COOP-CT-2004-507981

WAPSCIENCE

WASTEWATER TREATMENT PLANT IMPROVEMENT BY SMART SENSORS AND COMPUTATIONAL INTELLIGENCE

Instrument:	Cooperative Research Project - CRAFT
Thematic Priority:	NA

Activity report

Period Covered: From 01.03.2006 to 26.10.2007	Date of Preparation: 29.11.07
Start date of the project: 27.10.2004	Duration: 36 months
Project Coordinator Name:	Prof. Michael Bongards
Project Coordinator Organisation Name:	Cologne University
	Revision 3

1. Project objectives, major achievements

1.1 Project objectives, current relation to state-of-the-art

The WAPSCIENCE project aims to develop an integrated solution that will improve the efficiency of municipal and industrial wastewater treatment plants at comparatively small costs. The project includes two developments. (1) The first refers to the development of a robust, smart, low-cost on-line-sensor for the measurement of the concentration of nitrate and ammonia in wastewater treatment plants (WWTPs). (2) The second refers to the development of a self-adaptive system to identify abnormal situations, predict critical states of the process and generate warnings about malfunctions of sensors and control-circuits.

1.1.1 Smart on-line Sensor

The development of low-cost sensor is based on ion selective electrodes (ISEs) which are currently being used successfully in many technological disciplines for different kind of purposes. Disciplines in which ISEs are mainly being used are environmental sciences, process technology, agriculture and medical sciences. Further ISEs are also being used in a lesser extent for the analysis of waste water. However wastewater is a very aggressive medium and one of the key problems in analyzing waste water with ISEs is membrane fouling.

Real time monitoring is hardly possible with sensors that are today on the market, because they are not protected against membrane fouling. Therefore contact between the sensor membranes and the waste water must be as short as possible. Often the sensors have to be cleaned with demineralized water or alcohol or a continuous automatic cleaning with pressed air is necessary. Even though these sensors are cleaned after every measurement, often the lifetime of these sensors is very short (6 weeks to six months).

1.1.2 Self-adaptive software-system

The development of a self-adaptive system is based on Computational Intelligence and aims to gain information about the present and future state of the plant. Basis for implementation are advanced methods like Artificial and Self Organising Neural Networks (ANNs and SONNs), Fuzzy Logic or statistical techniques. There combination allows identifying of abnormal situations, predicting critical states of the process and generating warnings on malfunctions of the sensors and control-circuits. Additionally the results can be used for implementation of predictive feedback-control.

Computational Intelligence (CI) is the generic term for computer-aided methods of knowledge processing i.e. Fuzzy-Control, Neural Networks and Genetic Algorithms. Mainly the first two of these methods are used in wastewater treatment plant.

Neural Networks optimise control-tasks with their autonomous self learning ability. They are able to learn the behaviour of highly non-linear multi-parameter processes based on training examples without human programming-efforts. Further they possess a high error tolerance towards unknown situations so that process-states that were not trained can be predicted reliable. Neuronal Networks have been used in wastewater technology to test and verify measured data (Haeck et al., 1998; Hansen et al., 1999), or to estimate substitute values that can't be measured during failure or calibration of the sensors (Haeck et al. 1999).

Fuzzy Control is the second CI-tool that has been used successfully in wastewater treatment (Baumann 2001). The method is able to convert human knowledge into rule-based control strategies. „If - then - Rules“ designed by engineers or operators are compiled directly into control algorithms. Further these rules can be generated automatically or manually by analysis of process-data or by experiments with simulation models.

Additionally to the CI methods also multivariate statistical methods like PCA (principle component analysis) gained more attention in process industries over the past decade – as evident by the large number of publications in this area. See for example: Albazzaz et al. (2005), Chena et al. (2004), Krueger et al. (2004), and Kourti et al (1995).

PCA in combination with outlier detection algorithms allows identifying the abnormal situations in the data sets.

1.2 Take-up recommendations from previous reviews

N.A.

1.3 Objectives for reporting period, major achievements

1.3.1 Development / Test of a smart on-line sensor

- Referring to the software problems indicated in the first activity report, some parts of sensor software has been redesign and improved.

- Due to problems with Sensor production caused by the change of supplier the production process has been redesign and improved by reducing production costs. During the redesign process some difficulties with production quality has been detected and solved. However the problems lead to delay of the project.

- 5 Sensor units for field tests has been produced and delivered to Partners (Eudig, Anord, Questor, Technor, UniCologne)

- A plan for the field test has been developed. The plan includes instructions for measurements and sensor calibration tests. The goal is to identify limitations and potentials of the sensor unit in different European countries, where the environmental conditions are very different.

- Sensors has been installed and tested by partners on different wastewater treatment plans in different European countries (Germany, Ireland, Greece)

- Test arrangement for laboratory tests with artificial wastewater has been designed and build by RTD partner Questor.

- A plan for tests with artificial wastewater has been developed and executed by RTD partner Questor.

1.3.2 Development / Test of the self-adaptive software-system

- Referring to the first activity report some modules of self adaptive software – system has been adapted to the requirements of the project tasks (such as handling with sensor errors, etc.)

- Different laboratory tests have been made with software system to analyse the accuracy of prediction respectively identification of faults and changes in process behaviour.

- Different proceedings have been developed to improve the accuracy of the results.
- Long time - laboratory tests of software system in combination with sensor have been made.
- A plan for field test of the software system in combination with sensor has been developed.
- The software has been tested with data gained from sensor field tests of different installations by various partners as Uni Cologne, Uni Siegen, CTI.
- The software has been tested in a field test installation on a wastewater treatment plant.

1.4 Comments of most important problems

- During the reporting period a problem with sensor production has been occurred. SME-partner Hydrion had to change the producer of their sensors. The first sensors build by the new producer had different failures which were based on bad quality of the production. Hydrion has working hard on the solution of the problem and redesign completely the production process. The quality problem could be solved and additionally a reduction of production costs has been achieved. However the occurred problems resulted in a delay of the project. Therefore prolongation of the project has been requested and was accepted by European Commission.
- In February 2007 SME partner and project coordinator Eudig declared bankruptcy. This leads to a temporary stop of the project activities and a loss of a part of project funding. After the problem has been discussed in a meeting with representatives of EC in Brussels the partners agreed to continue the project. Anyway the loss of time has required a second prolongation of project, which has been requested and accepted by EC. Further the circumstances made it necessary to reschedule the project time-table to reach the project aims with the reduced time and without the former coordinatorEudig.

2. Workpackage progress (for each WP)

2.1 Previous reporting period

Workpackage number	WP1. Development of a smart on-line sensor			**Start date or starting event:**				27.10.04
Participant Short Name	Eudig	Hydrion	Anord	Technor	Uni Cologne	Uni - Siegen	Ques-tor	CTI
Person-months per participant:	4	12	-	-	9	-	-	-

Objectives:

To build a robust, real-time, low cost multi-sensor device for the analysis of ammonia and nitrate in wastewater.

Progress towards objectives, achievements:

Development of the sensor is completed.

Deviation from workprogramme, corrective actions:

Indicated problems in the previous report has been solved

Deliverables:

D1:

Report on the development of the smart on-line sensor unit Sensor with integrated electronics and digital USB-interface (already published).

D2:

Public executive summary report on the smart on-line sensor (already published)

Milestones and expected result:

M1:
Robust multi-sensor device

Workpackage number	WP2. Development of the self-adaptive software-system			**Start date or starting event:**			27.10.04
Participant Short Name	Eudig	Hydrion	Anord	Technor	Uni Cologne	Uni - Siegen	Ques-tor	CTI
Person-months per participant:	5	-	-	-	7	0	-	11

Objectives:
Based on methods of computational intelligence, a self adaptive software system using Artificial Neural Networks (ANNs) will be developed to identify abnormal situations, predict critical states of the process and generate warnings about malfunctions of the sensors and control-system.

Progress towards objectives, achievements:
The development of self adaptive system is completed.

Deviation from workprogramme, corrective actions:

Deliverables

D3:

Software Prototype and Report on the development of the self-adaptive software-system. (already published)

D3a:

Software Prototype and User Manual of a complete suite for prediction, fault diagnosis, data assurance and integrity based on Self Organising Networks (SONNs)

D4:

Public executive summary report on the self adaptive software system. (already published)

Milestones and expected result:

M2:
Prototype of the Self-adaptive Software system.

Workpackage number	WP3 - System Integration			**Start date or starting event:**			27.07.05
Participant Short Name	Eudig	Hydrion	Anord	Technor	Uni Cologne	Uni - Siegen	Ques-tor	CTI
Person-months per participant:	9	-	-	-	4	0	-	-

Objectives:

Integration of the predictive software into the SCADA-Software.

Progress towards objectives, achievements:

The developments on Integration of the predictive software into the SCADA-Software have been completed.

Deviation from workprogramme, corrective actions:

Deliverables:

D5:

Report on System Integration. (already published)

D6:

Public executive summary report on System Integration. (already published)

Milestones and expected result:

M3:
Integrated Self-adaptive Software system as element of a SCADA.

2.2 Current reporting period

Workpackage number	WP4 - Optimisation and test of sensors and algorithms in WWTPs	**Start date or starting event:**	27.10.05

Participant Short Name	Eudig	Hydrion	Anord	Technor	Uni Cologne	Uni - Siegen	Ques-tor	CTI
Person-months per participant:	16	3	6,5	14	24,2	19	4,7	6,1

Objectives:

To test and refine the operating prototype of ion sensitive sensors in combination with the self-adaptive software in WWTP in three European countries.

Progress towards objectives, achievements:

Sensor development:

- 5 Sensor units for field tests has been produced an delivered to Partners (Eudig, Anord, Questor, Technor, UniCologne)
- A plan for the field test has been developed. The plan includes instructions for measurements and sensor calibration tests. The goal is to identify limitations and potentials of the sensor unit in different European countries, where the environmental conditions are very different.
- Sensors have been installed and tested on wastewater treatment plants in different EU countries. (German, Ireland, Greece - Overall 7 different installations).

Self adaptive software system

- Different tests have been made with software system to analyse the accuracy of prediction respectively identification of faults and changes in process behaviour.
- Different proceedings have been developed to improve the accuracy of the results.
- Long time - laboratory tests of software system in combination with sensor have been made.
- The software has been tested with data gained from sensor field tests of different partners by various partners.
- The software has been tested in a field test installation on a wastewater treatment plant.

Sensor tests with artificial wasterwater

- Test arrangement for laboratory tests with artificial wastewater has been designed and build.
- A plan for tests with artificial wastewater has been developed and executed.

Deviation from workprogramme, corrective actions:

- Due to problems with Sensor production caused by the change of supplier the production process has been redesign and improved by reducing production costs. During the redesign process some difficulties with production quality has been detected and solved. However the problems lead to delay of the project. Corrective actions: a prolongation of the project has been requested and accepted later by European Commission
- Due to the bankruptcy of Eudig a second prolongation has been requested and accepted by European Commission. Further the circumstances made necessary to reschedule proceeding to reach the project aims with reduced time.

Deliverables:

D7:

Report on optimisation and test of sensors and algorithms in WWTPs.

D8:

Public executive summary report on optimisation and test of sensor and algorithms.

Milestones and expected result:

M4:
The final prototype.

Workpackage number	Wp5. Evaluation of achievements and preparation of technical documentation			**Start date or starting event:**			27.08.06	
Participant Short Name	Eudig	Hydrion	Anord	Technor	Uni Cologne	Uni - Siegen	Ques-tor	CTI
Person-months per participant:	0	0,5	0,5	0,5	1	0,5	0,5	0,7

Objectives:

To evaluate the developed system based on the results of tests in the previous work packages and prepare the final documentation.

Progress towards objectives, achievements:

- Final documentation has been developed in close cooperation of all partners.

Deviation from workprogramme, corrective actions:

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Deliverables

D9:

Report on evaluation achievements.

D10:

Public executive summary report on evaluation achievements.

Milestones and expected result:

M5:
Final documentation.

Workpackage number	Wp6. Project management	**Start date or starting event:**	27.10.04

Participant Short Name	Eudig	Hydrion	Anord	Technor	Uni Cologne	Uni - Siegen	Ques-tor	CTI
Person-months per participant:	2	0,5	0,5	0,5	1	0,3	0,3	0,9

Objectives:

To manage the project including work progress and allocation of resources monitoring, coordination of the partners, aggregation of results.

Progress towards objectives, achievements:

During the project regular meetings have been held.

For better information exchange website with an internal achieve has been operated over the whole project time to give the partners the access to up-to-date information's relating to the project.

For important milestones responsible partners has been identified. Such partners were responsible for achievement of the milestones.

Periodical progress state reports have been collected by project coordinator.

Deviation from workprogramme, corrective actions:

Deliverables

D11:

Project Management Reports

D12:

Plan for using and dissemination of knowledge.

Milestones and expected result:

2.4 List of deliverables

Del. No.	Deliverable name	Work package no.	Date due	Actual/Forecast delivery date	Estimated indicative person-months *)	Used indicative person-months *)	Lead contractor
D1	Smart on-line sensor	WP1	09.12.05	09.12.05	25	25	Hydrion
D2	Smart on-line sensor executive summary report	WP1	09.12.05	09.12.05	--	--	Hydrion
D3, D3a	Self-adaptive Software system	WP2	09.12.05	09.12.05	29	23	Uni Cologne and CTI
D4	Self-adaptive Software system executive summary report	WP2	09.12.05	09.12.05	--	--	Uni Cologne and CTI
D5	System Integration	WP3	09.12.05	09.12.05	15	13	Eudig
D6	System Integration executive summary report	WP3	09.12.05	09.12.05	--	--	Eudig
D7	Optimisation and test of sensors and algorithms	WP4	09.12.07	09.12.07	46,5	93,3	Uni Cologne
D8	Optimisation and test of sensors and algorithms executive summary report	WP4	09.12.07	09.12.07	--	--	Uni Cologne
D9	Evaluation of achievements	WP5	09.12.07	09.12.07	8	4,2	Uni Cologne

2.5 List of milestones

Milestone no.	Milestone name	Workpackage no.	Date due	Actual/Forecast delivery date	Lead contractor
M1	Robust multi-sensor device	WP1	27.10.05	27.10.05	Hydion
M2	Prototype of the Self-adaptive Software system	WP2	27.07.05	27.07.05	Uni Cologne
M3	Integrated Self-adaptive Software system as element of a SCADA-software	WP3	27.10.05	27.10.05	Uni Cologne and CTI
M4	The final prototype	WP4	26.10.07	26.10.07	Uni Cologne
M5	Final documentation	WP5	26.10.07	26.10.07	Uni Cologne

3. Consortium management

3.1 Management tasks, achievements and problems

In February 2007 SME partner and project coordinator Eudig has declared bankruptcy. This leads to a temporary stop of the project activities and a loss of a part of project funding. After the problem has been discussed in a meeting with representatives of EC in Brussels partners agreed to continue the project while Eudig has been excluded from the project. The circumstances made necessary to reschedule proceeding to reach the project aims with reduced funding and time. Further this leads to changes of technical Annex 1 and consortium agreement where Uni Cologne has been chosen as a new project coordinator. Both documents have been submitted to the technical and financial project-officers of the EC.

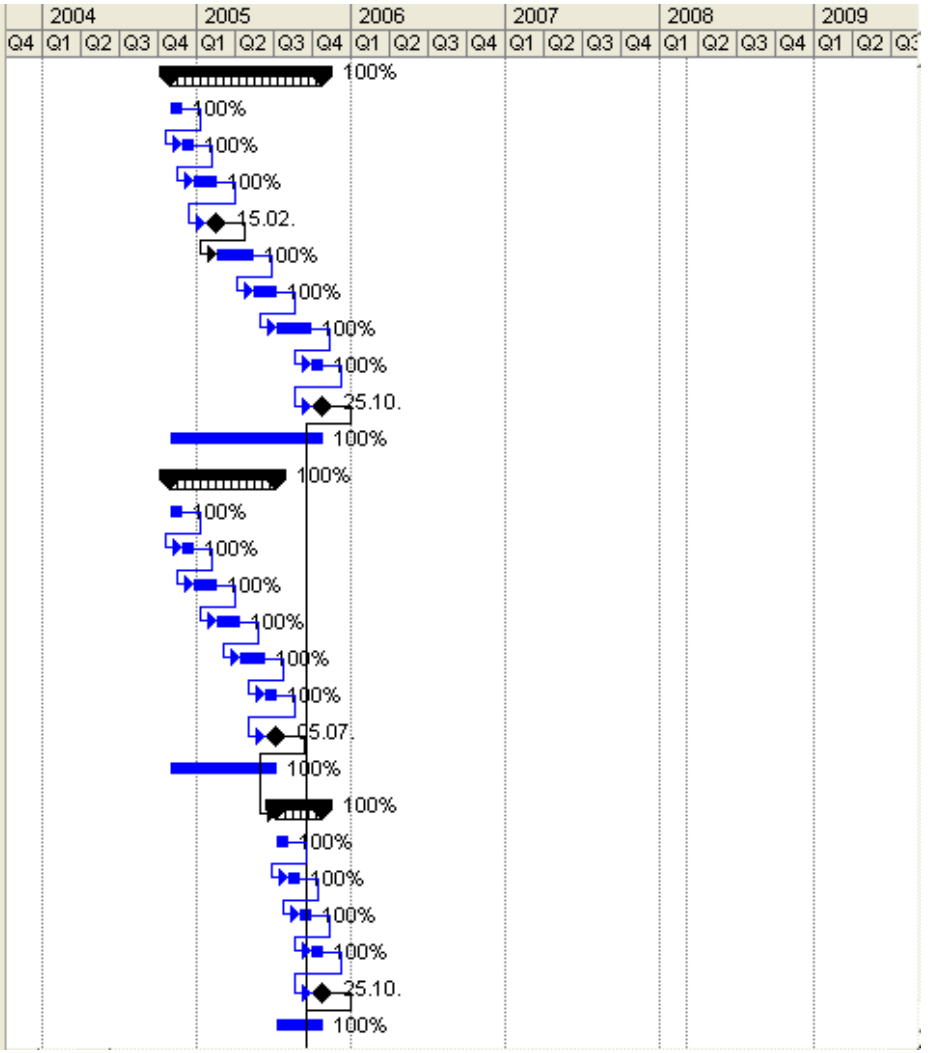
3.2 Contributions and responsibilities of contractors

Referring to first period reports responsibility of the Uni Siegen has been changed. Due to this situation some parts of EC funding scheduled to Uni Siegen has been assigned to Uni Cologne. Both parties agree with this transfer.
By this reassignement the Uni Cologne will investigate more time in tests scheduled for WP4

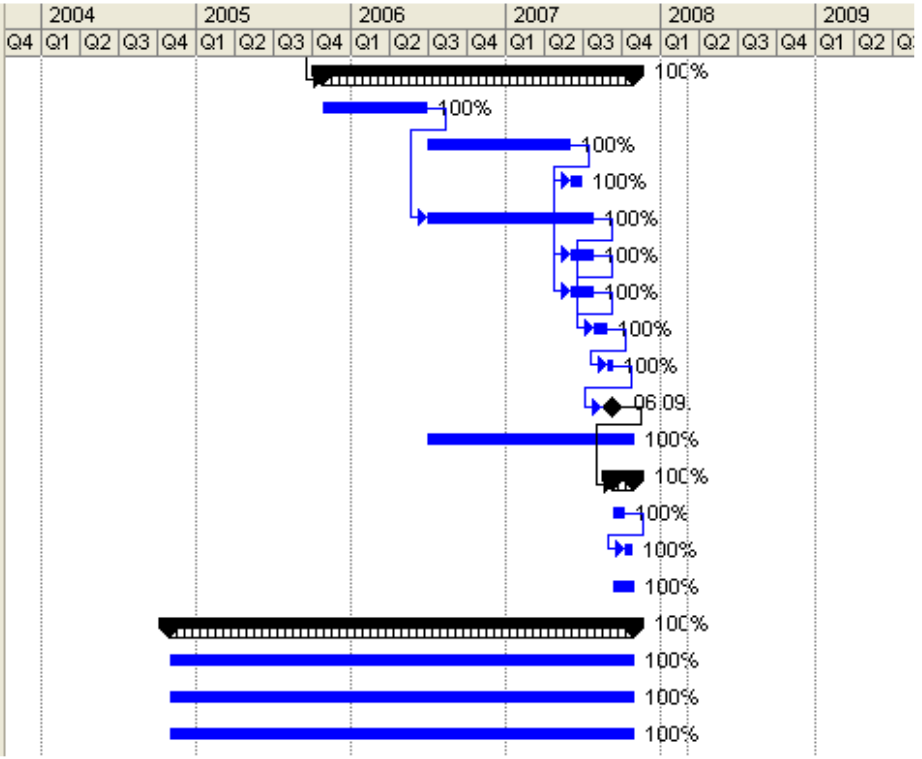
After the exclusion of Eudig from the project the responsibilities of Eudig concerning management activities have been taken over by the Uni Cologne. Technical activities have been continued by a cooperation of Uni Cologne and Uni Siegen.

3.3 Project timetable and status Table

	Vorgangsname	Dauer	Anfang	Ende
1	**WP1: Development of a Smart on-line**	**260 Tage**	**Mi 27.10.04**	**Di 25.10.05**
2	Analysis State of the art-smart senso	4 Wochen	Mi 27.10.04	Di 23.11.04
3	Requirements and specifications	4 Wochen	Mi 24.11.04	Di 21.12.04
4	Development of a robus multi-sensor	8 Wochen	Mi 22.12.04	Di 15.02.05
5	MileStone: robust multi-sensor device	0 Tage	Di 15.02.05	Di 15.02.05
6	Laboratory Test of a robust multi-sen:	12 Wochen	Mi 16.02.05	Di 10.05.05
7	Software development for the sensor	8 Wochen	Mi 11.05.05	Di 05.07.05
8	Test of the smart sensor - unit - proto	12 Wochen	Mi 06.07.05	Di 27.09.05
9	Documentation	4 Wochen	Mi 28.09.05	Di 25.10.05
10	Milestone: Smart sensor unit working	0 Tage	Di 25.10.05	Di 25.10.05
11	Report	52 Wochen	Mi 27.10.04	Di 25.10.05
12	**WP2: Development of the self - adapt**	**180 Tage**	**Mi 27.10.04**	**Di 05.07.05**
13	Analysis of the state of the art	4 Wochen	Mi 27.10.04	Di 23.11.04
14	Requirements and spezifications	4 Wochen	Mi 24.11.04	Di 21.12.04
15	Design and Implementation	8 Wochen	Mi 22.12.04	Di 15.02.05
16	Graphical User Interface	8 Wochen	Mi 16.02.05	Di 12.04.05
17	Test of the Software	8 Wochen	Mi 13.04.05	Di 07.06.05
18	Documentation	4 Wochen	Mi 08.06.05	Di 05.07.05
19	Milestone: Prototype of Software-Moc	0 Tage	Di 05.07.05	Di 05.07.05
20	Report	180 Tage	Mi 27.10.04	Di 05.07.05
21	**WP3: System Integration**	**80 Tage**	**Mi 06.07.05**	**Di 25.10.05**
22	Interface Implementation	4 Wochen	Mi 06.07.05	Di 02.08.05
23	Reduced Version	4 Wochen	Mi 03.08.05	Di 30.08.05
24	Full Version	4 Wochen	Mi 31.08.05	Di 27.09.05
25	User Manual	4 Wochen	Mi 28.09.05	Di 25.10.05
26	Milestone: Integrated system as eleme	0 Tage	Di 25.10.05	Di 25.10.05
27	Report	16 Wochen	Mi 06.07.05	Di 25.10.05



	Vorgangsname	Dauer	Anfang	Ende
28	**WP4:Optimisation and test of sensor**	**523 Tage**	**Mi 26.10.05**	**Fr 26.10.07**
29	Optimisation of production process	35 Wochen	Mi 26.10.05	Di 27.06.06
30	Delay (caused by insolvency of Eudig	48,4 Wochen	Mi 28.06.06	Do 31.05.07
31	Test with artifical wastewater	4 Wochen	Fr 01.06.07	Do 28.06.07
32	Field Test - German WWTPs and rede	56,4 Wochen	Mi 28.06.06	Do 26.07.07
33	Field Test - Irish WWTPs and redesigr	8 Wochen	Fr 01.06.07	Do 26.07.07
34	Field Test - Greece WWTPs and rede:	8 Wochen	Fr 01.06.07	Do 26.07.07
35	Prototype adaption and upgrading	4 Wochen	Fr 27.07.07	Do 23.08.07
36	User Training	2 Wochen	Fr 24.08.07	Do 06.09.07
37	Milestone: Tested and optimised syste	0 Tage	Do 06.09.07	Do 06.09.07
38	Report	348 Tage	Mi 28.06.06	Fr 26.10.07
39	**WP5: Evaluation of archievements an**	**36 Tage**	**Fr 07.09.07**	**Fr 26.10.07**
40	Preparation of technical documentatio	4 Wochen	Fr 07.09.07	Do 04.10.07
41	Evaluation of archievements	3 Wochen	Fr 05.10.07	Do 25.10.07
42	Report	36 Tage	Fr 07.09.07	Fr 26.10.07
43	**WP6: Managment**	**783 Tage?**	**Mi 27.10.04**	**Fr 26.10.07**
44	Meetings	783 Tage	Mi 27.10.04	Fr 26.10.07
45	Ongoing Project Managment	783 Tage?	Mi 27.10.04	Fr 26.10.07
46	Coordination of preparatory measures	783 Tage?	Mi 27.10.04	Fr 26.10.07



3.4 Coordination activities, Meetings

During the third project period following meetings have taken place:

25 November 2005	Midterm Meeting in Haiger, Germany hosted by Eudig
12 July 2006	Project progress meeting in Athens, Greece hosted by CTI
23 May 2007	Consortium meeting with representatives of EC in Brussels
24 October 2007	Final project meeting in Belfast, hosted by Questor

4. Other issues

Projects which were subject to requirements and/or recommendations concerning ethical issues
N.a.