PROJECT FINAL REPORT

GRANT AGREEMENT NUMBER	249295
PROJECT ACRONYM:	MANTRAS
PROJECT TITLE:	A Novel Mathematical Framework for the Modelling and the Analysis of Transportation Networks
FUNDING SCHEME:	Marie Curie Actions, International Re-integration Grant (IRG)
BENEFICIARY:	Technische Universiteit Delft, The Netherlands
LATEST VERSION OF ANNEX I:	November 2009
PERIOD COVERED:	January 1, 2010 — December 31, 2013
SCIENTIFIC REPRESENTATIVE:	prof. Bart De Schutter
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HISTORY CHART

Issue	Date	Changed Pages	Cause of Change	Implemented by
1.0	02/15/2014	All sections	New document	A. Abate
2.0	02/25/2014	All sections	Feedback on content	D. Adzkiya
3.0	03/10/2014	All sections	Revision	A. Abate

AUTHORIZATION

No.	Action	Name	Signature	Date
1	Preparation of first draft	A. Abate		02/15/2014
2	Approval of final draft	A. Abate		03/10/2014

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1 About this report

1.1 Project data

Grant Agreement Number: **249295**

Project Acronym: **MANTRAS**

Project Title:
A Novel Mathematical Framework for the Modelling and the Analysis of Transportation Networks

Funding Scheme: **Marie Curie Actions, International Re-integration Grants (IRG)**

Date of latest version of Annex I against which the assessment will be made:
November 2009

Final report, period covered:
from **January 1, 2010** to **December 31, 2013**

Name, title and organization of the scientific representative:
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1.2 Declaration

I, as a researcher in charge of this project, declare that:

- This periodic report represents an accurate description of the work carried out in the project for this reporting period;
- The project has fully achieved its objectives and technical goals for the period;
- The financial statement which is 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 (Chapter 4).

Alessandro Abate

March 10th, 2014

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2 Project summary

2.1 Short description (publishable summary)

Transportation networks are ubiquitous nowadays: people move over transit links (airspace, highway systems, networks of subways and railways), trade goods through industrial networks (logistics and production networks, manufacturing systems) and assets through financial networks (market and banking systems), support their lifestyle via distribution networks (power, energy, food and water distribution systems), and communicate and exchange knowledge through information networks (based on telephone lines, satellite stations, optical grids, cable and wireless internet, postal networks and the media). A reliable, resilient, secure, efficient, and effective operation of these networks is of paramount importance both when the systems are operated to the limits of their performance during critical situations, as well as under regular operating conditions. The quest for a quantitative understanding of these networks and of their properties necessitates the development of descriptive formal models to represent, analyze, and control them. Discrete Event Systems (DES) and Stochastic Hybrid Systems (SHS) are general mathematical models that, while rather different in nature, by virtue of their structural properties and dynamical features are both particularly suitable at modelling transportation networks.

2.2 Expected final results and potential impact

This project has two original objectives. The first major goal is theoretical, and is aimed at introducing a formal mathematical framework that is capable of connecting between the theory of DES and that of SHS. The second objective deals with the applications of this novel formal model in the description, analysis, and control of classes of transportation networks (road traffic networks and railway systems). This innovative project is expected to yield theoretical results that will be foundational for further investigations, and to originate compelling and relevant practical outcomes of considerable industrial, economic, societal, and environmental impact.

2.3 Work timeline and plans

According to the proposed work plan, the project would focus on the theoretical foundations within its first half, while moving towards an emphasis on applications over its second half. In particular, the work plan is structured as follows:

(0 - 6 months) Early theoretical investigations. Literature research, work on existing models.

(6 - 18 months) Main achievements on the theoretical part. Early dissemination of research.

(18 - 30 months) Development of first case studies. Benchmark study of these new models and control algorithms. Further advancements of the theoretical investigations. Dissemination of work through collaborations with other academic institutions. Major theoretical publications released. Early applicative publications. Presentation of research at conferences or workshops, and organization of scientific events.

(30 - 48 months) Development of applications in real-world studies. Organization and systematization of theoretical investigations. Applied publications released. Presentation of research at conferences, workshops, and industrial meetings.

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3 Core of the report

3.1 Project objectives

With focus on the proposed work plan, the following items recapitulate the principal objectives:

- Main theoretical investigations and computational studies;
- Dissemination of research, both theoretical, computational, and applicative;
- Additional applications and studies.

Furthermore, the project has achieved this additional objective:

- Programming of a software toolbox, and publication of the software.

3.2 Work progress and achievements

In this section we summarize the work carried out and main achievements of the project in terms of research and development. The subsections are organized according to the four items above.

3.2.1 Main theoretical and computational investigations

Summary of achieved objectives

The early achievements attained are highlighted below:

- development of a novel technique, to obtain finite abstractions of Max-Plus-Linear (MPL) autonomous models;
- formal connection between MPL models and finite-state labeled transition systems (LTS);
- proof of simulation or of bisimulation of the LTS abstraction over the original MPL model;
- development of a computational benchmark to test the numerical performance of the abstraction procedure;
- connection with use of model checking techniques for the formal verification of MPL models over their LTS abstractions.

The core of the work has investigated the use of finite abstractions for the verification of Max-Plus-Linear (MPL) autonomous models. Abstractions are characterized as finite-state labeled transition systems (LTS) and are obtained by first partitioning the state space of the MPL and associating states of the LTS to the partitions, then by defining relations among the vertices of the LTS, corresponding to dynamical transitions between the MPL state partitions, and finally by labeling the LTS edges according to one-step time properties of the events of the MPL model. In order to establish formal equivalences, the finite LTS abstraction is proven to either simulate or to bisimulate the original MPL model, the difference depending on its determinism. The computational performance of the abstraction procedure has been tested on a benchmark. Finally, the project has studied properties of the original MPL model by verifying equivalent specifications on the finite LTS abstraction. The theoretical points above have been documented in the publication P1.1.
Furthermore, the project has worked on the following:

- extension of the above results to non-autonomous models; P1.5
- study of robustness of MPL models against perturbations on initial conditions and action of exogenous disturbances, within LTS abstractions;
- forward and backward reachability analysis of autonomous and non-autonomous models via LTS abstractions; P1.3, P1.6
- early results on control synthesis over MPL models via LTS abstractions. P1.5

In P1.2 (which includes P1.1 and P1.5) we have finally put forward a systematic framework for formal verification of Max-Plus-Linear (MPL) models against a Linear Temporal Logic (LTL) formula. Our approach is based on finite abstractions. Abstraction is a fundamental concept that permits the analysis of systems with large or even infinitely-many states. This approach enables the study of general properties of the MPL model by verifying (via model checking) equivalent logical specifications over the finite abstraction.
With regards to the abstraction of MPL models, we propose a new technique that generates a finite-state abstract Transition System (TS) in a finite number of steps. Given an MPL model, we formulate the MPL model as a (concrete) infinite-state TS. Then we partition the set of states into finitely many partitioning regions. All concrete states that belong to the same partitioning region is mapped by the abstraction function f to a unique abstract state. We require that each partitioning region is a Difference-Bound Matrix (DBM) [7, Sec. 4.1] and the dynamics that are active in each partitioning region is affine. There is a transition from abstract state $f(s)$ to state $f(s')$ if there is a transition from concrete state s to s'. Computationally, we leverage one-step forward-reachability analysis over PWA representation of MPL dynamics, and DBM to represent regions over the state and control spaces.
The obtained abstract TS simulates the concrete TS if the partition of the state space is proposition preserving, i.e. the abstract states are associated with equally labeled concrete states only [3]. The simulation relation preserves all linear-time properties including LTL formulae, since the concrete TS does not have terminal states, i.e. the concrete TS is nonblocking. Thus if the abstract TS satisfies an LTL formula, the concrete TS also

satisfies the LTL formula. However the reverse does not hold in general, i.e. if the abstract TS does not satisfy an LTL formula, the concrete TS may still satisfy the LTL formula.
Having obtained an abstract TS that simulates the concrete TS, it makes sense to attempt deriving an abstract TS that bisimulates the concrete TS by using a partition refinement procedure. In this case, an abstract TS satisfies an LTL formula if and only if the concrete TS satisfies the LTL formula. However the refinement procedure may not terminate. We provide sufficient conditions for the existence of an abstract TS that bisimulates the concrete TS. Whenever the sufficient conditions are fulfilled, we describe a finite-time procedure to determine an abstract TS that bisimulates the given concrete TS.
Next we compute quantities associated with the transitions of the abstract TS. The quantities represent the time difference between consecutive events of the MPL model. If the MPL model is nonautonomous, it is furthermore possible to compute quantities describing: 1) the subset of the outgoing partitioning region that is actively enabled by the transition under some input signals; or 2) the subset of the control inputs that actively leads states from the outgoing partitioning region to the destination region. These quantities allow for flexibility in using the abstract TS for analysis of the original MPL model.
P1.2 develops a case study in transportation (railway) network to elucidate the discussed notions and concepts.

In P1.3 and P1.6, we generalize results for reachability analysis of MPL models. We extend the results for forward reachability by considering an arbitrary set of initial conditions. Additionally for backward reachability analysis, we are able to handle nonautonomous MPL systems and state matrices that are not max-plus invertible.
The approach is as follows. We first alternatively characterize MPL dynamics by Piecewise Affine (PWA) models, and show that they can be fully represented by Difference-Bound Matrices (DBM) [7, Sec. 4.1], which are quite simple to manipulate computationally. We further claim that DBM are closed over PWA dynamics, which leads to being able to map DBM-sets through MPL models. We then characterize and compute, given a set of initial states, its "reach tube," namely the union of sets of reachable states (aggregated step-wise as "reach sets"). The set of initial conditions is assumed to be a union of finitely many DBM, which contains the class of max-plus polyhedra and of max-plus cones as a special case. The approach is also applied to backward reachability analysis. Due to the computational emphasis of this work, we provide a quantification of the worst-case complexity of the algorithms and of the operations that we discuss throughout the work. Interestingly, DBM and max-plus polyhedra have been used for reachability analysis of timed automata [5, 10] and implemented in UPPAAL [4] and in `opaal` [6], respectively. Although related scheduling problems can be solved via timed automata [1], this does not imply that we can employ related techniques for reachability analysis of MPL systems since the two modeling frameworks are not comparable.

VeriSiMPL ("very simple") is a software tool to obtain finite abstractions of Max-Plus-Linear (MPL) models. MPL models, specified in MATLAB, are abstracted to finite-state Transition Systems (TS). The abstract TS is formally put in relationship with the concrete TS associated with the MPL model via a (bi)simulation relation. The abstraction procedure runs in MATLAB and leverages sparse representations, fast manipulations based on vector calculus, optimized data structures such as Difference-Bound

Matrices [7], and parallel computing toolbox of MATLAB. The obtained TS abstractions can be pictorially represented via the Graphviz tool and exported to structures defined in the PROMELA. This enables the verification of MPL models against temporal specifications within the SPIN model checker [8]. The toolbox is freely available at `http://sourceforge.net/projects/verisimpl/`.

Recently we have added some features to VeriSiMPL. One of them is computing forward and backward reachability of autonomous and nonautonomous MPL models. Currently we are working on the finite abstraction of switching Min-Plus-Linear systems with application to network calculus [9]. Furthermore we are also looking at possible improvements of the current implementation by using a lower-level programming language, e.g. C, and using a tailored data structure, e.g. binary decision diagram.
VeriSiMPL has been presented in P1.4.

As promised in the DoW, in P3.1 we extend our results to stochastic MPL models, in an interesting connection with related modern work on finite abstractions of uncountable-state stochastic processes. This work investigates the use of finite abstractions to study the finite-horizon probabilistic invariance problem over Stochastic Max-Plus-Linear (SMPL) systems. SMPL systems are probabilistic extensions of discrete-event MPL models that are widely employed in the engineering practice for timing and synchronisation studies. We construct finite abstractions by re-formulating the SMPL system as a discrete-time Markov process, then tailoring formal abstraction techniques in the literature to generate a finite-state Markov Chain (MC), together with precise guarantees on the level of introduced approximation. This finally allows probabilistically model checking the obtained MC against the finite-horizon probabilistic invariance specification. The approach is practically implemented via a dedicated software, and elucidated in this work over numerical examples. The dedicated software will be as well published, as done for VeriSiMPL.
This work is about to be submitted: we will pursue further dissemination in the near future.

Collaborations

The work has been performed by Alessandro Abate and Dieky Adzkiya, a PhD student at the Delft Center for Systems and Control, who is expected to graduate on these topics in mid 2014. Mr. Adzkiya is supervised by dr. Abate.
Furthermore, the work has benefitted from the feedback of Bart De Schutter, professor at the Delft Center for Systems and Control and collaborator in the project. We have collaborated with Sadegh E.S. Soudjani and Manuel Mazo at DCSC.

3.2.2 Dissemination of research

The above theoretical results have been presented with a total of five published or accepted international, peer-reviewed conference articles, one journal article published and one provisionally accepted, one conference articles presently under review, and additional working drafts.

The articles are available on dr. Abate's website as preprints (thus, abiding by copyright requirements). The internal reports are directly obtainable upon request. The software has been published on `Sourceforge`, thus abiding by the Commission open access policy. The support of the Marie Curie Actions has been referenced in all publications, conference papers, presentations and posters in connection with this project.

Articles published or accepted for publication

Paper number	Publication data	Status
P1.1	D. Adzkiya, B. De Schutter and A. Abate, *Abstraction and Verification of Autonomous Max-Plus-Linear Systems*, Proceedings of the 31st American Control Conference, Montreal, CA, Jun 2012.	published
P1.2	D. Adzkiya, B. De Schutter, A. Abate, *Finite Bisimulations of Max-Plus-Linear Systems*, IEEE Transactions on Automatic Control, vol. 58, nr. 12, pp. 3039-3054, Dec. 2013.	published
P1.3	D. Adzkiya, B. De Schutter, A. Abate, *Forward Reachability Computation for Autonomous Max-Plus-Linear Systems*, TACAS 2013.	to appear
P1.4	D. Adzkiya, A. Abate, *VeriSiMPL: Verification via biSimulations of MPL models*, "Quantitative Evaluation of Systems," K. Joshi et al. eds., LNCS 8054, pp. 274–277, Springer Verlag, 2013. Presented at the *10th International Conference on Quantitative Evaluation of SysTems*, Buenos Aires (AR), Aug. 2013.	published
P1.5	D. Adzkiya, B. De Schutter and A. Abate, *Finite Abstractions of Nonautonomous Max-Plus-Linear Systems*, Proceedings of the 32nd American Control Conference, Washington, DC, Jun 2013.	published
P1.6	D. Adzkiya, B. De Schutter and A. Abate, *Backward Reachability of Autonomous Max-Plus-Linear Systems*, WODES 2014.	to appear
P1.7	D. Adzkiya, B. De Schutter, A. Abate, *Reachability Analysis of Autonomous Max-Plus-Linear Systems*, 31st Benelux Meeting on Systems and Control, Heijen, NL, Mar. 2012.	published

Articles submitted

Paper number	Publication data	Status
P2.1	D. Adzkiya, B. De Schutter and A. Abate, *Computational Techniques for Reachability Analysis of Max-Plus-Linear Systems*, Automatica, 2013.	provisionally accepted

P2.2	B. Dahlan, D. Adzkiya, A. Abate, and M. Mazo, Jr., *Verification of Properties for Network Calculus Elements via Finite Abstractions*, CDC 2014.	under review

Internal Reports

Paper number	Publication data	Status
P3.1	D. Adzkiya, S.E.S. Soudjani, and A. Abate, *Technical Report on Abstractions of Stochastic Max-Plus-Linear Systems*. Internal Report, Delft Center for Systems and Controls, TU Delft, 2014.	completed

Related research activities

Alessandro Abate has given an invited presentation on the topics of this research at the workshop "Hybrid Autonomous Systems" at ETAPS11, in Saarbrücken, April 2011. He has furthermore participated to the "Conference of Stochastic Systems Biology," at Monte Verità, Switzerland, in July, 2011. A. Abate is Publicity Chair, Member of Organizing and Program Committee for the 4th IFAC Conference on Analysis and Design of Hybrid Systems (ADHS), Eindhoven 2012 and the Program Committee for the international workshop on Hybrid Systems: Computation and Control (HSCC), Peking 2012. A. Abate has been Member of International Program Committee, 3rd International Workshop on Dependable Control of Discrete Systems (DCDS), June 2011. These events closely relate to the topics of this research project.
Dieky Adzkiya has taken part in a number of educational events, has presented most of the accepted articles at conferences. In particular,

- Workshops:
  1. Distributed Supervisory Control of Large Plants (DISC) Summer school. Topic: Automata and Petri nets perspectives
  2. HYCON2-EECI International Graduate School on Control. Topic: Specification, Design and Verification of Distributed Control Systems
- Schools:
  1. Measure Theory and Integration, EWI, TU Delft
  2. Stochastic Differential Equations, Dutch Master's Degree Programme in Mathematics
  3. Systems and Control Dutch Master's Degree Programme in Mathematics
  4. Modeling and Control of Hybrid Systems, Dutch Institute of Systems and Control
  5. System Identification for Control, Dutch Institute of Systems and Control
- Conferences:

1. Benelux meeting 2012, Dutch Institute of Systems and Control
2. 2013 American Control Conference, IEEE Control Systems society

Dr. Abate has also hosted a few visiting scientists that are working on topics closely associated to the project, thus again increasing the visibility of the project to a wide audience. In particular: Ian Mitchell (U. of British Columbia), Calin Belta (Boston University), Alexandru Mereacre (RWTHA, now at Oxford).

3.2.3 Additional applications and case studies

A case study from rail traffic monitoring and management, as discussed in the DoW, has been developed in all the main publications.

Further, in P2.2 we have focused our attention towards network calculus [9], a mathematical set of tools employed to provide strong performance guarantees for deterministic communication systems. Interestingly, in network calculus traffic sources are modeled in a way that allows for the flow generated by these sources to be aperiodic. This motivates the present work, which provides some first steps towards the automatic verification of communication properties interesting for controller implementations. In particular, we focus on the automatic verification of virtual delays and backlog bounds of a network. Both of these issues are highly relevant in control implementations: the first one can be typically assumed to provide a bound for the delay in the feedback measurements; and the latter is necessary to guarantee the absence of packet drop-outs.
Although such properties can already be analyzed using network calculus tools, the virtue of our approach lies in its completely automated nature, and in that it opens the door to the automatic verification of certain communication topologies, e.g. flow aggregates, which network calculus cannot easily cope with. Furthermore, the use of symbolic abstraction approaches similar to those proposed for the automatic synthesis of control software, enables the simultaneous verification of control and communications software.
Our approach consists of two steps. In the first step, we construct a switched min-plus-linear (MiPL) system from a network calculus element. Then we abstract the switched MiPL system into a finite-state system. The abstraction procedure of switched MiPL systems is an extension of [2]. The abstraction procedure in [2] is formula free, whereas in this work we leverage formula-based abstractions. Computationally the abstraction procedure makes use of the piecewise switched affine representation. A piecewise switched affine system is described by a set of switched affine dynamics defined over a corresponding region in the state space. In order to establish formal relationships between the concrete model and its abstraction, we argue that in general the abstraction simulates the concrete model. The simulation preorder relation preserves linear temporal logic (LTL) formulae, since the concrete model is nonblocking [3].
The approach to attain abstractions developed in this work can be interpreted in the context of literature focused on construction of finite-state (quotient) models of given systems. However the techniques for abstractions of piecewise affine (PWA) systems in the literature [11] do not appear to be directly usable in our problem, since their techniques depends on a specific LTL formula. On the other hand, our abstraction only depends on

the set of atomic propositions. Thus our abstraction can be used to verify any LTL formula constructed from the set of atomic propositions.

3.2.4 Benefit of this grant on the PI and associated researcher's careers

This career has benefitted the PI both academically, in terms of development of education, and with regards to re-integration.
Alessandro Abate is the principal organizer of Dagstuhl Seminar "Modeling, Verification, and Control of Complex Systems for Energy Networks", Oct 2014, and of Workshop on "Verification of Stochastic Hybrid Systems" at IEEE ECC13.
Alessandro Abate has given numerous invited presentations on the topics of this research at workshops and at academic and industrial events and venues. IN particular:
Department of Engineering Sciences, Control Group, Oxford University, Nov 2013 - Department of Signals and Systems, Chalmers University of Technology, Nov 2013 - Institute for Automation, Tsinghua University, Beijing, Sept 2013 - Institute of Software, Chinese Academy of Sciences, Beijing, Sept 2013 - Workshop on "Formal Verification of Embedded Control Systems," Lund University, Apr 2013 - Automatic Control Lab, ETH Zurich, Apr 2013, Department of Computer Science, VU University Amsterdam, Dec 2012 - Johann Bernoulli Institute for Mathematics and Computer Science, University of Groningen, May 2012 - Contraintes group, INRIA Paris-Rocquencourt, Mar 2012 - Department of Computer Sciences, Oxford University, Mar, May 2012 - Computer Science Laboratory, SRI International, Dec 2011 - Seminar, Delft Center for Microbial Systems Biology, May 2011- Workshop on Hybrid Autonomous Systems, at ETAPS 2011, Saarbrücken, Apr 2011 - Department of Computer Sciences, Universität des Saarlandes, Nov 2010 - Department of Systems Engineering, Boston University, Nov 2010 - LIDS Seminar, Department of Electrical Engineering and Computer Sciences, MIT, Nov 2010 - AVACS Workshop, "AVACS meets Control", Sep 2010 - Dagstuhl Seminar "Verification over discrete-continuous boundaries", Jul 2010 - Department of BioTechnology, Faculty of Applied Sciences, TU Delft, May 2010 - Seminar, Department of Computer Science, RWTH Aachen University, DE, Feb 2010 - Seminar, Department of Mechanical Engineering, TU Eindhoven, Feb 2010.
He has further increased his expertise and visibility both within the Hybrid Systems area, as well as within the Formal Verification community. In particular, he is an Associate Editor of Nonlinear Analysis: Hybrid Systems (An IFAC Journal, Elsevier), and a Member of International Program Committee for UNCECOMP15, MAANS14, QEST14, MTNS14, HAS14, HSCC14, ICCPS14, ICPSNA13, DCDS13, MED13, HSCC13, ADHS12, MED12, HSCC12, DCDS11, MED11, HSCC10.
Alessandro Abate is a member of IEEE (CSS society), ACM, IFAC, SIAM. He is further a member of Technical Committee on "Systems Biology" IEEE CSS, on "Hybrid Systems" IEEE CSS, on "Discrete Event and Hybrid Systems" (TC1.3) of IFAC, and on "Stochastic Systems" (TC1.4) of IFAC.
Dr. Abate has been successful in the acquisition as a PI of EU FP7 grants on topics related to this Marie Curie project, for instance the STREP project MoVeS, and the IAPP project AMBI.
Dr. Abate has helped teaching a class on "Modeling and Control of Hybrid Systems,"

TUDelft course SC4160, Semester 2, Quarter 3, in Delft, The Netherlands. He has supervised a host of MSc projects on the topic of this research.
Back from the USA, Dr. Abate has been embedded at TU Delft within a tenure-track system. He has recently accepted a position as Associate Professor at the University of Oxford, UK. He has thus fully re-integrated within the European research and academic environment.
More information can be found on the PI webpage:

http://www.dcsc.tudelft.nl/∼aabate

Dieky Adzkiya has taken part in a number of educational events, has presented most of the accepted articles at conferences, and has been additionally seconded to Honeywell Labs in Prague (CZ), in order to sharpen his professionalisation.

3.2.5 Reflection on goals and achievements

Deviations from Annex I

There have not been clear deviations from Annex I.
The emphasis on the computational aspects associated the theoretical studies, as discussed in the previous paragraph, has turned out to be a more important aspect than expected in Annex I. The development of the associated software is an important output of this new emphasis.

Reasons for failing to achieve critical objectives

There have been neither failures in achieving critical objectives, nor delays.

Corrective actions

Based on the above discussion, no corrective actions are deemed to be necessary.

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4 Explanation of the use of resources

The table in the following section provides an explanation of personnel costs, subcontracting and any major costs incurred, such as the purchase of important equipment, travel costs, large consumable items, etc., linking them to the performed work.

Beneficiary: TU Delft

Personnel, subcontracting and other major cost items for the Beneficiary, for the period 01-01-10 / 31-12-11

Item description	Amount in € with 2 decimals	Explanations
Personnel direct costs	32,555.17 €	Salary of the researcher
Personnel direct costs	62,216.01 €	Salary of a PhD student
Remaining direct costs	3,019.32 €	Travel costs
Remaining direct costs	3,178.46 €	Equipment costs
Remaining costs	135,225.06 €	Overhead

Total : 236,194.02 €

Personnel, subcontracting and other major cost items for the Beneficiary, for the period 01-01-12 / 31-12-13

Item description	Amount in € with 2 decimals	Explanations
Personnel direct costs	9,833.00 €	Salary of the researcher
Personnel direct costs	85,382.80 €	Salary of a PhD student
Remaining direct costs	5,112.68 €	Travel costs
Remaining direct costs	1,116.00 €	Equipment costs
Remaining costs	138,566.40 €	Overhead

Total : 240,010.88 €

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5 Financial statement

A financial statement (Form C) has been submitted along with this scientific report.

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