shown to effectively provide pWCET estimations. MBPTA and HyPTA cover both single-path and multipath programs. For the setup we used, the WCET estimations are comparable to those provided by Static-timing analysis, mainly when some information to do STA is missing, e.g. the address of some access to memory, in which case the pWCET estimations obtained with our PTA techniques are several times (from 2x to 6x) better than those provided by STA.
The novel implementation of the ARINC 653 Operating System developed in PROARTIS is shown to have a fully composable timing behaviour. This allows the timing analysis of the application to be performed ignoring the time cost (which is virtually jitterless) *and* the state perturbation (which is none) of execution in the Operating System in response to calls made into it, whether explicitly or implicitly, during steady-state activity of the application.
We successfully applied the PROARTIS method to FCDC avionics application, and computed probabilistic WCET for different code patterns and cache usage representative of AFS applications. We validated results obtained with benchmarks, confirmed that the pWCET computation required a limited number of observations to

be computed, and finally suffer little average performance degradation, giving satisfactory indicators regarding industrial scalability.

HyPTA was implemented in RapiTime and successfully applied to the testing of a flight guidance system for a missile (also know as the Rapita Missile Guidance Demonstrator).

4 Deliverables and Milestone Tables

4.1 Deliverables

The project has successfully completed all Deliverables to date. All Deliverables marked RE* / PU will be publicly available within 12 months of their delivery to the EC. This is to allow ample time for the publication submission and peer review process while at the same time making deliverables available to the Public as soon as possible.

TABLE 1. DELIVERABLES

Del. no. [1]	Deliverable name	WP no.	Lead bene-ficiary	Nature [2]	Dissemi-nation Level	Delivery date [4]	Achieved Yes/No	Actual / Forecast achievement date	Com-ments
D1.2	Platform Design Guidelines for Single Core	WP1	BSC	R	RE* / PU	27	yes	27	none
D2.2	SW Design / Programming Guidelines for Single Core	WP2	UNIPD	R	RE* / PU	27	yes	27	none
D2.3	Certification Arguments Guidelines (Initial Draft)	WP2	RAPITA	R	RE* / PU	27	yes	27	none
D3.4	Probablistic and Statistical Technics for Timing Analysis in Single Core	WP3	INRIA	R	RE* / PU	27	yes	27	none
D3.5	Integrated Single Core Toolchain Prototype	WP3	BSC	P	RE* / PU	27	yes	27	none
D4.3	Single Core Case Study Results	WP4	AFS	R	RE	27	yes	27	none

D5.6	Period 2 Project Report	WP5	BSC	R	PU	27	yes	27	none
D6.5	Period 2 Dissemination and Use Report	WP6	BSC	R	PU	27	yes	27	none

Table 1: Deliverables

4.2 Milestones

The project has successfully achieved all Milestones to date.

TABLE 2. MILESTONES

Milestone no.	Milestone name	WPs no.	Lead beneficiary	Delivery date from Annex I [1]	Achieved Yes/No	Actual / Forecast achievement date	Comments
M1	Overall research objectives defined and research infrastructure established.	WP1, WP2, WP3, WP4	RAPITA	6	Yes	6	All of the deliverables (D1.1, D2.1, D3.1, D3.2, D4.1 and D5.3) required for the successful achievement of this milestone were completed. The project progress is in line with the plan of record.
M2	**Probabilistic single core processor approach implemented and relevant results analysis complete.**	WP1, WP2, WP3, WP4	BSC	27	Yes	27	This milestone has been successfully achieved: we have delivered hardware and software design guidelines for developing single core processors with probabilistic support. In addition, we have provided the first results for certification arguments, probabilistic analysis methods to analyse single core processors, a probabilistic WCET analysis tool prototype for single core processors and the Avionics Case Study design and execution for single core. We have also delivered the complete integrated tool-chain for single core processors (simulator, RTOS, run-time libraries). This Milestone is verified through the deliverables D1.2, D2.2, D2.3, D3.4, D3.5 and D4.3.

Table 2: Milestones

5 Project Management (WP5)

5.1 Project Management

As described in the previous version of this report, Work Package 5, consisting of the Coordination and Project Management of the PROARTIS Project, is the shared responsibility of the Project Manager (Gina Alioto and Xavier Salazar) and the Technical Manager (Francisco J. Cazorla); however, it also includes the active participation of all project Partners through the Executive Board which is integral to the successful management of the project.

Much of the first year of the Project was spent putting high level processes in place to ensure smooth communication between the Partners as well as to drive the project forward per the Description of Work.

As noted by the Project Officer and the Reviewers in the P1, there was a delay in attaining the project's milestones for MS2. The Project Coordinator requested a six-month extension to the Project Officer. Two were the main reasons to request this extension:

- Different backgrounds: PROARTIS brings together individuals with diverse scientific backgrounds in order to cover all areas of expertise for the project. Despite the collaborative nature of the team, it took the team nearly 15 months to settle on a common vocabulary for the project, to fully understand the nature of the problems addressed in PROARTIS and to converge on the solutions required to solve these problems.
- Real-world applications: One of the key achievements of PROARTIS is the use of real-world (Airbus) applications. Using these applications, however, has translated into a significant amount of integration and support work which has contributed to the delay in starting / completing some of the other critical tasks in the project.

The extension request was executed via an amendment to the Executive Board (EB) and the revised DoW with all the timings adapted. This extension was conceded and it does not require any extra funding from the EC side. The extension, only affected the Single-core phase of the project (Phase2 according to the updated DoW) that is actually increased by 6 months. The last multicore phase maintains its duration though its start is delayed 6 months.

5.1.1 Communication (T5.1 Internal consortium communication strategy definition)

In the first and second period of the PROARTIS project WP5 employed an interactive internal communication strategy consisting of email lists (BSC set-up and now maintains Distribution Lists in order to facilitate the routing of information requests to the appropriate individuals and groups), project Portal (D5.2), regular teleconferences in addition to several face-to-face meetings. The implementation of these easy-to-use management tools combined with regular interactions resulted in to smooth communication between all Partners throughout the first and second period of the project.

Similarly to Period 1, the PROARTIS Team held regular monthly teleconferences to evaluate progress against project plans, identify major problems and co-ordinate project-related interactions among the WP Leaders. Each of the teleconference agendas consisted of two distinct parts: 1) the Executive Board Meeting in which the voting members discussed general and high level technical project progress toward the plan of record and assigned actions; and 2) the Technical Meeting in which WPLs and individual contributors regularly shared status and results as well as discussed relevant technical issues in greater detail. The Project Manager, working with the Technical Manager, called and prepared the Executive Board Meetings for which the Project Manager would create the agenda and provide the minutes. The Technical Manager, working with the Project Manager, prepared the Technical Meeting for which the Technical Manager would provide the agenda and minutes. The Project Manager was in turn responsible for collecting feedback and ultimately publishing all meeting documentation to the Project Portal. Action items were uniquely identified by meeting date and number (i.e. 101215.A5) and were tracked from meeting to meeting by the Project Manager in order to ensure prompt resolution. When the discussion of complex technical issues were threatened by meeting time constraints, Work Package Leaders were encouraged to hold additional meetings and / or to start technical discussion forums on the Project Portal or via email.

The Executive Board and Workpackage leaders called 2 face-to-face meetings consisting of technical discussions between the Work Package Leaders. During these face-to-face meetings a half-day Executive Board Meeting was held. These meetings facilitated tight collaboration among the project Partners ensuring that the project has progressed according to the plan of record. Moreover, in the April Face-to-face Meeting held in the Canary Islands, the Industrial Advisory Board was invited to assist with the final Design Review before heading into the Implementation phase. The details (suggestions and outcomes) of this meeting have been included in detail in the D6.5 Period 2 Dissemination and Use Report.

Work Package Leaders, Institutions and individual contributors alike called 5 additional face-to-face meetings. In these meetings, they focused on the Toolchain and different inter-workpackage technical aspects of the project.

The following table lists all of the meetings held during this reporting period.

EXECUTIVE BOARD / TECHNICAL MEETINGS			
DATE	**MEETING**	**DURATION**	**LOCATION**
24-Apr-12	F2F Technical Meeting WP1, WP2, WP3	1 day	Göteborg, SWEDEN
12-Apr-12	Executive Board / Technical Meeting		Teleconference
5-Apr-12	Teleconference WP3 and Analysis		Teleconference
4-Apr-12	Teleconference ERCTS		Teleconference
28-Mar-12	Teleconference DEC Meeting		Teleconference
23-Mar-12	F2F Technical Meeting WP3	1 day	York, UK

16-Mar-12	Executive Board / Technical Meeting		Teleconference
28-Feb-12	F2F Technical Meeting - Workshop WP2 Certification Meeting (Toulouse, FRANCE)	2 days	Toulouse, FRANCE
14-Feb-12	Executive Board / Technical Meeting		Teleconference
26-Jan-12	F2F Technical - Workshop WP2, WP3 (Nancy, FRANCE)	2 days	Nancy, FRANCE
19-Dec-11	EB/F2F Technical Meeting (Barcelona, SPAIN)	4 days	Barcelona, SPAIN
28-Nov-11	F2F Technical Meeting - Workshop WP3, WP4 (Toulouse, FRANCE)	1 day	Toulouse, FRANCE
24-Nov-11	Executive Board / Technical Meeting		Teleconference
20-Nov-11	F2F Technical Meeting - Workshop RTSS (Vienna, AUSTRIA)	1 day	Vienna, AUSTRIA
16 Nov-11	F2F Technical Meeting - Workshop POK (Padova, ITALY) WP1, WP3	3 days	Padova, ITALY
16-Nov-11	Teleconference WP1, WP3		Teleconference
10-Nov-11	Teleconference WP1, WP3		Teleconference
4-Nov-11	Teleconference WP1, WP3		Teleconference
20-Oct-11	Teleconference WP1, WP3		Teleconference
14-Oct-11	Executive Board / Technical Meeting		Teleconference
05-Oct-11	Executive Board / Technical Meeting		Teleconference
28-Sep-11	Teleconference WP1, WP3		Teleconference
22-Sep-11	Teleconference WP1, WP3		Teleconference
23-Sep-11	Executive Board / Technical Meeting		Teleconference
20-Sep-11	Executive Board / Technical Meeting		Teleconference
01-Sep-11	Review Meeting	1 day	Brussels, BELGIUM
12-Jul-11	Executive Board / Technical Meeting		Teleconference
06-Jul-11	F2F Technical Meeting - Workshop WP1, WP2, WP3 and WP1, WP3	3 day	Lisbon, PORTUGAL
04-Jul-11	F2F Technical Meeting WP3	1 day	Porto, Portugal,
14-Jun-11	Executive Board / Technical Meeting		Teleconference
08-Jun-11	F2F Technical Meeting - Workshop WP1, WP2, WP4 - workshop on POK, PROARTIS-SIM and hardware assumptions in AFS case studies	3 days	Toulouse, France
17-May-11	Executive Board / Technical Meeting		Teleconference

16-May-11	Teleconference WP1, WP2, WP4		Teleconference
09-Apr-11	F2F EB/IAB Meeting (Maspalomas in Canary Islands, SPAIN)	5 days	Canary Islands, SPAIN
05-Apr-11	F2F Technical Meeting - WP Meeting: WP1, WP2 (Madrid, SPAIN)	1 day	Madrid, SPAIN
11-Mar-11	Executive Board / Technical Meeting		Teleconference
10-Feb-11	Executive Board / Technical Meeting		Teleconference
08-Feb-11	Webinar		Webinar

Table 3: Teleconferences and Face-to-face Meetings

5.1.2 Monitoring Project Progress (T5.3 Technical management progress tracking and T5.4 Effort and financial tracking)

The regular Executive Board / Technical Meetings described in the previous section are the single most important venue for tracking project progress. The General Assembly continues to meet via teleconference on regular basis in order to review progress toward critical project deliverables and milestones, to assess risk and to assign actions at a coarse-grain level. More importantly and at a more fine-grain level, each Partner provides a regular update to the Project Plan (see below) at these teleconferences in order to ensure that implementation and evaluation for each software product is on track.

PROARTIS Release Plan
v26

PRIORITIES:
1 Must be implemented
2 Strongly Recommend
3 Best Effort

RELEASES GUIDE (Deadlines will be added later)

Relea	*Original*	*Revised*	*Feature Complete*	*Integration Compl*	*Results Obtained*	*Release*	*Objective*
R1	M06	M06				Component Selection	Selection of initial tools for Stack: Applications, SysSW and HW (NO INTEGRATION)
R2	M12	M15	31-ene-10			Initial Integration (Boc	PSB1, EEMBC and SeqFCDC with Stack (Stub), SEC-SIT-SAT
R3	x	M24	10-feb-12			Single-core 1	PSB2, PSB3, Quicksort, Binary Search, A653FCDC with Stack (POK), SEC-SIT-SAT, SEC-DIT-DAT, DEC-SIT-SAT
R4	M21	M27	07-abr-12			Single-core 2	PSB4, Missle Guidance Simulator, A653FCDC, A653FWS with Stack, DEC-DIT-DAT, DEC-SEC / AdaCore Platform
R5	M30	M42				Multi-core 1	A653FCDC + A653FWS with Stack, DEC-DIT-DAT, DEC-SEC / AdaCore Platform

REF	RELEA	PLATFORM	APPS / SYS / HW	WP	PRIORITY	OWNER	COMPONENT	PRODUCT	SINGLE	MULTI	ACTIVITY	STATUS	NOTES
1	R2	C/C++	Apps	WP4	1	EQ	Application	PSB1	Y	Y	Bring up Application (contains SEC-SIT-SAT)	DONE	NONE
2	R2	C/C++	Apps	WP4	1	EQ	Application	EEMBC	Y	Y	Bring up Application (contains SEC-SIT-SAT)	DONE	NONE
3	R3	C/C++	Apps	WP4	1	EQ	Application	PSB2	Y	Y	Bring up Application (designed to contain SEC-DIT-DAT)	DONE	NONE
4	R3	C/C++	Apps	WP4	1	EQ	Application	PSB3	Y	Y	Bring up Application (designed to contain DEC-SIT-SAT)	DONE	NONE
5	R4	C/C++	Apps	WP4	1	EQ	Application	PSB4	Y	Y	Bring up Application (designed to contain DEC-DIT-DAT)	DONE	NONE
6	R3	C/C++	Apps	WP4	1	EQ	Application	Quicksort (Malardalen Benchmark)	Y	Y	Bring up Application (contains SEC-DIT-DAT)	DONE	NONE
7	R3	C/C++	Apps	WP4	1	EQ	Application	Binary Search (Malardalen Benchmark)	Y	Y	Bring up Application (contains DEC-SIT-SAT)	DONE	NONE
8	R3	C/C++	Apps	WP4	1	EQ	Application	Missile Guidance Simulator (Benchmark)	Y	Y	Bring up Application (contains DEC-DIT-DAT)	DONE	NONE
9	R2	C/C++	Apps	WP4	1	FW	Application	SeqFCDC	Y	Y	Create sequential version of app and limit dependencies on ARINC (simulate remaining dependencies via stub implementation)	DONE	NONE

Figure 1: Project Plan sorted by Partner for ease-of-update in regular Teleconferences

5.1.3 Quality Assurance (Task 5.2 Establishing project management and quality assurance procedures)

In Period 1, WP5 proposed and the Executive Board approved a Quality Assurance process to ensure that each deliverable would be reviewed against a well-defined set of criteria. At the start of the project, the project team established a list of the Main Authors and Review Owners for every Deliverable for the duration of the project. The Main Author generates the Deliverable using a standard Deliverable template to ensure a homogeneous structure and appearance. S/He then passes the Deliverable on to the internal Reviewer. The Reviewer provides comments in a standardized Deliverable Review Form that includes the complete list of criteria. The Main Author revises the Deliverable and sends it to the Executive Board for a final approval before sending it to the European Commission. This process is described in detail in the D5.2 Project Handbook; the Deliverables List (including Main Author and Reviewer) as well as the Review Form and templates are all posted to the Project Portal.

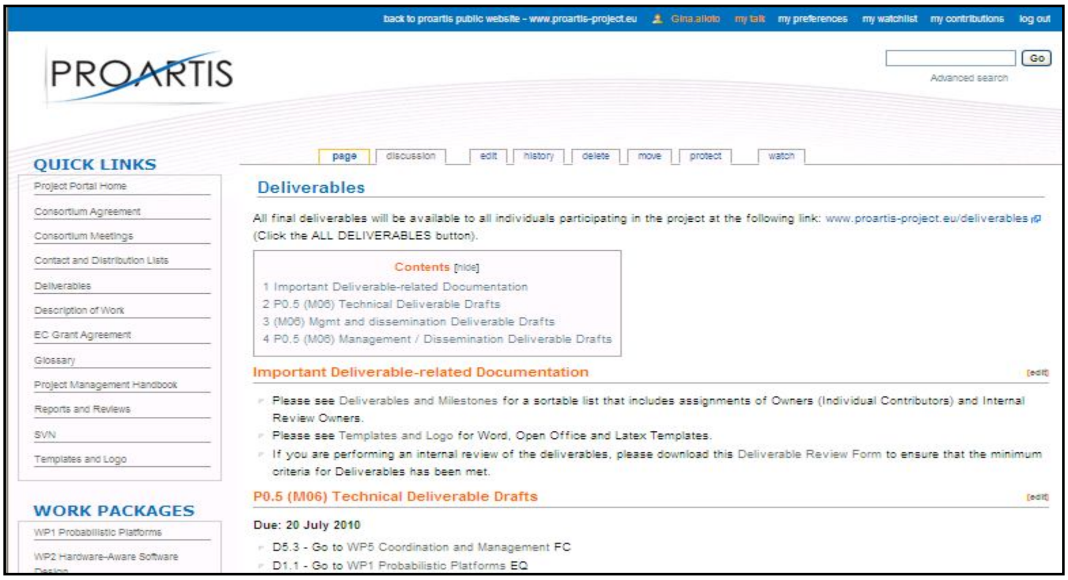


Figure 2: PROARTIS Project Portal Deliverables Page

5.1.4 Legal and Financial Management of the Contract (T5.4 Effort and financial tracking)

During the first year of the project, there were no changes to the consortium or to the legal status of the Partners that required any modification to the EC Grant Agreement, and subsequently no related changes were required to the Consortium Agreement.

As explained in the introduction of Section 5.1, during the second period the Project Coordinator requested a six-month extension. Therefore an amendment request was sent on January 2012 for including new project dates in Gran Agreement with a new version of Annex I - DoW. The modification was accepted by the Project Officer in February 2012.

6 Dissemination (WP6)

The project dissemination activities are described in D6.5, Period 2 Dissemination and Use Report, which describes the PROARTIS Project activities related to dissemination that occurred during Period 2 of the PROARTIS Project and additional plans for Period 3.

The only WP6 task active during period 2 was T6.4: partner dissemination. Each partner was encouraged to promote the project and its result through individual and joint activities. Now that significant progress has been achieved on the scientific research and direction, the main dissemination objective for period 2 was to produce scientific publications relating to the project.

A tremendous effort was spent on scientific dissemination, which has resulted in seven papers being prepared. Three joint papers covering the approach have been accepted a top-tier conference (ECRTS 2012) and a journal (ACM TCES) and to the WCET workshop at ECTRS 2012. Four more submissions are currently under review at strong conference events.

One of the wider challenges that has been overcome is to gain a wider acceptance by the real-time scientific community of the new ideas of the project, mixing statistics, probability and random behaviour. The existing culture has a rather different expectation of avoiding probabilities all together. During this period we have seen significant take-up and interest of this new area, due in part to the activities of PROARTIS, including invited talks.

There have been six invited talks to the scientific community including two keynote presentations at key conferences: ECRTS and RTSS, plus two invited talks at universities, a talk at a HIPEAC project event and a presentation at the IOLTS conference. Most of these talks have focused on the project directly, showing motivation and results for this new area. In the same direction, four specific talks to external industries have taken place to ARM, Infineon, IBM and ESA (European Space Agency), with the aims of spreading awareness and seeking longer-term exploitation opportunities.

There have been specific collaboration activities with several E.C. projects, including parMERASA, HIPEAC and TIMMO2USE. Minor interactions with ACROSS, T-CREST, HiPARTES, multiPARTES and SFdS (French Statistical Society) have also been noted and activities with some of these are expected to continue into period 3.

Exploitation activities have started, with preparation for one patent applications (BSC), use of the technology in tool support (RPT), use of the results in teaching (UNIPD) and for use of the technology in future product (AFS).

In summary, following the key scientific work, the project focused on and has succeeded in producing some strong scientific deliverables during this period and will continue this effort into the next period.

7 Explanation of the use of the resources

7.1 Planned vs. Actual Effort Spent by Work Package

The work performed (effort) in the project and the usage of resources generally progressed in accordance with the work plan. During the 3-month extension accepted for the second period, the consortium has kept on working at full effort resulting in an extra spending of personnel effort (of about 19% more). Planned effort per WP has been adapted therefore to the new period dates. This shows the general commitment of all the partners to overcome all the challenges.

	WP1		WP2		WP3		WP4		WP5		WP6		TOTAL	
PARTNER	Actual WP Total	Planned WP Total(*)	Actual WP Total	Planned WP Total (*)	Actual WP Total	Planned WP Total (*)	Actual WP Total	Planned WP Total (*)	Actual WP Total	Planned WP Total (*)	Actual WP Total	Planned WP Total (*)	Actual WP Total	Planned WP Total (*)
BSC	19,50	19,20	5,25	6,79	2,25	2,36	0,75	1,54	5,70	3,25	1,50	0,45	34,95	33,58
RAPITA	3,00	5,94	9,00	4,70	16,60	14,15	1,00	4,61	0,50	0,25	1,60	0,45	31,70	30,10
UNIPD	4,10	5,94	26,55	20,36	2,50	1,57	5,30	1,54	0,50	0,25	1,00	0,15	39,95	29,81
INRIA	0,15	0,46	0,15	0,52	20,66	15,72	0,49	0,51	0,50	0,25	0,50	0,15	22,45	17,62
AFS	0,80	0,46	1,40	1,04	0,80	0,39	7,20	4,61	1,00	0,25	0,40	0,30	11,60	7,05
TOTAL	27,55	32,00	42,35	33,42	42,81	34,20	14,74	12,80	8,20	4,25	5,00	1,50	140,65	118,17

(*) Readapted planning including the 3 months extension

Table 4: P2 Person Months Status

	WP1		WP2		WP3		WP4		WP5		WP6		TOTAL	
PARTNER	Actual WP Total	Planned WP Total	Actual WP Total	Planned WP Total	Actual WP Total	Planned WP Total	Actual WP Total	Planned WP Total	Actual WP Total	Planned WP Total	Actual WP Total	Planned WP Total	Actual WP Total	Planned WP Total
BSC	11,40	11,28	2,15	2,31	2,50	2,15	0,60	0,60	6,96	6,88	2,10	2,10	25,71	25.33
RAPITA	4,50	3,49	2,00	1,60	16,00	12,91	1,00	1,80	0,30	0,53	1,60	2,10	25,40	22.43
UNIPD	0,90	3,49	8,05	6,94	0,55	1,43	0,98	0,60	0,40	0,53	0,40	0,70	11,28	13.69
INRIA	0,14	0,27	0,12	0,18	10,05	14,34	0,16	0,20	0,52	0,53	0,42	0,70	11,41	16.22
AFS	0,30	0,27	0,40	0,36	0,30	0,36	2,40	1,80	0,30	0,53	0,30	1,40	4,00	4.71
TOTAL	17,24	18,80	12,72	11,38	29,40	31,20	5,14	5,00	8,48	9,00	4,82	7,00	77,8	82.38

Table 5: P1 Person Months Status (for reference)

In order to cover all the technical deliverables for MS2 and recover the delay incurred in the first reporting period, the project team has invested more effort than initially planned. In particular, during Period 2, WP2 (+26%) and WP3 (+33%) have required more effort than planned owing to the high complexity of the challenges faced in the work. This is especially reflected in the figures presented by UNIPD (ca. +34%), which recovered the effort under-spending incurred in the first reporting period, INRIA (+27%), which needed extra resources to face the complex cultural, scientific and technical WP3 challenges, and AFS, which had to use extra resources (+65%) to integrate the novel PROARTIS technologies in a real industrial application in WP4. BSC on its part needed extra effort in WP5 due to the work necessary for the extension amendment and change of project manager. WP6 also needed more resources because of the ramp-up of the project to disseminate project progress / results and recover the lower effort devoted during the first period.

This trend can be observed in Figure 3, which shows the PM effort for Period 2 with respect to the planned efforts including the 3 months of extension attributed to the reporting period (the other 3 being accounted for in the final period).

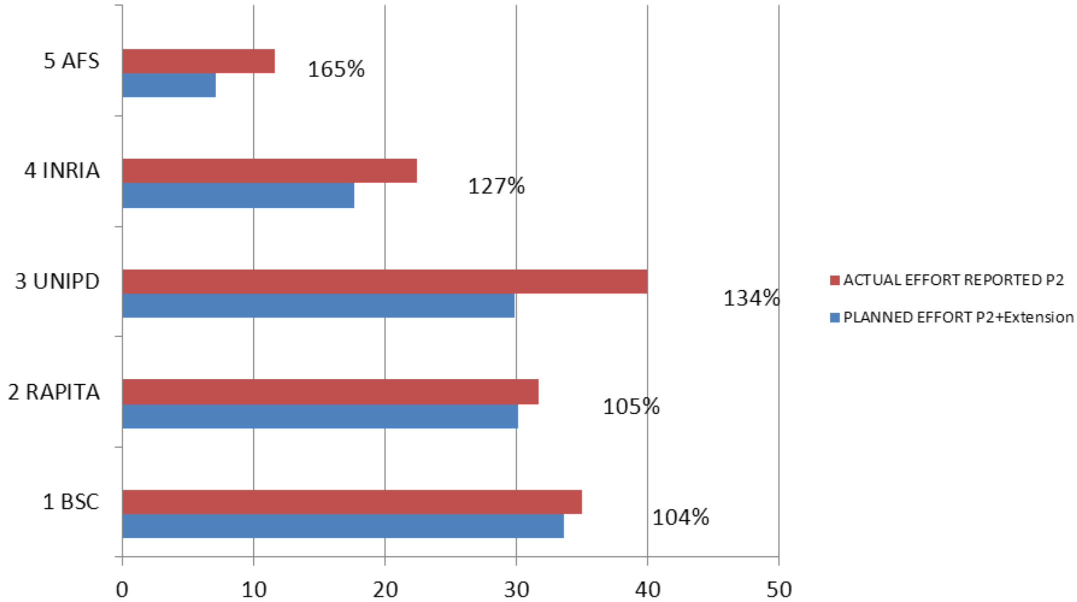


Figure 3: P2 reported PM efforts vs P2 Planned efforts

Adding up the total cumulated effort reported far in the Project over the first two reporting periods, shows the current general situation of the project.

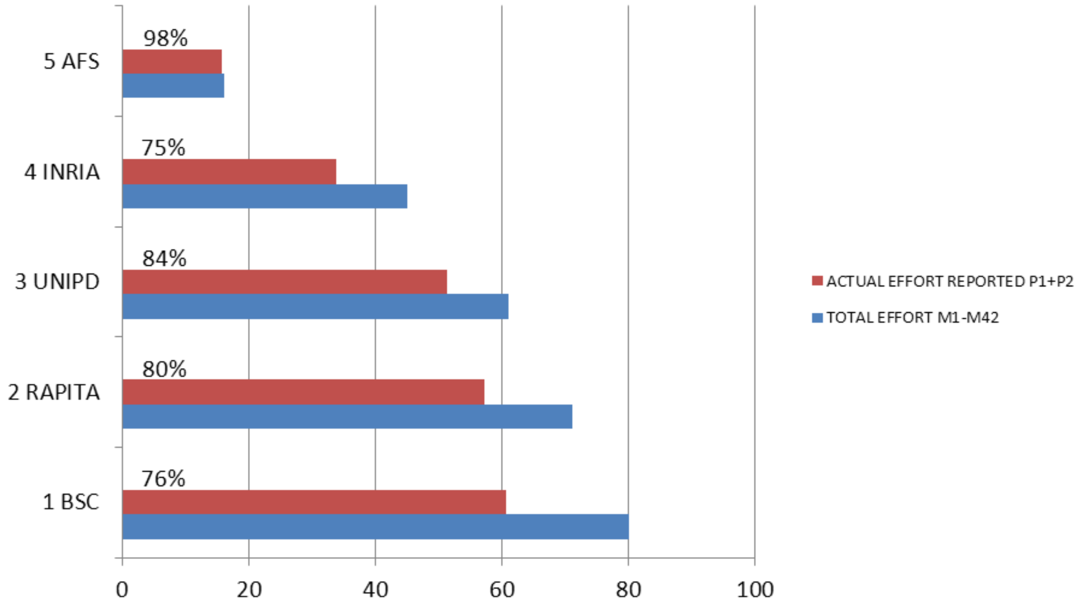


Figure 4: P1+P2 reported PM efforts vs Total Planned Effort

Due to the 3-month extension occurring in Period 2, Figure shows some peak in the use of the available effort: 218.45 PM has been used so far out of the 273 PM available in the Project overall, 80% of the total in terms of person months, for 65% of the whole duration. Continuing at this pace in the last period would cause an extra effort of about 16% at the end of the project. This risk is especially relevant for AFS, which has consumed 98% of its initially planned effort. It is important to notice that this deviation reads large and obvious because AFS were the partner with less planned effort in the first place. Our reading of this trend is that it shows the AFS commitment towards the project as the cost of the employed extra resources are being internally funded by AFS, and AFS intends to continue funding the complementary effort till the end of the project. All partners are aware of the project status in this regard, which will be closely monitored, and in any case no extra costs will be claimed.

7.2 Costs Claimed by Partner

In general, for P2, the work in the project and the usage of resources progressed in accordance with the new work plan, generally showing only slight extra-costs in spite of the extra effort incurred in the period:(the total reported cost is 1.010.333 € vs the planned cost of 1.003.768 €, including 3 extra months to equate the comparison, for a deviation of ca. 1%. P1 needs to be adjusted -15.228 €. Overall, the total amount of cumulated project costs reported so far (P1+P2) is 1.672.411 € at 69% of the total original budget (2.425.654 €) or 64% of the total budget after the amendment (2.603.890 €), which shows that project is financially on track. Moreover, the Coordinator (BSC) and the partners have provided an explanation in the case of any notable discrepancies.

Personnel, subcontracting and other major cost items for Beneficiary 1 - Barcelona Supercomputing Center - Centro Nacional de Supercomputación (BSC)			
Work Package	**Item description**	**Amount**	**Explanation**
1	RTD Personnel costs	74,749 €	19,50 PMs
2	RTD Personnel costs	13,892 €	5,25 PMs
3	RTD Personnel costs	12,567 €	2,25 PMs
1-3	RTD (5) Travel / Accommodation	201 €	Travel costs fo 1 person to F2F Technical Meeting (Madrid, SPAIN), 5-Apr-11
1-3	RTD (3) Travel / Accommodation	9,418 €	Travel costs for 4 BSC people (4.574,05 €) and 5 IAB Members (4.843,88 €) for EB/IAB F2F Technical Meeting (Gran Canaria, SPAIN), 09-apr-11
1-3	RTD (8) Travel / Accommodation	947 €	Travel costs for 1 person to F2F Technical Meeting (Toulouse, FRANCE), 08-jun-11
1-3	RTD (2) Travel / Accommodation	9,253 €	Travel costs for BSC collaborators' stay during july-11 and dec-11
1-3	RTD (6) Travel / Accommodation	543 €	Travel costs for 1 person to Technical Meeting (Padova, ITALY), 17-nov-11
1-3	RTD (10) Travel / Accommodation	1,213 €	Travel costs for 1 person to F2F Technical Meeting (Vienna, AUSTRIA), 20-nov-11
1-3	RTD (7) Travel / Accommodation	1,499 €	Travel costs for 1 person to F2F Technical Meeting (Paris/Nancy, FRANCE), 26-jan-12
1-3	RTD (9) Travel / Accommodation	486 €	Travel Costs for 1 person to F2F Technical Meeting (Toulouse, FRANCE), 29-feb-12
1-3	RTD (11) Travel / Accommodation	827 €	Travel costs for 1 person to F2F Technical Meeting (York, UK), 1 person, 23-mar-12

1-3	RTD (12) Travel / Accommodation	617 €	Travel costs for 1 person to F2F Technical Meeting (Goteborg, SWEDEN), 24-abr-12
1-3	RTD Equipment	117 €	Software and equipment for project development and follow up
1-3	RTD Other	487 €	Hosting costs for project meetings
1-3	RTD Other	79 €	Renewal of ACM subscription
1-3	RTD Subcontracting	2,566 €	Organization services for F2F EB/IAB Technical Meeting (Gran Canaria, SPAIN), 09-apr-11
	RTD Indirect Costs	92,048 €	
4	DEM Personnel Costs	5,611 €	0,75 PMs
	DEM Indirect Costs	5,104 €	
5	MGT Personnel costs	23,774 €	5,70 PMs
5	MGT Travel / Accommodation	1,798 €	Travel costs for 3 people for Project review meeting (Brussels, BE), 01-sep-11
5	MGT Consumables	65 €	Material for project reviews
5	MGT Subcontracting	2,320 €	Certificate on the Financial Statement for Cost Claims
5	MGT Other	503 €	Bank Commissions related to Period 1 Payment
	MGT Indirect Costs	21,622 €	
6	OTH Personnel costs	5,361€	1,5 PMs
6	OTH (1) Travel / Accommodation	387 €	Travel costs for 1 person for Project presentation at ESA Workshop (Amsterdam, NL), 27-sept-11
6	OTH (4) Travel / Accommodation	1,626 €	Travel costs for 1 person, ASPLOS 2012 Conference, ARM and Infineon Dissemination (London, UK), 06-07-mar-12
6	OTH Equipment	983 €	Web Server for Project Portal and Public Website
6	OTH Consumables	204 €	Registration and renewal of PROARTIS web-domain
	OTH Indirect Costs	4.876 €	
	Total Indirect Costs	123,650 €	
TOTAL COSTS AS CLAIMED ON FORM C		295,742 €	

Table 6: Personnel, subcontracting and other major cost items for 2 BSC

Explanations: In the table below OTH (1) was a trip to the European Space Agency in which one person from BSC presented the PROARTIS project. Similarly, OTH (4) was a combined trip to two of the major European chip manufacturers in which two

members of the BSC (only one charged to the PROARTIS project) presented the main achievements of the project to ARM and Infineon employees.
RTD (2) are the stays of Emery Berger at BSC, during which Emery significantly contributed to the compiler randomisation techniques developed in WP1.
RTD (3) is a PROARTIS workshop. BSC costs include the cost of the trip of the BSC team. The BSC costs also include the IAB trips. As defined in the DoW, BSC under its RTD budget put the costs of IAB. IAB is a cost/effective manner for the project to obtain industrial feedback and a path to exploitation and dissemination.
RTD (5), RTD (6), RTD (7), RTD (8), RTD (9) and RTD (11) are trips of BSC team members to have technical discussions with other project partners. These trips (and the relevant technical meetings) are a key element to make the project to progress on the technical side.
RTD (10) is a trip of the Technical Coordinator to present the PROARTIS project as a keynote in the CRTS workshop (held with RTSS 2011 conference) and to meet with other PROARTIS team members present at the same event.

Other dissemination events where done during this period, e.g. keynote of the Technical Coordinator in the CRTS workshop in July 2011 in Porto, free of charge for the PROARTIS project.

Deviations: Spending in this period was 97% compared to expected numbers. In total 78% of overall budget has been executed. Main reason for the deviation is the +20% extra spending of the first period –extra spending at this point has been reduced to +17% (despite the 3 extra months), which indicates costs are being closely monitored and situation has been addressed.

The following table shows the detailed costs of P1 adjustment:

Personnel, subcontracting and other major cost items for Beneficiary 1 - Barcelona Supercomputing Center - Centro Nacional de Supercomputación (BSC) **PERIOD 1 ADJUSTMENT**			
Work Package	**Item description**	**Amount**	**Explanation**
1-3	RTD Travel / Accommodation	6,226 €	IAB Travel and Meeting costs (Barcelona, SPAIN) - 8 people
TOTAL COSTS AS CLAIMED ON FORM C		6,226 €	

Table 7: Period 1 Adjustment for BSC

P1 Adjustment explanation: This correction is in response to the rejected costs from the Form C period 1, where IAB travel costs and related IAB Barcelona meeting costs had been incorrectly classified as MGT instead of RTD.

Personnel, subcontracting and other major cost items for Beneficiary 2 - Rapita Systems Ltd. (RAPITA)			
Work Package	**Item description**	**Amount**	**Explanation**
1	RTD Personnel costs	12,663 €	3 PMs
2	RTD Personnel costs	37,989 €	9 PMs
3	RTD Personnel costs	70,178 €	16.6 PMs
4	DEM Personnel costs	3,412 €	1 PMs
5	MGT Personnel costs	2,725 €	0.50 PMs
6	OTH Personnel costs	5,167 €	1.6 PMs
3	RTD [T2] Travel / Accommodation	912 €	Travel costs for 1 person for Technical Meeting, (Porto, Portugal) 4/7/2011
3	RTD [T0] Travel / Accommodation	2,950 €	Travel costs for 2 people for EB/IAB Technical meeting (Gran Canaria, Spain), 8/4/2011
6	OTH [T4] Travel / Accommodation	1,541 €	Travel costs for 1 person for IOLTS conference (Athens, Greece) 13/7/2011
5	MGT [T5] Travel / Accommodation	1,062 €	Travel costs for 2 people for project review (Brussels, Belgium)1/9/2011
3	RTD [T22] Travel / Accommodation	1,260 €	Travel costs for 1 person for F2F Technical Meeting,(Toulouse, France), 27/11/2011
3	RTD [T25] Travel / Accommodation	810 €	Travel costs for 1 person for F2F EB/Technical Meeting (Barcelona, Spain), 19/12/2011
3	RTD [T32] Travel / Accommodation	787 €	Travel costs for 1 person for F2F Technical meeting, (Nancy, France), 25/1/2012
3	RTD [T37] Travel / Accommodation	1,043 €	Travel costs for 2 people for F2F Technical Meeting (Toulouse, France), 28/3/2-12
6	OTH [T16] Travel / Accommodation	349€	Travel 1 person Invited dissemination talk at (Universidad de Alcala, Spain), 24/09/2011
3	RTD Other	64€	Hosting costs for F2F Technical meeting (York, UK) 22/03/2012
5	MGT Other direct costs	30 €	Misc MGT costs
	REMAINING DIRECT COSTS	0 €	
	Indirect Costs	85,765 €	
TOTAL COSTS AS CLAIMED ON FORM C		228,708 €	

Table 8: Personnel, subcontracting and other major cost items for 2 RAPITA

Explanations: Travel items T2, T0, T5, T22, T25, T37 are technical project meetings. There was an additional meeting in York, for which we incurred some hosting costs, making the 7 technical meetings that Rapita was involved in. T16 was a dissemination activity where we presented PROARTIS at the University of Alcala (see D6.5), at an invited talk. A similar talk to the University of Granada incurred no chargeable costs and is therefore not listed here. T5 was a dissemination activity at a conference (see D6.5). The other direct costs concerns shipping of signed contract documents during the start of the project.

Deviations: The total person months spent during the period was 31.70; this is higher than planned and largely due to the extension of the project. Most of the effort was spent on tool support (WP3) and certification arguments (WP2). Costs for the period are slightly higher than planned, again due to the project extension. A small amount of additional travel during the period is noted for an additional WP3 technical meeting. Overall, we remain approximately on budget to complete the project.

The following table shows the detailed costs of P1 adjustment.

Personnel, subcontracting and other major cost items for Beneficiary 2 - Rapita Systems Ltd. (RAPITA) during **PERIOD 1 ADJUSTMENT**			
Work Package	**Item description**	**Amount**	**Explanation**
6	OTH Travel / Accommodation	868 €	Travel costs, 1 person, Travel to ECRTS conference for dissemination and coordination of the WCET workshop (Belgium) July 2010
6	OTH Other	128 €	Training and networking activity for Annual Northern Aerospace Forum
6	OTH Other	313 €	Training and networking activity for Pebble Bay training
	REMAINING DIRECT COSTS	0 €	
	Indirect Costs	785 €	
TOTAL COSTS AS CLAIMED ON FORM C		2,094 €	

Table 9: Period 1 Adjustment for RAPITA

P1 Adjustment Explanation: There is also an adjustment to period 1 form C provided. This correction is in response to the rejected costs from the Form C period 1, where 3 travel items had been incorrectly classified as MGT instead of OTHER. The WCET workshop activity is an important event for this project, Rapita had people on the program committee and steering committee, and it was important for the project that we attended. We had a paper presented, and as a workshop, the networking and discussions, as much as the publication, are important to the project. The other two travel items are to local influential networking events where we discussed PROARTIS and certification issues.

Personnel, subcontracting and other major cost items for Beneficiary 3 - Università degli Studi di Padova (UNIPD)			
Work Package	**Item description**	**Amount**	**Explanation**
1	RTD Personnel costs	10,101 €	4.10 PM
2	RTD Personnel costs	48,672 €	26.55 PM
3	RTD Personnel costs	10,260 €	2.50 PM
4	RTD Personnel costs	9,598 €	5.30 PM
5	RTD Personnel costs	2,052 €	0.50 PM
6	RTD Personnel costs	4,104 €	1.00 PM
1-3	RTD Travel / Accommodation	3,989 €	Travel costs for 4 persons for EB/IAB F2F Technical Meeting (Gran Canaria, Spain), 09-apr-11

1-3	RTD Travel / Accommodation	1,955 €	Travel costs 3 persons for F2F Technical Meeting (Toulouse, France),08-june-11
5	MGT Travel / Accommodation	551 €	Travel costs for 1 person for Project review meeting (Brussels, BE), 01-sep-11
1-3	RTD Equipment and services	1,988 €	Procurement of 3 laptops and laboratory equipment for use by the UNIPD team in the project.
	Indirect Costs	55,960 €	
TOTAL COSTS AS CLAIMED ON FORM C		149,230 €	

Table 10: Personnel, subcontracting and other major cost items for 3 UNIPD

Explanation: In the reporting period, UNIPD increased the person effort deployed in WP2 and WP4 especially: this is where the most technical difficulties arose in completing the implementation of the single-core version of the time-composable operating system needed for the PROARTIS execution stack and in supporting the integration of the industrial use case. The relative increment was substantial (+10.1 pm in total for P2), only in part to compensate for the effort under-utilisation incurred in P1 (-2.3 pm). Such an increment results from the later-than-planned achievement of the full staffing of the UNIPD project team and the concurrent higher-than-planned level of involvement of the team leader, which reflects the complexity of the technical and scientific challenges faced by the project. The increase in effort did however incur a considerably smaller increase in labour cost owing to the lower incidence of personnel hourly rate used at UNIPD for their technical staff. The compound effect of these two events should enable UNIPD to retain all of its planned staffing profile in place until the end of the project (which is crucial to achieve the technical goals of the project), while only incurring a modest financial investment to support the relevant costs (essentially for a fraction of the effort devoted to the project by the UNIPD team leader).

Deviations: Costs have recovered slightly first period under-spending, but still 54% of the total budget has been executed.

Personnel, subcontracting and other major cost items for Beneficiary 3 - Università degli Studi di Padova (UNIPD) **PERIOD 1 ADJUSTMENT**			
Work Package	**Item description**	**Amount**	**Explanation**
1-3	RTD Personnel costs	-3,830€	Recalculated effort 9,5 PM
4	DEM Personnel costs	1,136 €	Recalculated effort 0,98 PM
5	MGT Personnel costs	-1,088 €	Recalculated effort 0.8 PM
RTD	RTD Travel / Accommodation	1,055 €	Reassignment of rejected costs from MGT to RTD as requested. Travel costs 1 person to EB/Technical Meeting (Barcelona, SPAIN)
	Indirect Costs	-1,636 €	
TOTAL COSTS AS CLAIMED ON FORM C		-4,363 €	

Table 11:Period 1 Adjustment for UNIPD

P1 Adjustment Explanation: The costs previously reported for Period 1 had to be slightly adjusted to account for a reduction in the total number of person hours that the RTD project personnel at UNIPD could account to PROARTIS and to a variation in the actual costs thereof, due to a change in the interpretation of the applicable laws. There is also a correction in response to the rejected costs from the Form C period 1

Personnel, subcontracting and other major cost items for Beneficiary 4 – Institut National de Recherche en Informatique et Automatique (INRIA)			
Work Package	**Item description**	**Amount**	**Explanation**
1	RTD Personnel costs	775 €	0.15 PMs
2	RTD Personnel costs	775 €	0.15 PMs
3	Personnel costs	83,486 €	20.66 PMs
4	Personnel costs	2,120 €	0.49 PMs
5	Personnel costs	2,583 €	0.50 PMs
6	Personnel costs	2,583 €	0.50 PMs
1-3	RTD (1) Travel / Accommodation	6,050 €	Travel costs for 4 people for EB/IAB F2F Technical Meeting (Gran Canaria, Spain), 09-apr-11
1-3	RTD (2) Travel / Accommodation	3,802 €	Travel costs for 2 people for F2F technical meeting (Porto, Portugal), 04-jul-11
5	MGT (3) Travel / Accommodation	367 €	Travel costs for 1 person for Project review meeting (Brussels, BE), 01-sep-11
1-3	RTD (5) Travel / Accommodation	2,030 €	Travel, 2 people for F2F EB/Technical Meeting (Barcelona, Spain), 19-dec-11
6	OTH (6) Travel / Accommodation	694 €	Travel costs for 4 people, ACTRISS Probabilistic dissemination seminar (Paris, France), 10-Mar-11
6	OTH (7) Travel / Accommodation	93 €	Travel costs for 1 person, INED Seminar of French statistical society (Massy, France)
6	OTH (8) Travel / Accommodation	192 €	Travel costs for 1 person, French statistical society Statistic meeting (Paris, France)
6	OTH (9) Travel / Accommodation	155 €	Travel costs for 1 person French statistical society meeting day on statistic (Paris, France)
	REMAINING DIRECT COSTS	0 €	
	Indirect Costs	90,181€	
TOTAL COSTS AS CLAIMED ON FORM C		195,886 €	

Table 12: Personnel, subcontracting and other major cost items for 4 INRIA

Explanation: RTD(1) covers the travel fees for four persons from INRIA to a face to face meeting with all partners of the project as well as to IAB meeting. The participation of all members of INRIA team in such meeting is crucial since their knowledge is complementary and also to build a common vocabulary with the other partners. RTD(2), RTD(4) and RTD(5) are face to face meeting with PROARTIS partners dealing with particular topics that only needed the participation of the concerned people within the INRIA team. RTD (3) concerns a review meeting in

Bruxelles where the participation of the WP3 leader was mandatory. OTHER(6) covers the travel fees for a probabilistic day within the French real-time community. This day was proposed and organized by the INRIA team and the presence of the entire team was required either for formal presentations or dissemination within the community. OTHER(7), OTHER(8) and OTHER(9) are travel fees of INRIA team to workshops organized by the French statistical society. These meetings allow to update the knowledge of the INRIA team and also to interact with the statistical community. This interaction is essential for later dissemination (and networking) of the theoretical results of PROARTIS.

Deviations: Costs follow the general tendency of the slight personnel extra spending. Spending in this period was 96% compared to expected numbers counting the 3 extra months. In total 65% of overall budget has been executed, therefore INRIA is financially on track.

Personnel, subcontracting and other major cost items for Beneficiary 4 – Institut National de Recherche en Informatique et Automatique (INRIA) **PERIOD 1 ADJUSTMENT**			
Work Package	**Item description**	**Amount**	**Explanation**
	Indirect Costs	-7,965 €	
TOTAL COSTS AS CLAIMED ON FORM C		-7,965 €	

Table 13: Period 1 Adjustment for INRIA

P1 Adjustment Explanation: The indirect costs include adjustments (-7,965 €) consecutive to the definitive calculation of the indirect costs of 2011.

Personnel, subcontracting and other major cost items for Beneficiary 5 - Airbus Operations SAS (AFS)			
Work Package	***Item description***	***Amount***	***Explanation***
1	RTD Personnel costs	5,110 €	0.8 PM
2	RTD Personnel costs	9,118 €	1.4 PM
3	RTD Personnel costs	5,110 €	0.8 PM
4	RTD Personnel costs	22,352 €	3.5 PM
4	DEM Personnel costs	24,593 €	3.7 PM
5	MGT Personnel costs	6,792 €	1 PM
6	RTD Personnel costs	2,555 €	0.4 PM
1-3	RTD Travel / Accommodation	3,054 €	Travel costs for 2 people for EB/IAB F2F Technical Meeting (Gran Canaria, Spain), 09-apr-11
1-3	RTD Travel / Accommodation	981 €	Travel costs 1 person for F2F EB/Technical Meeting (Barcelona, Spain), 19-dec-11
5	MGT Travel / Accommodation	1,089 €	Travel costs for 1 person for Project review meeting (Brussels, BE), 01-sep-11
	REMAINING DIRECT COSTS	0 €	
	Indirect Costs	60,013 €	
TOTAL COSTS AS CLAIMED ON FORM C		140,767 €	

Table 14: Personnel, subcontracting and other major cost items for 5 AFS

Explanation: In the reporting period, AFS increased the person effort deployed in WP2 and especially in WP4: as it is where the most technical difficulties arose in completing the integration of the PROARTIS platform simulator and operating system to support the execution of the industrial use case. The person effort impact against planned costs is however limited, thanks to the availability of an additional AFS resource and lower personnel hourly rate against staffing and personnel hour rates originally taken into account. Current costs reported by AFS are on track against planned costs (~105% of the costs planned for the first two periods of the project, ~60% of the overall AFS budget allocation). As a result AFS person effort commitment during the third period of the project is not compromised and AFS intends to continue funding internally any necessary complementary effort till the end of the project.

Deviations: Although AFS reported the effort spent on the project accurately, as stated in phase 1 report, they faced an internal accounting system problem that does not allow them to accurately report the cost repartition associated with this effort, allowing only to report through an RTD associated booking number. This means that until correction of this issue, all project-associated costs were reported under the Activity RTD despite the fact that the majority of their costs are associated for work under the DEMO Activity (WP4) and there should have been a fraction of the costs under the MGT activity. RTD and DEMO categories are both funded at 50% and this is lower than the rate for MGT, so the Coordinator and AFS financial team have agreed to report all activity under RTD until the internal AFS problem is rectified. This problem has been solved in November 2011, i.e. late in the reporting period, which explains why WP4 activities are reported both under RTD and DEMO but still with an imbalance towards RTD, and only a small amount appears under MGT.

Personnel, subcontracting and other major cost items for Beneficiary 5 - *Airbus Operations SAS* (AFS) **PERIOD 1 ADJUSTMENT**			
Work Package	**Item description**	**Amount**	**Explanation**
4	RTD Personnel costs	-3,054 €	Change in Personnel Costs
	Indirect Costs	-8,166 €	
TOTAL COSTS AS CLAIMED ON FORM C		-11,220 €	

Table 15:Period 1 Adjustment for AFS

P1 Adjustment Explanation: Period 1 adjustment is motivated because of the definitive calculation of hour rate and indirect costs of the given period.

8 Financial statements – Form C and Summary financial report

Note: The Form C for each Beneficiary will be entered into the NEF Tool and "finalized" after the validation from project officer.

9 Certificates

NO.	PARTNER NAME	SHORT NAME	CFS PROVIDED	COMMENT
1	Barcelona Supercomputing Center	BSC	Yes	Expenditure Threshold reached
2	Rapita Systems Ltd.	RAPITA	No	Expenditure Threshold not reached
3	Università degli Studi di Padova	UNIPD	No	Expenditure Threshold not reached
4	Institut National de Recherche en Informatique et Automatique	INRIA	No	Expenditure Threshold not reached
5	Airbus France SAS	AFS	No	Expenditure Threshold not reached

Table 16: Certificates