Systems and Control

3TU.Federation (Delft University of Technology,
Eindhoven University of Technology,
University of Twente)

QANU, July 2012

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This report was finalized on 12 July 2012.

Report on the master's programme Systems and Control of the 3TU.Federation

This report takes the NVAO's Assessment Framework for Limited Programme Assessments as a starting point.

Administrative data regarding the programme

Master's programme Systems and Control

Name of the programme:	Systems and Control
CROHO number:	60359
Level of the programme:	master's
Orientation of the programme:	academic
Number of credits:	120 EC
Specializations or tracks:	
Location(s):	Delft, Eindhoven, Enschede
Mode(s) of study:	full time
Expiration of accreditation:	TUD: 31-12-2013; TU/e: 18-04-2013; UT: 18-04-2013

The visit of the assessment committee Systems and Control to the 3TU.Federation (Delft University of Technology, Eindhoven University of Technology, University of Twente) took place on April 12th and 13th 2012.

Administrative data regarding the institution

Name of the institution:	3TU.Federation (Delft University of Technology, Eindhoven University of Technology, University of Twente)[1]
Status of the institution:	publicly funded institution
Result institutional quality assurance assessment:	TUD has passed the institutional assessment. At TU/e and UT the result is pending.

Quantitative data regarding the programme

The required quantitative data regarding the programme are included in Appendix 5.

[1] The 3TU construction and organisational context of the programme are elucidated on p. 11.

Composition of the assessment committee

The committee that assessed the master's programme Systems and Control consisted of:

- Prof. J. (Joos) Vandewallle (chair), professor at the Department of Electrical Engineering (ESAT) of the University of Leuven (Belgium);
- Prof. J.C. (Jan) Willems, emeritus professor of Systems and Control at University of Groningen and visiting professor of the research group Signals, Identification, System Theory and Automation (SISTA) at the Department of Electrotechnical Engineering (ESAT) at University of Leuven (Belgium);
- F.B. (Frank) Sperling, technical director of Nobleo (technical consultancy) and Senior Technologist at Philips Innovation Services;
- Prof. R.K. (René) Boel, emeritus professor at the School of Engineering, University of Gent (Belgium);
- J. (Jasper) Boomer, MSc student of Industrial Engineering & Management at University of Groningen.

The committee was supported by Daan de Lange MA, who acted as secretary.

Appendix 1 contains the CVs of the members of the committee.

Working method of the assessment committee

Preparation
QANU received the self-evaluation report of the master's programme Systems and Control. After having established that the report fulfilled the criteria of relevance and completeness, the project leader distributed it and the additional information among the members of the assessment committee. The committee members were asked to formulate their remarks, comments and questions regarding the self-evaluation report and the additional documents prior to the site visit.

In addition to the self-assessment report, each committee member received three recent theses. In consultation with the chair, it was decided that the selection of theses should cover the full range of marks given. The committee members also received QANU's checklist for the assessment of theses to ensure that their assessments were comparable. Since the committee had to evaluate a programme leading to a scientific degree (MSc), it paid specific attention to the scientific level of the theses, requirements, accuracy of judgment by the reviewer and the assessment procedure used.

The project leader drafted a programme for the site visit. This was discussed with the chair of the committee and the coordinator of the programme. As requested by QANU, the coordinator of the programme carefully composed and selected representative panels. Before the site visit, both staff members and students were informed about the opportunity to speak to the committee confidentially during the 'consultation hour'. No requests were received for the consultation hour.

Site visit
The site visit took place on April 12th and 13th 2012. It started with a preparatory committee meeting, in which the committee members were instructed on their task, as well as on the

structure of the accreditation system and the Assessment Framework for Limited Programme Assessments of the NVAO. The committee members discussed their findings based on the self-evaluation report they had received prior to the site visit. They also debated their task, working methods and the questions and issues to be raised in the interviews with representatives of the programme and other stakeholders. During the site visit, the committee conducted interviews with the programme management, students, staff members, graduates, members of the Education Committee, the Board of Examiners and student advisors. They also studied further materials made available by the programme, including study material, exams, assignments and other assessments.

After the concluding meeting with the management on the final day of the site visit, the committee members extensively discussed their assessment of the programme and prepared a preliminary report. The site visit concluded with a presentation of the preliminary findings by the chairman. This presentation consisted of a general assessment and several specific findings and impressions of the programme, as well as some recommendations. The schedule of the site visit is included in appendix 6.

Report
After the site visit, the secretary produced a draft version of the report on the programme and presented it to the members of the committee. Subsequently, the secretary processed corrections, remarks and suggestions for improvement provided by the committee members to produce the revised report. This was then sent to the 3TU.Federation to check for factual errors, inaccuracies and inconsistencies. Comments and suggestions provided by the 3TU were discussed with the chair of the assessment committee and, where necessary, with the other committee members. Based on the committee's decisions to incorporate or ignore comments and suggestions, the secretary compiled the final version of the programme report.

Decision rules
In accordance with the NVAO's Assessment Framework for Limited Programme Assessments (as of November 22nd 2011), the committee used the following definitions for the assessment of both the standards and the programme as a whole.

Generic quality
The quality that can reasonably be expected in an international perspective from a higher education bachelor's or master's programme.

Unsatisfactory
The programme does not meet the current generic quality standards and shows serious shortcomings in several areas.

Satisfactory
The programme meets the current generic quality standards and shows an acceptable level across its entire spectrum.

Good
The programme systematically surpasses the current generic quality standards across its entire spectrum.

Excellent
The programme systematically surpasses the current generic quality standards well across its entire spectrum and is regarded as a national/international example.

Summary judgement

This report reflects the assessment committee's findings and considerations on the 3TU.Federation's master's programme in Systems and Control (S&C) at Delft University of Technology (TUD), Eindhoven University of Technology (TU/e) and the University of Twente (UT). The evaluation of the committee is based on information provided in the self-evaluation report, the selected theses, additional documentation provided during the site visit and interviews conducted with staff, students and graduates of the programme. During its assessment, the committee observed positive aspects as well as aspects which could be amended. Taking these aspects into consideration, the committee decided that the programme fulfils the requirements set by the NVAO for accreditation.

Standard 1: Intended learning outcomes
The field of Systems and Control is concerned with problems related to dynamic phenomena in interaction with their environment. The objective of the master's programme S&C is to bring together students from a variety of backgrounds in engineering in order to study both S&C theory and the engineering aspects of dynamic systems in a wide range of application areas. Its principal idea is that S&C should be approached from three generic themes: identification, modelling and control. These themes constitute the underlying concept of the 'systems thinking' philosophy, which is of fundamental importance for many technological fields. The programme has a strong multidisciplinary character. It aims at a common theoretical foundation (the model-based design paradigm), from which students can specialise among a large number of application areas and local orientations. Its objectives are oriented towards both scientific research and applications in an industrial context. The programme therefore strives to achieve a balance of academic and professional field competences.

The committee established that the intended learning outcomes meet the demands of a university-level master's programme. They correspond to internationally accepted descriptions of a S&C master's programme and cover the aim to enable students to acquire both scientific and professional skills, paying attention to a profound knowledge of the engineering sciences, the effective use of that knowledge, fundamental research skills, communicative skills and academic and intellectual reflection. The committee concludes that the programme provides graduates with a solid foundation, qualifying them for a career in their field of specialization. The multidisciplinary character and the abstraction level it requires, clearly meet the complex demands of the S&C field and can rightfully be considered a unique selling point. The programme strives to achieve a very high theoretical level along with practical competences and experience. In this respect, the programme surpasses the current generic quality standards. The committee assesses the first standard as 'good'.

Standard 2: Teaching-learning environment
The Systems and Control programme has a workload of 120 EC and consists of a combination of a common core curriculum and local specialisations. The core courses are compulsory and make up 24 EC of the first year. In addition, students take electives and a specialization part which prepare them for their internship and graduation project in the second year. The design of the curriculum is clear and cohesive. Its components are structured in such a way that they cover a very wide range of applications and orientations from one integrating paradigm. In doing so, the curriculum succeeds in creating interdisciplinarity, which is vital to the academic master level. The programme ensures a progressive integration of theoretical knowledge and practical skills. Students are given the opportunity to carry out final projects in inspiring research groups and excellent facilities. The laboratory infrastructure can be called impressive.

The committee highly values the design, implementation and organisation of the teaching-learning environment. It concludes that the programme demonstrates a good balance between theory, practical work, and research and design projects. It pays attention to the use of knowledge of the engineering sciences, research skills, and professional competences. The academic environment in which S&C students work is very inspiring, internationally oriented, and provides constant interaction between education, research and design. As such, the programme offers a very solid and scientifically grounded preparation for the professional field as well as for a scientific career. The committee concludes that the core courses have an excellent level that should enable students to achieve the intended learning outcomes. However, considering that the most difficult part for many students is the abstraction level required for the theoretical foundation of the programme, as well as the linking of this abstraction level to practical designs, the management should consider extending the core programme at the expense of the elective part.

The committee recognises the staff's scientific quality, national and international academic reputation and teaching experience. The assignment-based didactical approach stimulates the students' creativity, which is essential to a high-quality engineering education. With regard to 3TU cooperation however, improvements could be made. The committee recommends investing in better IT solutions to share course material and create virtual classrooms, in order to stimulate synergy between the locations. Another point of attention is the staff-student ratio, which seems to be decreasing. Still, the committee has the opinion that the S&C programme can be considered an international best practice as an appealing interdisciplinary programme.

Standard 3: Assessment and achieved learning outcomes
The committee concludes that the programme uses a reasonable mix of assessments, with a balance between theory and application, although since the programme is mostly assignment-based, 3TU may consider focussing a bit more on the latter. The Examination Committees use different instruments to guarantee the quality of the examinations. During the site visit, several plans were presented regarding the harmonization of assessment procedures and the use of common assessment forms. Especially with regard to the theses, the committee believes that these plans have to be put into practice as soon as possible. The committee recommends that the Examination Committees play a proactive role in harmonizing and implementing the assessment policies. With regard to the thesis evaluation forms, best practices should be discussed in order to create a common one.

The level of the thesis reports studied by the committee differed considerably. Some of them were excellent, but on more than one occasion the committee found them rather marginal. Regarding the fact that graduation projects have a workload of at least 40 EC, the committee would expect the thesis reports to have a bit more body. Still, it concludes that the intended learning outcomes are achieved. The level of the graduation projects is satisfactory and graduates easily find work within the professional field, where they perform to everyone's satisfaction.

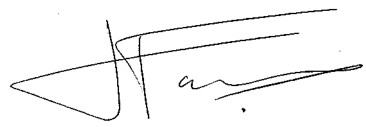
The committee assesses the standards from the Assessment Framework for Limited Programme Assessments in the following way:

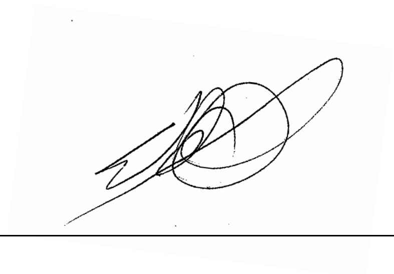
Standard 1: Intended learning outcomes	**good**
Standard 2: Teaching-learning environment	**excellent**
Standard 3: Assessment and achieved learning outcomes	**satisfactory**

General conclusion **satisfactory**

The chair and the secretary of the committee hereby declare that all members of the committee have studied this report and that they agree with the judgments laid down in the report. They confirm that the assessment has been conducted in accordance with the demands relating to independence.

Date: 12 July 2012





Prof. Joos Vandewallle

Daan de Lange, MA

Description of the standards from the Assessment Framework for Limited Programme Assessments

Organisational context of the programme: 3TU.Federation

In 2003 the Delft University of Technology (TUD), Eindhoven University of Technology (TU/e) and the University of Twente (UT) joined forces in the 3TU.Federation. This federation aims to promote innovation by combining and concentrating the three universities' strengths in research, education and knowledge transfer. As a result, five joint master's programmes were developed. The master's programme in Systems and Control (S&C) is one of them.

The start of the master's programme in Systems and Control was closely linked to the establishment of the Delft Center for Systems and Control (DCSC) in 2003 and the merger of three former Systems and Control groups within TUD. The S&C programme has been offered by the 3TU.Federation since 2007 at all three locations. The 3TU.Federation has an Education Board, which is in charge of the 3TU cooperation with regard to educational matters. The Education Board consists of members of the Executive Boards responsible for education at the three institutions. The education branch of the 3TU.Federation has established several groups in which the three universities cooperate, covering quality assurance and accreditation, internationalisation, ICT, multimedia facilities and educational pathways.

For the S&C programme specifically, there is a 3TU Coordination Group which supports the 3TU.Education in matters requiring formal harmonisation procedures (e.g. tuition fees, lecture schedules, rules and regulations) and the informal exchange of information and experiences. It consists of S&C administrative staff members from the three technical universities. The programme has installed joint platforms for the Programme Directors, Examination Committees, Admission Committees and Education Committees. Operational responsibility for the implementation of the programme and daily matters lies with the Programme Directors of the three programmes. The S&C courses are provided by staff members from the various faculties.

The Master's degree programme in Systems and Control constitutes a step towards the formation of a joint 3TU Graduate School within The Dutch Institute of Systems and Control (DISC). This interuniversity research institute unites academic groups in the Netherlands that are active in S&C theory and engineering. It offers a nationally organised graduate programme for PhD students in this field. The MSc programme positions itself ambitiously as a top quality programme. As such, it is expected to attract top-ranking students from around the world.

Formally, the S&C MSc programmes at the three locations are independent programmes with a high level of collaboration. Every location has its own board of examiners, education committee and student association(s). Together with NVAO (Accreditation Organisation of the Netherlands and Flanders), a procedure was developed for reaccreditation of all 3TU MSc programmes. The three local programmes have produced one joint self-evaluation report. The assessment procedure is treated as if it concerns one programme. The committee assessed the programmes during one site visit and presents its results in a single report. The assessment of each standard is valid for the three locations. If any differences between them were observed, this is mentioned in the report.

Standard 1: Intended learning outcomes

The intended learning outcomes of the programme have been concretised with regard to content, level and orientation; they meet international requirements.

Explanation:
As for level and orientation (bachelor's or master's; professional or academic), the intended learning outcomes fit into the Dutch qualifications framework. In addition, they tie in with the international perspective of the requirements currently set by the professional field and the discipline with regard to the contents of the programme.

1.1 Findings

The field of Systems and Control is concerned with problems related to dynamic phenomena in interaction with their environment. It covers many aspects of our modern lives, ranging from the manufacturing and semiconductor industries, infrastructure management, transportation, communications and logistics, energy generation and distribution to the medical profession and the family household. According to the self-evaluation report, the world increasingly depends on this field of expertise, as it becomes more and more automated and guided by technology. The programme thus anticipates a growing need for top-quality control engineers and researchers with education on an academic master level.

The objective of the MSc programme is to bring together students from a variety of backgrounds in engineering in order to study S&C theory, as well as the engineering aspects of dynamic systems in a wide range of application areas. The programme is directed towards the analysis and design of reliable and high-performance measurement, estimation and control strategies for technological, dynamic processes. Its principal idea is that the S&C field should be approached from three generic themes: identification, modelling and control. These themes constitute the underlying concept of the 'systems thinking' philosophy, which is of fundamental importance for many technological fields. The programme has a strong multidisciplinary character. It aims at a common theoretical foundation (the model-based design paradigm), from which students can specialise among a large number of application areas and local orientations. Its objectives are oriented towards both scientific research and applications in an industrial context. The programme therefore strives to achieve a balance of academic and professional field competences.

The goals have been concretized into twelve learning outcomes. They are listed in the Teaching and Examination Regulations (TER), which are the same for all three locations. Like all 3TU programmes, the S&C programme has arranged its learning outcomes along the lines of seven "Meijers' criteria". These criteria are broad competences that cover the Dublin descriptors in a more detailed way and constitute a domain-specific framework of reference which is equivalent to the Dutch Qualification Framework. Appendix 3 shows how the Meijers' criteria have been translated into the following learning outcomes:

1. Graduates have both a broad and profound knowledge of the basic engineering sciences (electrical engineering, mechanical engineering, applied physics, applied mathematics).
2. Graduates have the skills needed to use their knowledge effectively. The discipline is mastered at various levels of abstraction, including a reflective understanding of its structure and relations to other fields, covering in part the forefront of scientific or industrial research and development.
3. Graduates have the capability to apply knowledge at an advanced level within the discipline of systems and control engineering.
4. Graduates have both a broad and profound scientific and technical knowledge of the discipline of systems and control engineering. This knowledge forms the basis for

innovative contributions to the discipline in the form of new designs or the development of new knowledge.

5. Graduates have a thorough knowledge of the paradigms, methods and tools, as well as the skills needed for the active application of this knowledge for analysing, modelling, simulating, designing and performing research with respect to innovative, technological, dynamic systems, taking into account the various application areas.
6. Graduates have the capability to manage scientific research independently.
7. Graduates are able to solve technological problems in a systematic way involving problem analysis, formulating sub-problems and providing innovative technical solutions. This includes a professional attitude towards identifying and acquiring any missing expertise, monitoring and critically evaluating existing knowledge (or knowledge that is in development), planning and executing research, adapting to changing circumstances, and integrating new knowledge while considering its ambiguity, incompleteness and limitations.
8. Graduates have the attitude needed to maintain professional competence independently through lifelong learning.
9. Graduates have the capability needed to work both independently and in multidisciplinary teams, interacting effectively with specialists and taking initiatives where necessary.
10. Graduates have the capability to communicate effectively (including presenting and reporting) about their work with a professional public in English.
11. Graduates have the capability to communicate effectively (including presenting and reporting) about their work with a non-specialised public in English.
12. Graduates have the capability to evaluate and assess the technological, ethical and societal impact of their work, and to take responsibility with regard to sustainability, the economy and social welfare.

The committee established that the learning outcomes are clearly related to the interdisciplinary character the S&C programme is aiming at. It also established that they reflect both the professional and scientific orientation of the programme. Within the programme the students apparently experience a positive balance between the theoretical and practical orientation. During the site visit the programme management explained that it does intend to stimulate to enter a PhD programme. Ten students are currently following a pre-PhD track (six of them from S&C), for which DISC has obtained funding from the Netherlands Organisation for Scientific Research, NWO.

The learning outcomes of the programme are geared towards the Domain-Specific Framework of Reference, which was developed by the programme management. The committee studied this document to get an overview of the domain and to see if the programme objectives tie in with the international perspective of the requirements currently set by the professional field and the discipline with regard to the contents of the programme. It used the Framework to compare the programme's objectives and final qualifications with other international master's degrees. A benchmark study carried out in 2011 among programmes in the UK and Scandinavia revealed that the final qualifications correspond to those of foreign programmes. There is a consensus on what a S&C programme must provide: a broad engineering foundation (including mathematical techniques, modelling, linear and non-linear systems, optimisation and techniques for optimal and advanced control), specialisations, and theory as well as practice. Most programmes award 120 EC and consist of core courses, electives and a graduation project, the latter representing an average of 30 per cent of the programme size. Generally accepted programme elements are: 1) Modelling and Systems Analysis, 2) Control Theory, and 3) System Identification.

The Domain-Specific Framework of Reference also refers to a survey carried out among representatives of the professional field. According to this survey, the industry considers all seven competences of the Meijers' criteria relevant, but most importantly the S&C skills. It demands practical experience and wants graduates to be able to transfer new tools for the modelling, analysis and design of advanced control systems to an industrial context. The committee confirms these professional and theoretical criteria of the industrial S&C field. In fact, the range of application areas in which graduates should be able to find employment is very wide. According to the committee, this justifies the emphasis the programme puts on local specialisations in addition to a core programme. This is rightly considered to be a domain-specific requirement, while it also stresses the multidisciplinary character of the field itself.

During the site visit, students stated that they were very positive about the aims and orientation of the S&C programme. They are also optimistic about their chances on the labour market. Not all of them have a clear vision of what kind of career they would prefer, but the overall impression they get from alumni and staff is that opportunities are good and there is a demand for them. Alumni confirmed that after graduation they quickly found employment at the desired level, both in science and in industry.

1.2 Considerations

The committee established that the intended learning outcomes meet the demands of a university-level master's programme. They are academic in nature, and their level corresponds to general, internationally accepted descriptions of a master's programme. The final qualifications are based on internationally accepted standards of the S&C domain, as well as the requirements set by the professional field. The learning outcomes cover the programme's aims to enable students to acquire both scientific and professional skills, paying attention to a profound knowledge of the engineering sciences, the effective use of that knowledge, fundamental research skills, communicative skills and academic and intellectual reflection. The committee applauds the fact that the three locations have together established one programme with the same aims, by using one common set of final qualifications and Rules and Regulations for Education and Examination. The committee concludes that the programme provides graduates with a solid foundation qualifying them for a career in their field of specialization.

Like all other 3TU programmes, the S&C programme uses the Meijer's criteria as its starting point in formulating its final qualifications. The committee thinks that this framework is appropriate. It is also very ambitious, since the programme is supposed to examine all learning outcomes. As complete as the list of twelve final qualifications may seem, the committee would like to recommend adding one more. During the assessment, the committee became convinced that creativity is a very important part of the programme (see also: Standard 2 'Teaching-learning environment', *didactics*). Students have to use knowledge effectively and develop design skills. The combination of research, modelling and designing requires creative skills that are now implicitly taught and assessed. By making it an explicit learning outcome, students are stimulated even more to develop these skills which are essential for a master's level.

The committee agrees with the principal idea of the programme that the S&C field should be approached from the generic themes of modelling, control and identification, which constitute the 'systems thinking' philosophy. The multidisciplinary character and the abstraction level it requires clearly meet the complex demands of the S&C field and can rightfully be considered a unique selling point. The programme strives to achieve a very high theoretical level along with practical competences and experience. In this respect, the programme surpasses the current generic quality standards. The committee assesses the first standard as more than satisfactory.

The committee established that the management has a clear vision of the programme's objectives and concludes that the final qualifications are a very appropriate formulation of these objectives. It noticed that the ambitions of the S&C programme are more concerned with the industrial output than with preserving the scientific capital. It is sympathetic towards the initiative of a pre-PhD programme, but thinks that scientific output should be formulated more explicitly as a 3TU ambition. The programme might even consider creating two specializations: one aimed at scientific research and the other aimed at industrial applications.

Overall, the committee has established that the level of the intended learning outcomes of the programme in Systems and Control matches the master's degree level and even surpasses the generic quality that can be expected. It therefore assesses the Standard 1 as 'good'.

1.3 Conclusion

Master's programme Systems and Control: the committee assesses Standard 1 as **good**.

Standard 2: Teaching-learning environment

The curriculum, staff and programme-specific services and facilities enable the incoming students to achieve the intended learning outcomes.

Explanation:
The contents and structure of the curriculum enable the students admitted to achieve the intended learning outcomes. The quality of the staff and of the programme-specific services and facilities is essential to that end. Curriculum, staff, services and facilities constitute a coherent teaching-learning environment for the students.

2.1 Findings

This standard describes the findings, considerations and conclusions of the committee regarding the teaching-learning environment. It begins with the contents and structure of the *curriculum*, the *scientific orientation* and the *cohesion of the programme*. After sections on *didactics, feasibility* and *programme-specific facilities*, the quality and quantity of the *academic staff* is assessed, as well as *student intake and internationalisation.* It concludes with a section about the *3TU cooperation.*

The curriculum of the programme

Like all 3TU master's programmes, the Systems and Control programme has a workload of 120 EC and consists of a combination of a common core curriculum and local specialisations. The core courses are compulsory and make up 24 EC of the first year. In addition, students take electives and a specialization part which prepare them for their internship and graduation project in the second year:

Year 1		**60 EC**
	Core programme	*24 EC*
	Specialisations / Electives	*36 EC*

Year 2		**60 EC**
	Internship (optional at TUD)	*15-20 EC*
	Literature Study (only at TUD)	*15 EC*
	Graduation Project	*40-45 EC*

The specific core courses are different for each of the three locations, but the topics they cover are the same. All students start with an Introduction Project (3 EC). The goal of this project is to refresh and apply theoretical knowledge gained in previous classical control courses and to acquire the ability to tune mechanical systems. Incoming students have various backgrounds, so theoretical and practical embedding is required. Next, students are introduced to the three generic aspects of systems and control engineering (about 6 EC each):

- **Modelling and System Analysis**: describing the dynamic behaviour of physical systems in terms of physical laws (electricity, hydraulics, thermodynamics, etc.);
- **Control Theory**: theorizing the measuring and control of dynamic systems and their feedback mechanisms;
- **System Identification**: mathematical modelling of dynamic systems based on statistical analysis of real-life data (e.g. Kalman filtering).

The core programme concludes with the Integration Project (about 5 EC). This course is based on practical laboratory sessions in which the students gain hands-on experience with the application of control theory to real world systems. Students are supposed to apply the theoretical knowledge gained in the previous core courses. The programme is directed towards both the analysis and design of technological dynamical processes. During the site visit the committee found that students were able to explain clearly what they learn in the core courses and what the relation of those courses is to the curriculum as a whole. Students like the idea of beginning practically and then learning to make matters more abstract and mathematical. They spoke enthusiastically about the theoretical framework the core programme provides, although the abstraction level and mathematics within the core programme are much more advanced than they were used to in their bachelor's programmes. It can be quite hard to catch up. During the site visit, the programme management claimed it puts a lot of emphasis on the mathematical components of the programme.

The committee studied the available information about all core courses, like course descriptions in the study guides, course material, assignments, and Blackboard sites. It established that the level of these courses is rather high and, in total provides students with a solid knowledge base matching the domain-specific requirements, albeit that variation in scientific quality was noticeable when comparing lecture notes of various courses. The learning outcomes are formally specified in the course descriptions. They are sufficiently concrete and describe in detail what students are supposed to learn. Students are well aware of the study goals. An appendix to the self-evaluation report contains a table that summarizes the contribution that the core courses make to the achievement of the intended learning outcomes.

The electives provide students with the opportunity to deepen and broaden their knowledge. Students select these courses from a list, choosing from each of the three locations. Almost all students only choose electives offered by their own university. The committee studied the list of electives, without assessing all courses in detail. The variety of courses is very wide. For example, TUD offers 35 electives. The specialization part must be chosen in consultation with the programme coordinator and the graduation project supervisor. Together with the Examination Committee they must approve the chosen curriculum in order to ensure a well-

balanced and well-considered programme that covers the final qualifications. The reality of the S&C programme involves many different individual study programmes. The committee verified that these programmes are indeed properly considered and that formal procedures are followed to ensure that each individual programme is assessed.
The second-year students do a research programme, most of which consists of a graduation project (40-45 EC). Furthermore, they can do either a literature study or an internship, which in many cases is combined with the graduation project. When an internship is integrated in the graduation project, students carry out their research in collaboration with an industrial partner or a research institute. The self-evaluation report shows a list of companies that have contributed to the realisation of the graduation projects. According to the committee, this illustrates the good connections of the 3TU with the professional field and the opportunity to provide students with relevant trainee posts and research environments. By assessing fifteen thesis reports (see also: Standard 3 'Assessment and achieved learning outcomes'), the committee got a good impression of the different sorts of graduation projects students do, some of them more theoretical, some more practical. The three locations clearly have their own options for specialisation within the master's programme. In Delft for instance, unlike Eindhoven, electromechanical engineering is not an option.

Scientific orientation
3TU strives to provide students with a high-quality and research-driven educational programme and to deliver graduates with an optimum balance of academic and professional field competences within their selected domains. The first year of the programme focuses on providing students with knowledge and helping them to develop a scientific attitude and capabilities. In the second year, when they undertake optional internships and the graduation project, they are intensively coached on this attitude and their capabilities in the field. The self-evaluation report states that this scientific orientation is vital to the programme. Relevant research programmes within the faculties are connected to programme components to ensure interaction between education and research. This is illustrated by the following:

- Research is used as a source of examples in the courses. The examples include 'own' research results (obtained by the groups at TUD, TU/e and UT). The lecture notes are largely based on research and associated papers. The committee established that some of the courses use research documented in papers written by the lecturers.

- Papers reflecting recent international research are part of the course material. Course materials also cite relevant papers presented at international conferences, and concepts from these papers are used during teaching. The lectures on 'Modelling and Simulation' are based on lecture notes, scientific papers on the results of relatively recent research, in relation to the topics that are discussed during the lecture.

- Research and design tasks in the courses are based on the academic research conducted by the group. For example, the 'Knowledge Based Control Systems' course is based on a large number of research papers.

- Many graduation projects are part of research projects conducted by staff members and/or PhD students. Research and design tasks generate independent contributions to the academic research of the group. All graduation projects are based on new developments, in the form of innovative designs (of systems, equipment or tools) or in the form of research aimed at discovering new knowledge.

The committee established that the scientific orientation of the programme is clearly reflected in the way courses are designed. It did notice tension, however, between the scientific objectives and the practically oriented graduation projects. In the meetings during the site visit, it discussed the balance between the academic and practical aspects of the graduation projects. The programme management explained that when a graduation project is combined with an internship (which is not an exceptional case), the supervisors of the internship and the university meet once a month to make arrangements about the project. The tutor from the university checks whether the project enables the student to realise the final qualifications. When a project does not meet the scientific requirements, students have to find a research project within the faculty to be able to graduate. According to the staff, the programme pays a lot of attention to research skills and scientific output. Alumni were convinced that their graduation projects had had the right balance between theoretical and practical objectives.

Cohesion of the programme
The self-evaluation report states that the programme is highly cohesive. Students follow the same compulsory core programme and focus on a specific cluster through their choice of electives. The internship, literature research or preparation for the graduation project, together with the actual project itself, constitute an individual specialization path. These components are intended to strengthen each other. Students may perform the work for their internship and graduation projects in one of many application areas. The core and cluster-specific electives enable students to carry out their internship and graduation work in one of these application areas. Alternatively, students may also work on theoretically oriented projects.

A key factor for the cohesion of the S&C programme is the establishment of a close working relationship between students and their supervisors or the programme coordinator. This relationship ensures the connection between the fundamental interests of the students and the scientific contents and quality of their study programmes. As previously stated, students compose their individual study programmes in consultation with the coordinator. The Examination Committee must approve of the proposal in order to ensure a well-balanced programme that is both coherent and covers the final qualifications. Students focus on a specific 'cluster' (e.g. process industry or mechatronics) requiring a choice of electives (students can correct any knowledge deficiencies during this phase).

The committee verified the internal consistency of the S&C programme by assessing the course materials and discussing with students, staff and the examination committee how the individual study programmes are composed. Students stated that they consider the core programme to be very well balanced, providing a strong knowledge base. The opportunity to follow one's own path by choosing electives in the first year that lead up to the graduation project in the second gives the programme flexibility while at the same time ensuring a synergy between the components. The sequence of the core courses is different at the three locations. In Delft, for example, the Introduction Course is followed by Control Theory, while in Eindhoven and Twente, Modelling and Identification come first. During the site visit TUD staff explained that Control Theory is considered to be an obstacle for students. By scheduling the course early in the curriculum, it functions as a wake-up call. The committee ascertained that the differences in programming and scheduling do not diminish the cohesion of the programme for any of the locations. The design of the curriculum (core, specialization, graduation project) guarantees a coherent structure. The entirety of the core courses can be considered cohesive as well. Its structure is very clear: 1) introduction project; 2) generic themes; 3) integration project. The last aspect should be a test of what students have learned.

Students admitted that it can be difficult to make this project practical. As such, it is a good preparation for the second year.

In the meeting with the Educational Committee, it was confirmed that unnecessary overlap between programme components is prevented by regularly evaluating the curriculum. Any doubts the committee had about the cohesion of the programme, given the wide variety of electives, were alleviated by the explanation of how the individual programme proposals are assessed by the Examination Committee. The committee also established that the local education committees take action to improve the programme and scheduling. They check the cohesion of the programme by evaluating the learning outcomes of the courses. The committee established that the teaching staff is well aware of the study goals to be covered by the courses they teach, and how these goals are related to the other courses. The programme and course content are not static. Students feel that their feedback on the programme and the individual courses is taken seriously. This was confirmed by student members of the local education committees.

Didactics
One of the topics discussed in the meeting with members of the teaching staff was the difficulty to embed students from various backgrounds within the master's programme. The self-evaluation report characterises incoming students as 'non-specialised researchers needing supervision'. The necessary embedding is claimed to be accomplished through introductory activities, the introduction project and the entire core programme. The focus is on the specialisation of knowledge and skills within the S&C domain. Students confirmed that the introductory activities had an integrating effect, both socially and academically. The didactical approaches of the programme are chosen to match the objectives and learning outcomes. The transfer of knowledge to students takes place through lectures. Skills and attitude are imparted through assignments, laboratory courses and projects.

According to the self-evaluation report, members of the teaching staff serve as 'guides' and as a source of inspiration to students. During the site visit teachers stated that they considered it their task to stimulate students to become creative scientists on an academic master's level. They do not wish to simply 'dictate recipes'. However, the students' level of ambition can vary considerably. Many of the courses are taken by both S&C students and students from other master's degree programmes, like Mechanical Engineering and Electrical Engineering. For those students, the S&C core courses are electives. As many as 70 students take the Control Systems course in Delft, only 35 of whom are S&C students. It seems that S&C courses are actually growing in popularity.

The self-evaluation report lists the main working methods used in the programme:

- **Cursory education** (lectures and workshops with an examination for each course). This form is used for the engineering sciences, for domain-specific knowledge, as well as for electives. It may include exercises and project work designed to train students in practical applications. In addition, a series of colloquia may be part of this educational form. Depending on the variant of an individual study programme, mandatory education may involve 50 per cent of the study load (the entire first year). The programme has introduced virtual classes and video lectures.
- **Assignments**. This form is used for the graduation project, the internship and the literature survey. The assignments take up the entire second year of the programme, thus comprising 50 per cent of the study programme. The internship is intended to give students first-hand experience and confront them with the level of work that will be

expected of them after graduation. The graduation project is intended to act as proof that students are able to conduct academic research independently.

- **Laboratory work**. The purpose of this format is to apply knowledge in laboratory settings, in which students gain hands-on experience with the application of S&C theory. One example is the Integration Project. In this course, students have the opportunity to design and implement their own controllers for various laboratory systems.

The committee studied the education methods as described in the course descriptions as well as the assessment methods. The didactical approaches are very much in line with the aims of the programme and are implemented adequately. It was stated by the students that master courses are really different from bachelor courses. Students have to do more assignments and write more reports, as a result of which they feel pushed to work harder. The students who were present at the site visit found this satisfying in the end. They got the feeling that 'we were really learning something'.

Feasibility

The S&C programme has a study load of 120 EC, which students have to complete within a two-year period. Not all students succeed in completing their studies within two years (see *student intake and internationalization*), but this should not necessarily be taken as an indication that the programme is not feasible. During the site visit, the programme management and educational committees explained how the structure of the programme enables students to compose a well-balanced and feasible curriculum. The mandatory part of the programme is scheduled in the first year and has considerably more contact hours than the second year, when students do their graduation projects. The courses are scheduled in such a way that students can choose specialisation courses and electives in each quartile. Many electives do not require other courses as prior knowledge. It is therefore possible to compose a feasible individual programme. The following table, derived from the self-evaluation report, shows the estimated time that students spend on different kinds of contact hours and self-study.

	Contact hours				Self-study and group work				
				Total				Total	Total
	Lectures, tutorials	Practical training, projects etc.	Graduation project		Individual study	Projects	Graduatio n project		
Year 1	25% (420 hours)	5% (70 hours)	0%	30% (490 hours)	60% (1000 hours)	10% (190 hours)	0%	70% (1190 hours)	**1680 hours**
Year 2	0%	1% (20 hours)	4% (70 hours)	5% (90 hours)	0%	30% (480 hours)	65% (1110 hours)	95% (1590 hours)	**1680 hours**
Overall	**13% (420 hours)**	**3% (90 hours)**	**3% (70 hours)**	**17% 580 hours)**	**30% (1000 hours)**	**20% (670 hours)**	**33% (1110 hours)**	**83% (2780 hours)**	**3360 hours**

As previously stated, students think the level of the courses is high compared to bachelor courses. Some students find the programme rather theoretical and mathematical. This especially applies to students coming from bachelor's programmes in higher professional education (who first attend a pre-master's programme). The Introduction Course is very important part of the programme. Students feel that they are being well supported and able to catch up with the ambitious level of the programme. Evaluations demonstrate that students think the programme is feasible. The fact that the mandatory part consists of many courses that have a study load of 3 EC and involve several assignments means that students need discipline to keep focused during the year. The committee established that the way in which

the programme components are divided over the two years guarantees a good distribution of the total study load. Starting with the mandatory part and practical training and then continuing with individual projects and group work is very suitable. According to the committee, the structure of the programme as such contributes to its feasibility.
Course scheduling is critically reviewed by the three local education committees. In their meeting during the site visit, they convinced the assessment committee that they play an active part in improving the programme. They gave examples of measures they had taken to improve the feasibility of the programme. One of the appendices to the self-evaluation lists improvements based on self-evaluations and the previous programme assessment. According to the committee, this illustrates the self-improving capability of the S&C programme.

Programme-specific facilities
At each of the 3TU locations, different spaces are allocated for teaching, self-study, assignments and laboratory work. In addition to the common facilities, each location has its own specific ones. At TUD, where the site visit took place, the Delft Center for Systems and Control (DCSC) has a well-equipped laboratory and technical support staff. Many of the research projects are performed in cooperation with industrial partners, often at experimental facilities located outside the university. Well-equipped laboratories are also available at TU/e and UT. Eindhoven has a shared Automotive Engineering Science laboratory, where specific power train and vehicle testing equipment is used for automotive control case studies. UT has a well equipped lab for robotics and mechatronic applications for both students and researchers. In addition there are extensive laboratory facilities in the Mechanical Automation Department.

On the second day of the site visit, committee members were given a tour of the facilities. They were very impressed. 3TU can rightfully claim to be well equipped to turn theoretical concepts into practical applications and experiments. The available facilities enable the educational programme to connect to research programmes in the faculties. In this respect, the interaction between research and education can be considered excellent. The committee established that S&C students have the opportunity to encounter state of the art research and development, like wind energy projects and robotics. This situation is very motivational. Students from all locations are very satisfied with the facilities.

According to the self-evaluation report an important facility, specific for the 3TU programmes, is the virtual classroom. This facility enables lectures to be offered by one teacher, with students at different physical locations in the same virtual classroom. Both teachers and students are positive about the quality of the images and sound produced in the 3TU virtual classroom. The committee established that the use of virtual classrooms is still rather limited and one-way, however. The programme management stated that they are looking into the possibilities to extend their use, in order to reduce the workload and further enhance synergy between the 3TU locations. Alumni and students confirmed the importance of video lecturing and virtual classrooms.

In addition to the physical facilities, there are three main sources of staff support to provide students with guidance for the programme: the student advisors and programme coordinator, assisting with the composition of the individual study programme, and the graduation project supervisors. The committee noted that the programme requires careful student guidance. It is enthusiastic about the evident success in providing it. Students seek student advisor guidance themselves, but the study advisors also monitor the results of all students. In cases of problems not directly related to the programme, each university has its own student counselling services. Each of the locations also has student associations.

Academic staff
The teaching staff of the S&C programme is strongly embedded within research groups of the faculties. They cover a wide variety of topics. As previously stated, this is vital to the scientific orientation of the programme. Students are exposed to relevant contemporary research questions on a daily basis. The self-evaluation report displays a list of research topics covered by professors at the three locations. The committee studied this list as well as the review of staff involved in the courses. It established that the 3TU has all the expertise it needs for the successful execution of the S&C programme, such as system identification, robotics, hybrid systems, linear and non-linear systems. All core components are amply covered by the highly qualified staff, while each location also has its own specialisations.

Several staff members have worked in industry or at research institutes. Some of them are combining jobs in industry with their positions at the university. Given the large numbers of students completing their graduation project and/or internship within industry, this ensures a thorough bond with industrial practice. Students who carry out their graduation project within affiliated groups are embedded in state of the art, science-based engineering environments. According to student evaluations, students are very satisfied with the support provided by the teaching staff and programme coordinators, which was confirmed during the site visit. The staff is very accessible and has allocated sufficient time for scheduled education activities. Staff members encourage ambitious students to collaborate on research and publication activities.

At TUD, the staff-student ratio is about 1:18; at TU/e and UT it is 1:15. In the near future, the prospective growth in the number of students and the decrease in funding by the Dutch government may lead to a re-evaluation of the number of courses and activities of the DCSC. This process will also include an increase in efficiency by combining courses for several target groups, the use of the 3TU virtual classroom, and additional support from PhD students and post-doctoral researchers. The committee discussed this prospect during the site visit. It was stated that the core courses are not in any danger of having to be made more efficient, considering the large number of students taking them. Another issue discussed during the site visit was the fact that TUD currently has several open positions. The employment policy of DCSC management is to strive for quality results in the short term, with an increased workload for the remaining staff members.

Student intake and internationalization
The admission requirements are laid down in the Teaching and Examination Regulations, which are same for all three locations. In the meeting with the Examination Committees it was confirmed that when an application is rejected at one location, this rejection automatically applies for the other locations. The self-evaluation report states that three categories of students are accepted:

1. Graduates holding an academic bachelor's degree (BSc) with a relevant background from a Dutch university (e.g. Applied Physics, Aerospace Engineering, Chemical Engineering, Electrical Engineering and Mechanical Engineering). For this category of students, admission is unconditional.
2. International academic bachelor's degree graduates (BSc) with a relevant background. Their admission procedure includes assessing the relevance and level of the applicant's diploma, English language proficiency, and marks obtained.
3. Higher professional bachelor's degree graduates (BEng) with a relevant background, mostly from the Netherlands, after completion of an appropriate pre-master's programme.

The first year requires the embedding of these students from various backgrounds. The committee discussed the issues with this embedding during the site visit. At TU/e foreign students were found to have more difficulties with lab skills, so extra attention is paid to their supervision. At least four times a year all S&C students in Delft meet to discuss their progress. All courses are in English. The programme management stated that the programme aims to attract a substantial number of students from abroad, to create an international academic environment. The ambitions of the programme include strengthening its position as a unique, attractive, nationally and internationally recognised interdisciplinary MSc. Students and staff members claimed that the international students generally integrate very well with the Dutch students.

Appendix 5 to this report contains a table that shows the total number of students registered in the S&C programme by year, location and group (students from the national bachelor's degree programmes; international students; bachelor's degree students from universities of applied sciences). TUD has an average intake of around 25 students per year; TU/e around 15 and UT only four (the S&C programme has only recently started there). During the site visit representatives of UT explained the recent transition that has been made in Twente, where the Mechatronics programme is now absorbed into the 3TU S&C programme. They convinced the committee that the new programme has a good potential. With its spirit and viability it is expected that student numbers will grow.

Also included in Appendix 5 are figures about student performance and the drop-out rate. The committee established that the drop-out rate is low and shows differences between the categories (6 per cent for international students; 15 per cent for Dutch BSc students; 25 per cent for BEng students). Likewise, the pass rates differ among the three categories of students. Most international students complete the programme within two years, while Dutch students take longer. In the self-evaluation report, these differences are explained by the 'zachte knip' (BSc students start the master's programme before having completed their bachelor) and the duration of the pre-master's programmes. Furthermore, international students feel a financial pressure to complete the programme on time, while Dutch students may also place priority at extracurricular personal development. The committee discussed the measures the programme management is taking to reduce drop-out rates and study delays. One of the actions initiated by the Boards of the three universities is removing the 'zachte knip'. Also, it appears that for BEng students the abstraction level can be too high. Stricter admission conditions may be required.

3TU cooperation

One of the reasons to embed the Systems and Control programme within 3TU is to allow students to take advantage of the opportunities offered by the three contributing universities. However, the self-evaluation states that 3TU cooperation could be improved. During the site visit the committee raised this matter in several panel meetings. The programme management first of all stated that it is convinced that the 3TU umbrella has added value in attracting students (especially international ones). Since the education branch of 3TU.Federation does not financially depend on new investments, its future is secure. It has never been the intention of TUD, TU/e and UT to merge the three programmes fully. The intention was to join forces instead of being academic rivals. The way cooperation should take shape has been discussed. The self-evaluation report formulates 3TU-specific ambitions:

- to increase the possibilities for video-supported teaching within the specialisations;
- to improve collaboration in assuring the quality of examinations;
- to enhance admission procedures and criteria and to improve intra-3TU communication;

- to maintain a continuous shared cycle of evaluation in order to strengthen 3TU coherence and to allow continuous improvement of the programmes.

As mentioned before, each location has its own education committee. All three of them meet together once a year (by video conferencing) to discuss topics like the internships, exchange of students and course evaluations. Members of the teaching staff in some cases exchange their lecture notes, but the cooperation has not been formalized. It is the opinion of the committee that this situation could be improved. This also applies to the IT infrastructure: to integrate the three local programmes, more virtual classrooms, shared databases for lectures and one blackboard system seem appropriate, as well as having representatives from the institutions involved on each other's thesis committees on a regular basis.

The committee asked whether students really profit from the 3TU construction. Most of the students the committee met during the site visit did not consider themselves 3TU students and did not travel to the other locations. In some cases, however, they felt that they did benefit from the expertise at other locations. The committee is convinced that 3TU has added value, considering the local specific orientations. The interaction between the location as stimulated by the DISC institute is promising.

2.2 Considerations

The committee highly values the design, implementation and organisation of the teaching-learning environment. A master's programme in Systems and Control requires a curriculum that covers both scientific and professional competences. The committee concludes that the programme demonstrates a good balance between theory, practical work, and research and design projects. It pays attention to the use of knowledge of the engineering sciences, research skills, and professional competences. The academic environment in which S&C students work is very inspiring, internationally oriented, and provides constant interaction between education, research and design. As such, the programme offers a very solid and scientifically grounded preparation for the professional field as well as for a scientific career.

As was stated in the Domain-Specific Framework of Reference, there is a broad consensus on what an S&C core programme must provide. On the basis of the information given in the self-evaluation, study guides, the course material studied and the meetings during the site visit, the committee concludes that the core courses have an excellent level that should enable students to achieve the intended learning outcomes. However, considering that the most difficult part for many students is the abstraction level required for the theoretical foundation of the programme, as well as the linking of this abstraction level to practical designs, the management should consider extending the core programme by including some additional courses covering in more detail the foundation of Systems and Control. This will inevitably require a corresponding reduction in the elective part of the programme, preserving both the high standards and the feasibility of the programme. Furthermore, the committee noticed some differences of emphasis between the three locations as well as differences between the quality of the electives. In general, though, the committee was very satisfied with the quality of the course material.

The committee could confirm that the design of the curriculum is very clear and cohesive. It can be regarded as an international example. First of all, the core, electives and specialisation part leading up to the graduation project are structured in such a way that they cover a very wide range of applications and orientations from one integrating paradigm. In doing so, the curriculum succeeds in creating interdisciplinarity, which is vital to the academic master level. A further deepening of the student's knowledge by combining the internship with the graduation project is encouraged but should not lead to a reduced interdisciplinarity of theory/practice, these two should therefore also be clearly separated in approach. Second, the programme ensures a progressive integration of theoretical knowledge and practical skills. Although less creative, the integration project is a good preparation for the second part of the programme, in which students focus on research and design. Third, students are given the opportunity to carry out final projects in inspiring research groups and excellent facilities. The laboratory infrastructure can be called impressive.

The committee recognises the staff's scientific quality, national and international academic reputation and teaching experience. It noticed that recent developments in scientific research are brought into the courses. The staff also has experience in industry. The assignment-based didactical approach stimulates the students' creativity, which is essential to a high-quality engineering education. The working methods meet the objectives of the programme components. Student evaluations indicate that the students are satisfied with the amount of support provided. The programme is highly demanding, but the teaching-learning environment makes it feasible. Moreover, the education committees have been shown to be able to take action to improve the programme and its feasibility.

With regard to 3TU cooperation, improvements could be made. The committee recommends investing in better IT solutions to share course material and create virtual classrooms, in order to stimulate synergy between the locations. Although 3TU may have to improve its reputation to attract more students, the staff-student ratio seems to be decreasing. This is a point of attention.

Still, the committee has the opinion that the S&C programme can be considered an international best practice as an appealing interdisciplinary programme It combines classical generic themes with recent developments in mechatronics and high-tech elements from electrical and mechanical engineering, as well as from computer science and mathematics. Students are trained in the whole cycle of theory, research, design and experimentation/ validation. They are enabled to reach a very high level.

2.3 Conclusion

Master's programme Systems and Control: the committee assesses Standard 2 as **excellent**.

Standard 3: Assessment and achieved learning outcomes

The programme has an adequate assessment system in place and demonstrates that the intended learning outcomes are achieved.

Explanation:
The level achieved is demonstrated by interim and final tests, final projects and the performance of graduates in actual practice or in post-graduate programmes. The tests and assessments are valid, reliable and transparent to the students.

3.1 Findings

The assessment modes for all course components are described in the course descriptions in the study guides. The committee established that a mix of evaluations, tests and examinations is used. Students are evaluated in a number of different ways to test their knowledge and skills and their application. They are informed about the assessment criteria prior to the test. During the site visit, students were asked whether they thought the assessments were representative. They stated that the exams mostly matched their expectations, but they also mentioned a discrepancy between the time spent on assignments within the curriculum ('80 per cent') and the grading of that part ('20 per cent'). According to the students, while the majority of the time is consumed by project work, the written examinations account for the majority of the grades. Since the challenge of the programme lies with linking theory and practice, students consider that project assignments should be the most important part to be assessed.

Each 3TU location has its own Examination Committee, responsible for everything related to the grading and order during examinations. The self-evaluation study gives a short description of these procedures. The committee verified that they are also laid down in the Teaching and Examination Regulations. In the self-evaluation report it is stated that these procedures should be harmonised further and that assessment policies will be updated. The committee detected that assessments are not being documented in a unified way. The Examination Committees stated that they are in a process of implementing a stricter assessment policy.

Considering that 3TU uses a common framework of final qualifications and Teaching and Examination Regulations, the committee was very interested in the way the local Examination Committees work together in maintaining an assessment system that checks whether the intended learning outcomes are achieved. During the site visit the Examination Committees explained that they use a common administrative system and strive to harmonize their policies. One of the plans discussed was to increase the existing practice of involving representatives from one institution in the thesis committees at other locations. They stated that as much as 25 per cent of the theses should be assessed in this way. However until 2010-2011 this was only an estimated 5 per cent. There has been a positive trend since then which according to the committee should be continued and not be limited to 25 percent. The committee urges the programme management to carefully document the composition of the thesis assessment committees, explicitly mentioning the contribution from representatives of the other institutions. Another plan involved creating common assessment forms. For the other 'classical' regulatory tasks of the Examination Committee, 3TU cooperation did not seem to offer much of an advantage.

As previously stated, the Examination Committee assesses all individual study programme proposals to check if the programmes truly meet the final qualifications. There are 'standard programmes' that are undeniably in order, but for most electives, students consult the programme coordinator in order to ensure the quality and feasibility of their programmes. The committee established that this procedure is done very carefully. On the other hand, it also established that there are as many as twelve final qualifications, which makes it difficult to make sure they are all covered by each individual programme Final Qualifications 11 ('Graduates have the capability to communicate effectively with a non-specialised public in English') and 12 ('Graduates have the capability to evaluate and assess the technological, ethical and societal impact of their work, and to take responsibility with regard to sustainability, economy and social welfare) are related to four parts in the programme: Introduction Project SC; Integration project; Practical Training (internship); Graduation Project, but have in the average a limited degree of explicit assessment. The extent of the assessment varies a lot among the different students, and may be rather limited for some of them, depending on the elective programme approved for the students. The entry level of English is checked according to the Teaching and Examination Regulations, but students' language skills are not explicitly assessed during the curriculum as one of the learning outcomes to be achieved. Furthermore, the reports and theses students write all seem to be addressed to a highly specialised public.

The committee assessed the achieved learning outcomes by inspecting a selection of the master thesis reports from the two most recent cohorts of the programme. This selection was done at random by the project leader (ensuring that all grades were represented) and the committee members. Consideration in selecting the thesis reports was given to the grading (low, average and high grades) and the three locations. The committee found that theses were either directed toward industry or to more theoretical questions (to a lesser extent). A few thesis reports could be considered excellent academic work, almost ready to be published as a scientific paper. Generally, however, the grades of the thesis reports were rather high, considering the fact that graduation projects amount to at least 40 EC. What struck the committee was that in several cases, the mathematical 'grammar' was a bit careless. The same applied to the use of English. In other cases, candidates were rather limited in their use of the academic literature. One thesis report was considered unsatisfactory. The conclusion of this work was not related to the formulation of the problem. During the site visit this report was discussed with a member of the graduation committee. The committee

The overall level of selected thesis reports demonstrated that the intended learning outcomes were achieved.

In the self-evaluation, several other observations are listed to support this conclusion:

- Graduates easily obtain jobs at their academic level with various high-profile companies;
- Graduates are well prepared for positions as PhD candidates, and they are successful in obtaining such positions;
- Outcomes from the recently conducted employer survey indicate that graduates demonstrate above-average compliance with the final qualifications;
- The results of the S&C alumni questionnaire indicate that the system of assessment is appropriate for achieving the final qualifications and subsequently preparing students for the professional field.

3.2 Considerations

The committee concludes that the programme uses a reasonable mix of assessments, with a balance between theory (written exams) and application (assignments), although since the programme is mostly assignment-based, 3TU may consider focussing a bit more on the latter. The written examinations are rather 'classical', but according to the committee, they ensure standard quality. The committee also established that the various assessments demonstrate a good balance between individual assignments and group work (such as lab reports).

The Examination Committees use different instruments to guarantee the quality of the examinations. During the site visit, several plans were presented regarding the harmonization of assessment procedures and the use of common assessment forms. Especially with regard to the theses, the committee believes that these plans have to be put into practice as soon as possible. Sub grades of which the final grade for the graduation project consists should be explicitly and carefully accounted for on the assessment form. Although 3TU does not intend to fully merge the three local programmes, the common framework of final qualifications and Teaching and Examination Regulations necessitates that the same assessment regime is applied to all 3TU students. The committee recommends that the Examination Committees play a proactive role in harmonizing and implementing the assessment policies. With regard to the thesis evaluation forms, best practices should be discussed in order to create a common one.

The committee concludes that the intended learning outcomes are achieved. There is evidence that graduates easily find work within the professional field and that they perform to everyone's satisfaction. The graduation projects also demonstrate that students achieve the final qualifications. However, the level of the thesis reports studied by the committee differed considerably. Some of them were excellent, but on more than one occasion the committee found them rather marginal. Regarding the fact that graduation projects have a workload of at least 40 EC, the committee would expect the theses to have a bit more body. According to the committee, this may also reflect the previously mentioned tension between practical aspects demanded by industry and scientific approaches required by the programme.

3.3 Conclusion

Master's programme Systems and Control: the committee assesses Standard 3 as **satisfactory**.

General conclusion

The committee concludes that the intended learning outcomes of the master's programme have been concretised well in terms of content, level and orientation. They fully meet the international requirements. It also concludes that the content and structure of the curriculum, staff and laboratory facilities constitute a coherent, attractive and challenging teaching-learning environment for the students. It can be considered an international best practice. The programme has an adequate assessment system and demonstrates sufficiently that the intended learning outcomes are achieved. However, assessment policies should be further improved and harmonized. The level of the theses can be improved as well. The committee thinks the programme may be assessed as 'good', but follows the decision rules of the NVAO, which determine that the final conclusion can only be 'good' if at least standard 3 is assessed as 'good'.

Conclusion

The committee assesses the *master's programme Systems and Control* as **satisfactory**.

APPENDICES

Appendix 1: Curricula Vitae of the members of the assessment committee

Prof. dr. ir. Joos Vandewalle obtained the electrical engineering degree and doctorate in applied sciences from KU Leuven, Belgium in 1971 and 1976. He is full professor at the Department Electrical Engineering (ESAT), Katholieke Universiteit Leuven, Belgium; head of the SCD division at ESAT, with more than 150 researchers. He held visiting positions University of California, Berkeley and I3S CNRS Sophia Antipolis, France. He teaches courses in linear algebra, linear and nonlinear system and circuit theory, signal processing and neural networks. His research interests are in mathematical system theory and its applications in circuit theory, control, signal processing, cryptography and neural networks. He (co-)authored more than 300 international journal papers and obtained several best paper awards and research awards. He is a Fellow of IEEE, IET, and EURASIP and member of the Academia Europaea and of the Belgian Academy of Sciences.

Ir. Frank Sperling received his Master's Degree in Mechanical Engineering (System and Control) in 1983 from the Delft University of Technology where he stayed on in a research position and later as assistant professor until he joined Philips Research in 1989. After seven years of research on Extreme Precision Motion Systems, primarily focused on applications in optical lithography he moved on to fulfil a number of management roles within Philips from 1996 until 2003, giving guidance to development groups of mechanical, mechatronics and control designers. In 2004 he left Philips to join SKF where he headed a small engineering research group on Mechatronics, in 2006 he accepted a job at ASML as project leader and later moved on to ASML line management in 2009. In 2011 he became a partner of, and accepted a position as technical director at Nobleo Technology, a consulting agency and knowledge house in the area of high-tech mechatronics.

Prof. dr. ir. Jan Willems was born in Bruges, Flanders, Belgium. He graduated from the University of Gent in 1963 with a combined degree in electrical and mechanical engineering. He obtained an M.Sc. degree from the University of Rhode Island and the Ph.D. degree from MIT. He was on the electrical engineering faculty of MIT from 1968 to 1973, including a one-year postdoctoral stay at Cambridge University. In 1973 he became professor of Systems and Control with the Mathematics Department of the University of Groningen. In 2003, he became emeritus professor. He is presently a Guest Professor at the Department of Electrical University of the KU Leuven.

Prof. dr. ir. René Boel (Aalst, Be., 1946) has obtained an electromechanical engineering degree from Ghent University in 1969 and a Ph.D. in Electrical Engineering and Computer Science at University of California Berkeley in 1974. He has been a FWO-researcher and a professor at Ghent University from 1975 till 2011. He also visited as a researcher or lecturer UC Berkeley, Imperial College London, Australian National University, Newcastle University and NTH Trondheim.

Jasper Boomer BSc was born in Utrecht and moved to Groningen in 2006 to study Industrial Engineering & Management at the Rijksuniversiteit Groningen. He received a bachelor degree in 2010. After that he studied at Kunliga Tekniska Högskolan (KTH) in Stockholm for a semester. Currently he is working on his master thesis on a hybrid controller for focal plane chopping in Groningen.

Appendix 2: Intended learning outcomes

1. Introduction

This Domain-Specific Framework of Reference (DSFR) was developed in view of the upcoming reaccreditation of the Systems & Control MSc programme of the three Dutch technical universities, i.e. TU of Delft (TUD), TU of Eindhoven (TU/e) and University of Twente (UT). These TU□ s together form the Federation of 3TU. 3TU has jointly established the Systems & Control programme at each of the three TUs in 2007, including successful New Studies Tests conducted by the Dutch accrediting body NVAO.

Systems & Control has a long-standing history in research and application, albeit embedded in such domains as mechanical engineering, electrical engineering and mathematics. As an educational domain, however, its history is much shorter. As a consequence, an established and accepted international DSFR does not yet exist. Therefore, 3TU S&C has developed the DSFR which is described in this document. This DSFR comprises an extension and update of the documentation that was provided earlier to NVAO for the New Studies Test.

All 3TU MSc's programmes, including Systems & Control, strongly stimulate a combination of a common core curriculum and „local" specialisations, to provide students with a high-quality, research-driven educational programme.

2. 3TU's description of the domain of Systems & Control

2.1. A brief history

The editorial of the first issue of Elseviers Systems & Control Letters, in 1981, gave this brief history of the domain:

> In 1868 James Clerk Maxwell took time away from his work on electromagnetic theory to write his famous paper on the stability of governors. For many this paper marks the beginning of control theory as an engineering discipline. In a similar way, the work done in the 1920's by Black and Nyquist on feedback amplifier design, building on earlier work of Heaviside and even Rayleigh, is often thought of as the precusor of system theory. Wiener and Kolmogorov, in the early 1940's, put stochastic ideas in the mainstream of the field. An important feature of this work was that it posed synthesis questions in a very direct way. This trend continued in the sixties with the coming to the foreground of optimal control and the recursive filtering ideas which paved the way for the introduction of the concept of state and the ideas of modeling and optimization which go along with it.

2.2. Overview of domain

In 2011 the Network of Excellence (NoE) leaders of HYCON2, the successor of HYCON (Highly-Complex and Networked Control Systems), a programme of the 7th Framework

Programme (FP7) of the EU, published a Position Paper on Systems & Control in FP8. HYCON2 being a comprehensive collaboration of European academia and industry, is to be considered as a thought leader in this field. From their report we quote:

What is systems and control science?

The field of **Systems and Control** provides the scientific foundations and the technology to **analyse** and to **design complex, dynamically evolving systems,** in particular systems in which **feedback** plays an important role. Feedback means that the effect of actions is monitored and future actions are planned taking this information into account. Feedback is ubiquitous in technical systems where it enables automation and autonomy, and in social, socio-technical, economic and biological systems. Systems and control is both a scientific core discipline and a crucial part of application areas such as automotive, aeronautics and aerospace, manufacturing, generation and distribution of electric energy, heating, ventilation and air conditioning, production of chemicals, paper, food and metals, robotics, supply chains and logistics, to name a few**.** The basic roles of Systems and Control Science are**:**

- **Model physical phenomena and artifacts** to understand and predict their dynamic behavior and the interactions among their components,
- **Develop control strategies and algorithms** to optimize the behavior of systems so that they accomplish certain intended functions, satisfy constraints, and minimize negative effects, e.g. consumption of resources,
- **Implement the control strategies** by selecting sensing devices, computing elements and actuators and integrating them into a system with maximum performance under cost constraints,
- **Validate and verify** that the implementation of the control strategies acting on the physical systems satisfies constraints and performance metrics.

Systems and control science provides the tools for proper modeling of dynamic physical, chemical, biological, economic and social systems and develops concepts and tools for their analysis and design. It integrates contributions from mathematics, signal processing, computer science and from the application domains. Systems and control science is indispensable to analyse, design, simulate, optimize, validate, and verify the technological and socio-technical systems of the next century that will be characterized massive interconnection, processing of huge amounts of data, new forms of synergy between humans and technical systems, and challenging requirements for substantially improved performance, reliability, and energy efficiency.

Abstracting an application problem to solve it by sound mathematical approaches is a fundamental and distinctive characteristic of control. If the abstraction captures an essential feature of a class of problems, then the results obtained in one application domain can then be transferred to other domains that *prima facie* look completely different. Furthermore this abstraction and systematization process enables a common interface to link different engineering areas; a very much desirable feature when developing new technologies that involve complex multi-domain systems.

Systems and control science, among other disciplines, has played an important enabling role in virtually all major technological evolutions until today, from the steam engine to rockets, high-performance aircrafts, space ships, high-speed trains, "green" cars, digital cameras, smart phones, modern production technology, medical equipments, and many others. It provides a large body of theory that enables the analysis of dynamic systems of all kinds in order to better understand their behaviors, to improve their design, and to augment them by advanced information processing, leading to qualitative leaps in performance.

Feedback control is the core of almost all embedded systems. Embedded systems interact with physical devices and systems, large and small, ranging from mobile phones to automotive engines, robots, up to entire industrial installations. More than 90% of all CPUs are currently deployed in embedded systems. During the last decade, such systems have seen a tremendous improvement of their performance most notably in cars, where the increase of safety (ABS, ESP, etc.) and the reduction of fuel consumption (EFI, EPS, etc.) are largely due to mechatronic design. That is, the combination of Mechanical engineering, Electronic engineering, Computer engineering, and Control systems engineering, in order to design and manufacture useful products. Recently *cyber-physical systems* have become synonymous with embedded systems, conceptualizing the strong interaction between the transmission and processing of information in real time (the cyber system) with the physical device or process.

Over the last fifty years the field of systems and control has seen huge advances, leveraging technology improvements in sensing and computation with breakthroughs in the underlying principles and mathematics.

3TU-S&C decided that its Systems & Control programme is *directed towards the analysis and design of reliable and high-performance measurement and control strategies for a wide variety of technological dynamical processes.* [3TU-S&C New Studies Test]. 3TU S&C builds on three disciplines, i.e. mathematics, mechanical engineering and electrical engineering. 3TU S&C chooses a focus of 'research drivenness' in combination with an intermediate position regarding application. In view of the research and educational strengths of its partners, and to create a good and sustainable position in academic master's teaching, 3TU-S&C agreed on the following:

3TU's position statement for its position within the domain of Systems and Control:
S&C is *directed towards the analysis and design of reliable and high-performance measurement and control strategies for a wide variety of technological dynamical processes. It is centered around fundamental generic aspects of systems and control engineering, while it stresses the multidisciplinary character of the field concerning its applications in* e.g. *mechanical engineering, electrical engineering, applied physics, aerospace engineering and chemical engineering. It takes the technological aspects of systems and control engineering as its starting point.*
[3TU-S&C New Studies Test]

Comparison with the final qualifications of 3TU S&C leads to the conclusion that the latter correspond very well with these three comparison programmes.

In summary, for the academic criteria:

Although a number of academic Master's degree programmes in Systems and Control and related areas exist across the globe, final qualifications are not readily available for comparison and benchmarking. The published aims are more numerous, however, and they indicate that programmes in Systems and Control should:

- Provide a broad engineering base, including mathematical techniques, modelling, linear and non-linear systems, optimisation and techniques for optimal and advanced control
- Provide specialisations
- Provide both theory as well as practice, enabling a professional career
    - Cater to a large variety of professional fields
    - Enable graduates to work on complex technical systems, as well as in research

At the benchmark universities, graduation projects range from 22 to 33 EC, with an average of 30 % of programme size. Programme sizes at the benchmark universities range from 60 to 150 EC.

The final qualifications of the Master's degree programme in Systems and Control correspond closely to those established at Manchester University, Chalmers University and Imperial College of London.

Strong points of S&C (curriculum, graduates) included: theoretical knowledge; modeling; dynamics and control systems and engineering; mathematical-analytical; systems thinking; structured working and thinking. The aspect of practical applications was mentioned as one of the weaker points. Other items mentioned were: synthesis (including mechanics); advanced control; systems architecture; systems engineering. Some other areas were mentioned as important, but it was not clear whether this respondent considered those weak or strong.

IEEE's Control Systems Society has recently published the results of a 2009 survey on control engineering. This is covered in paragraph 4.2. The HYCON2 Position Paper which was already mentioned in section 2.2 mainly focuses on research needs. A brief section on dissemination through education indicates the following requirement:

'A rigorous education in the fundamentals of controls and its applications together with the principles of economics is essential to develop a robust innovation ecosystem.'

However, this economics requirement does not pertain specifically to an S&C programme.

In summary, for the professional field criteria:
Personal skills (e.g. interpersonal skills, communication skills and enthusiasm) are required, although diverse responses were obtained with regard to types of skills. The seven competence areas (see Section 1.3) in the S&C programme are supported by the graduates, with a strong emphasis on skills specific to S&C. Graduates must be able to transfer new tools for the modelling, analysis and design of advanced control systems to the context of industry. The strengths of S&C are located on the academic, theoretical side. With regard to practical applications, S&C is considered weaker amongst graduates working in the professional field.

4. Criteria for an S&C programme

4.1. Criteria from academia
The sources also provide information regarding programme requirements. Generally speaking, programmes consist of a core, electives and a master's thesis. 3TU's 2011 benchmark focused on seven European comparison programmes. Although large differences were found, e.g. with respect to size (EC) and specialization, a number of programme subjects were found in all programmes compared:

- Modeling and systems analysis
- Control theory
- System identification (and related subjects)
- Distinct similarity in elective course topics

At the benchmark universities, the size of graduation projects ranges from 13 to 33 EC, equivalent to approximately 30% of programme size (on average).

4.2. Criteria from the professional field

Three main accrediting bodies were investigated: QAA of the United Kingdom has not produced a Subject Benchmark Statement on Systems & Control. It did produce a document on a Master in Engineering. ABET of the United States of America has defined criteria for a curriculum in Instrumentation and Control Systems Engineering Technology. However, these limit itself to *Associate Degree* en *Baccalaureates* [2010, p. 18] ASIIN of Germany also has a range of Subject-Specific Criteria sets, but Systems & Control is not available. IEEE has a Control Systems Society. It enabled an informal international survey (225 respondents of academia and professional field both from CSS members) in 2009 focusing on Control Systems graduate performance in industry. The main conclusions were:

- Academia and industry were generally in agreement on issues
- Industry judged graduates mainly as good or fair. Academia were more positive
- "Hands-on experience" is the area that most needs to be strengthened to better prepare control engineers; industry emphasizes the importance of "noncore" subjects such as real-time operating systems, real-time software techniques and system integration
- Industry: mathematical modeling of physical systems is a valuable skill. Models and methods considered to be "important" or "essential" include control-oriented models, simulation models for system verification or product design, nonlinear models, real-time models for hardware-in-the-loop verification and experimental system identification methods

- Classical control design techniques identified by industry respondents include PID tuning and integrator windup are considered "important" or "essential"
- Robust control design (H1, μ analysis) is considered among the least important of control topics by industry respondents, yet some of these topics are well covered in academic curricula according to faculty respondents. In contrast, survey data suggest that model predictive control (MPC) is an area of interest for industry that is not typically covered in a curriculum aimed at entry-level engineers
- More than 50% of industry respondents consider the following implementation issues to be "important" or "essential": Characteristics of sensors and actuators (84.9%), numerical methods for real-time integration (55.8%), real-time software techniques (69.2%) and real-time operating systems (50.9%).

INCOSE, the International Council on Systems Engineering, has published its Systems Engineering Vision 2020 in September 2007. INCOSE indicates that „the profession suffers from the lack of a set of unified principles. Also, the council considers that „in many respects, the future of systems engineering can be said to be "model-based" . As to teaching, „There is a trend toward increased use of scenario-based education and team projects that provide the opportunity to apply systems engineering to a real-world problem. Also, „Use of technologies such as simulation, visualization, and gaming will lead to innovations in systems engineering education." New institutional forms and frameworks will involve humans, organizations, technologies and environments appropriate for the resolution of contemporary issues of large scale and scope. (INCOSE also has an SE Competencies Framework 2010-0205, but this is available only to members.)

In summary, academic and professional field criteria and demands for a programme:

Programmes consist of a core, electives and a graduation project. Generally accepted programme elements are:

- Modelling and Systems Analysis
- Control Theory
- System Identification (and related subjects)
- There is distinct similarity in elective course topics.

At the benchmark universities, the size of graduation projects ranges from 13 to 33 EC, equivalent to approximately 30 % of programme size (on average).
According to a general survey conducted by CSS (IEEE Control Systems Society), „hands-on experience" is the area that most needs to be strengthened in order to improve the preparation of control engineers. The industry emphasises the importance of such „noncore" subjects as real-time operating systems, real-time software techniques and system integration. Mathematical modelling of physical systems is considered a valuable skill.

Models and methods considered „important" or „essential" include control-oriented models, simulation models for system verification or product design, nonlinear models, real-time models for hardware-in-the-loop verification and experimental system-identification methods.
Classical control-design techniques identified by industry respondents include PID tuning and integrator windup, which are considered „important" or „essential".
Model Predictive Control (MPC) is an area of interest for industry that is not typically covered in curricula aimed at entry-level engineers.

The industry considers the following implementation issues „important" or „essential": Characteristics of sensors and actuators (84.9%), numerical methods for real-time integration (55.8%), real-time software techniques (69.2%) and real-time operating systems (50.9%). Percentages refer to respondents.
The use of such technologies as simulation, visualisation and gaming will lead to innovations in education in systems engineering.

5. Sources

5.1. Academic

In the 2007 comparison study, Imperial College (London, UK), University of Sheffield (UK), University of Stuttgart (BRD), KTH (Stockholm, SW), ETH Zürich (CH), and Lund University (SW) were analyzed. In the 2011 comparison, the MSc in Control Systems of Imperial College (London, UK), the MSc in Control Systems of the University of Sheffield (UK), the program in Cybernetics of the University of Stuttgart, (BRD), the MSc in Systems, Control and Robotics at KTH (Stockholm, SW), the MSc in Robotics, Systems and Control at ETH Zürich (CH), Automation and Control at RWTH Aachen (BRD) and MSc courses in Systems and Control at Lund University (SW) were analyzed For this DSFR, programmes from Case Western Reserve University (USA), Sheffield University (UK), Chalmers University (Sweden), KTH (Sweden), Telemark University College (Norway), City University of London, University of Manchester were analyzed in addition. Manchester University, Chalmers University and Imperial College of London provided more detailed information on final qualifications.

5.2. Accrediting bodies

QAA of the United Kingdom, ABET of the United States of America, ASIIN of Germany were analyzed.

5.3. Professional field

IEEE's Control Systems Society, INCOSE, the International Council on Systems Engineering, and HYCON2 – NoE Leaders, Position Paper on Systems and Control in FP8. 2011. www.hycon2.eu were analyzed.

6. References

- Systems & Control Letters, vol. 1, No. 1, July 1981, p1
- Report on Comparison of Study Programs in Systems and Control. 3TU. January 24, 2007
- Report on Comparison of Study Programs in Systems and Control. 3TU. September 11, 2011
- Jeffrey A. Cook and Tariq Samad, Controls Curriculum Survey - A CSS Outreach Task Force Report. November 5, 2009
- Documents received from Manchester University, Chalmers University and Imperial College of London, September 2011
- Websites of QAA, ABET and ASIIN, visited on August 10, 2011
- Websites of programmes, visited on August 10, 2011
- Website of EECI, and IEEE"s Control Systems Society visited on September 1, 2011
- INCOSE, Systems Engineering Vision 2020. September 2007
- HYCON2 – NoE Leaders, Position Paper on Systems and Control in FP8. 2011. www.hycon2.eu

Appendix 3: Intended learning outcomes

The official final qualifications as published in the TER (Teaching and Education Regulations) have been slightly regrouped, for the sake of clarity and for comparison with the 3TU Academic Criteria.

1. Graduates have broad and profound knowledge of the basic engineering sciences (electrical engineering, mechanical engineering, applied physics, applied mathematics).

2. Graduates have the skills needed to use their knowledge effectively. The discipline is mastered at various levels of abstraction, including a reflective understanding of its structure and relations to other fields, covering in part the forefront of scientific or industrial research and development.

3. Graduates have the capability to apply knowledge at an advanced level within the discipline of systems and control engineering.

4. Graduates have broad and profound scientific and technical knowledge of the discipline of systems and control engineering. The knowledge is the basis for innovative contributions to the discipline in the form of new designs or the development of new knowledge.

5. Graduates have a thorough knowledge of paradigms, methods and tools, as well as the skills needed for the active application of this knowledge for analysing, modelling, simulating, designing and performing research with respect to innovative technological dynamical systems, taking into account the various application areas.

6. Graduates have the capability to manage scientific research independently.

7. Graduates are able to solve technological problems in a systematic way, involving problem analysis, formulating sub-problems and providing innovative technical solutions. This includes a professional attitude towards identifying and acquiring lacking expertise, the monitoring and critical evaluation of existing knowledge (or knowledge that is in development), planning and executing research, adapting to changing circumstances, and integrating new knowledge considering its ambiguity, incompleteness and limitations.

8. Graduates have the attitude needed to maintain professional competence independently through life-long learning.

9. Graduates have the capability needed to work both independently and in multidisciplinary teams, interacting effectively with specialists and taking initiatives where necessary.

10. Graduates have the capability to communicate effectively (including presenting and reporting) about their work with a professional public in English.

11. Graduates have the capability to communicate effectively (including presenting and reporting) about their work with a non-specialised public in English.

12. Graduates have the capability to evaluate and assess the technological, ethical and societal impact of their work, and to take responsibility with regard to sustainability, economy and social welfare.

Academic level and Masters'orientation
Level (Master) and orientation (Academic) are verified according to the 3TU Criteria for Academic Bachelor‟s and Master‟s Curricula.1 These criteria are defined in terms of seven broad competence areas, which are also known as the „Meijer‟s Criteria‟, after the leading developer of TU/e:

1. Competence in one or more scientific disciplines
2. Competence in conducting research
3. Competence in designing
4. Scientific approach
5. Basic intellectual skills
6. Competence in cooperating and communicating
7. Consideration of the temporal and social context

The domain-specific requirements have been incorporated into the learning outcomes according to the description provided in the table below. As shown in this table, the goals and objectives defined in the Teaching and Examination Regulations relate to the 3TU competence areas.

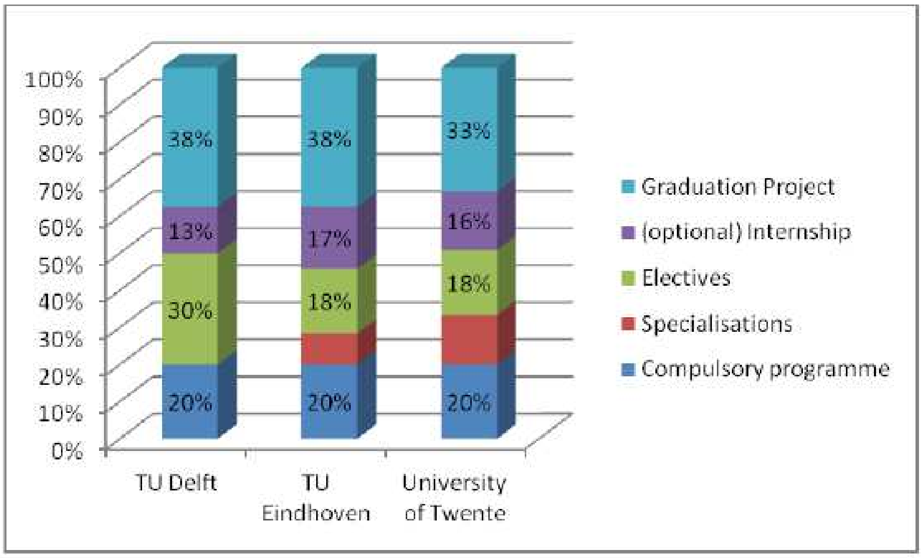
Relationship between the Final Qualifications and the 3TU academic criteria

	3TU academic criteria: Graduates:						
Final qualification	Are competent in one or more scientific disciplines	Are competent in doing research	Are competent in designing	Take a scientific approach	Possess basic intellectual skills	Are competent in cooperating and communicating	Consider the temporal and social context
Graduates have a broad and profound knowledge of the basic engineering sciences (electrical engineering, mechanical engineering, applied physics, applied mathematics)	X						
Graduates have the skills to use their knowledge effectively. The discipline is mastered at various levels of abstraction, including a reflective understanding of its structure and relations to other fields, covering in part the forefront of scientific or industrial research and development.		X					
Graduates have the capability to apply knowledge at an advanced level within the discipline of systems and control engineering.		X					
Graduates have a broad and profound scientific and technical knowledge of the discipline of systems and control engineering. The knowledge is the basis for innovative contributions to the discipline in the form of new designs or development of new knowledge.			X				
Graduates have a thorough knowledge of paradigms, methods and tools, as well as the skills needed for the active application of this knowledge for analysing, modelling, simulating, designing and performing research with respect to innovative technological dynamical systems, taking into account the various application areas.				X			
Graduates have the capability to manage scientific research independently.				X			
Graduates are able to solve technological problems in a systematic way					X		

involving problem analysis, formulating sub-problems and providing innovative technical solutions. This includes a professional attitude towards identifying and acquiring lacking expertise, the monitoring and critical evaluation of existing knowledge (or knowledge that is in development), planning and executing research, adapting to changing circumstances and integrating new knowledge, considering its ambiguity, incompleteness and limitations.							
Graduates have the attitude needed to maintain professional competence independently through life-long learning.					X		
Graduates have the capability to work both independently and in multidisciplinary teams, interacting effectively with specialists and taking initiatives where necessary.						X	
Graduates have the capability to communicate effectively (including presenting and reporting) about one's work with a professional public in English.						X	
Graduates have the capability to communicate effectively (including presenting and reporting) about one's work with a non-specialised public in English.						X	
Graduates have the capability to evaluate and assess the technological, ethical and societal impact of one's work and to take responsibility with regard to sustainability, economy and social welfare.							X

Appendix 4: Overview of the curriculum

University	Delft	Eindhoven	Twente
Compulsory programme	24 ECTS	24 ECTS	24 ECTS
Specialisations	0 ECTS [1]	9-10 ECTS	9-20 ECTS
Electives	36 ECTS	20-21 ECTS	20-21 ECTS
(optional) Internship	15 ECTS	15-20 ECTS	15-20ECTS
Graduation Project	30 or 45 ECTS	45 ECTS	40 ECTS
Total	*120*	*120*	*120*



Core courses:

At Delft University of Technology:

Code	Name	Teaching method	Assessment	Contact hours	EC
sc4010	Introduction Project SC	Lectures, project	Report, oral examination	28	3
sc4025	Control Theory	Lectures, exercises	Mid-term exam, Assignments, written examination	42	6
sc4092	Modelling and Non-linear Systems Theory	Lectures, exercises	assignments, written examination	42	4
sc4040	Filtering & Identification	Lectures	Written exam (open book), practical exercise.	28	6
sc4050	Integration Project SC	Project	Written report	40	5

At Eindhoven University of Technology:

Code	Name	Teaching method	Assessment	Contact hours	EC
4K410	Introduction Project (Digital Motion Control)	Lectures, learning under supervision, experimental work	Oral	32	3
4J520	Modelling (Non-linear dynamics)*	Lectures, practical	Written exam	28	3
5MX00	Modelling (Dynamical Systems)*	Lectures	Assignments, project work	24	3
4K560	Modelling (Physical Modelling for S&C)	Lectures, learning under supervision, self-study	Oral, assignments	28	3
5MB40	Identification (System Identification)	Lectures, learning under supervision	Written exam	32	3
4K580	Control (System Theory for Control)	Lectures, learning under supervision	Oral	28	3
5SC20	Control (State Space Control)	Lectures	Written	24	3
4K150	Control (Advanced Motion Control)	Lectures, learning under supervision	Oral, written report	28	3
4SC00	Integration Project Systems and Control	Lectures, assignment	Written report, contest	2	3

* One of the two courses 4J520 or 5MX00 is to be chosen.

At the University of Twente:

Code	Name	Teaching method	Assessment	Contact hours	EC
191211800	Introduction project	Lectures, practical	Report	16	3
191211110	Modelling: Modelling and Simulation	Lectures, tests, tutorials	Written Exam, final assignment	40	5
191211100	Mechatronic Design of Motion Systems	Lectures, tutorials	Written Exam	40	5
191571090	Identification: Time Series Analysis	Lectures	Written Exam	40	5
191210770	Control: Digital Control Engineering	Lectures	Written Exam	40	5
191159000	Integration Project	Lectures, practical	Report	20	5

[1] For a complete list of courses, inclusive the course contents, study goals, EC's, educational methods, literature and assessment, see the folder 'Extensive elaboration of the programme'

Appendix 5: Quantitative data regarding the programme

Data on intake, transfers and graduates

TUD INTAKE*	BSc National	International	BEng+	TOTAL
2007	12	5	4	21
2008	15	6	7	28
2009	13	18	2	33
2010	12	3	1	16
2011	20	9	1	30

TUD COMPLETED	BSc National	International	BEng+	TOTAL
2007	7	6		13
2008	3	8	2	13
2009	8	5	5	18
2010	11	3	2	16
2011	10	9	4	23

TU/e INTAKE*	BSc National	International	BEng+	TOTAL
2007	7	3	1	11
2008	6	6	2	14
2009	10	15	7	32
2010		15	3	18
2011	3	6	2	11

TU/e COMPLETED	BSc National	International	BEng+	TOTAL
2007			1	1
2008		1		1
2009	1	2		3
2010	2	3	3	8
2011		10		10

UT INTAKE*	BSc National	International	BEng+	TOTAL
2007				0
2008				0
2009		2		2
2010	1			1
2011	2	1	2	5

UT COMPLETED	BSc National	International	BEng+	TOTAL
2007				0
2008				0
2009				0
2010				0
2011		1		1

3TU INTAKE*	BSc National	International	BEng+	TOTAL
2007	20	8	4	32
2008	21	9	12	42
2009	22	38	8	68
2010	16	15	5	36
2011	23	15	15	53

3TU Total COMPLETED	BSc National	International	BEng+	TOTAL
2007	7	6	1	14
2008	3	10	3	16
2009	10	9	7	26
2010	11	3	3	17
2011	10	9	4	23

*The influx figures are independent of the completion figures. For 2011, data were collected through 1 October 2011

Teacher-student ratio achieved

- TUD 1:18
- TU/e 1:15
- UT 1:15

Average amount of face-to-face instruction per stage of the study programme

	Contact hours				Self-study and group work				
				Total				Total	Total
	Lectures, tutorials	Practical training, projects etc.	Graduation project		Individual study	Projects	Graduation project		
Year 1	25% (420 hours)	5% (70 hours)	0%	30% (490 hours)	60% (1000 hours)	10% (190 hours)	0%	70% (1190 hours)	**1680 hours**
Year 2	0%	1% (20 hours)	4% (70 hours)	5% (90 hours)	0%	30% (480 hours)	65% (1110 hours)	95% (1590 hours)	**1680 hours**
Overall	**13% (420 hours)**	**3% (90 hours)**	**3% (70 hours)**	**17% 580 hours)**	**30% (1000 hours)**	**20% (670 hours)**	**33% (1110 hours)**	**83% (2780 hours)**	**3360 hours**

Appendix 6: Programme of the site visit

Audit Systems and Control - 3TU.Federation. Delft, 12 and 13 April 2012

Day 1, 12 April 2012

08:45 - 09:00	**Arrival of committee and welcome**	Hans Hellendoorn (TUD) Peter Heuberger (TUD) Louis de Quelerij (TUD) Sven Laudy (3TU)
09:00 - 11:30	**Meeting committee (behind closed doors)**	
11:30 - 12:30	**Meeting with management and staff responsible for the programme (Dutch)**	Paul Rullmann (3TU) Hans Hellendoorn (TUD) Peter Heuberger (TUD) Paul Van den Hof (TUD/TUE) Robert Babuška (TUD) Rick de Lange (TUE) Henk Nijmeijer (TUE) Jan Willem Polderman (UT) Stefano Stramigioli (UT) (skype)
12:30 - 13:15	**Lunch**	
13:15 - 14:00	**Meeting with students (English)**	Django Van Amstel (TUD) Werner van Westering (TUD) Jesús Barradas Berglind (TUE) Eric Portema (UT)
14:00 - 14:45	**Meeting with staff members (English)**	Bart De Schutter (TUD) Tamás Keviczky (TUD) Raffaella Carloni (UT) Peter Breedveld (UT) Bram de Jager (TUE) Mircea Lazar (TUE)
14:45 - 15:00	**Break**	
15:00 - 15:30	**Meeting with student members Educational Committee (English)**	Cesar Uribe (TUD) Sultan Imangaliyev (TUE) Eric Portema (UT)
15:30 - 16:00	**Meeting with staff members Educational Committee (Dutch)**	Ton van den Boom (TUD) Gjerrit Meinsma (UT) Maurice Heemels (TUE)
16:00 - 16:15	**Break**	
16:15 - 17:00	**Meeting with Board of Examiners and student advisors (Dutch)**	Arjan den Dekker (TUD) Evert Vixseboxse (TUD) Paula Verbeek (TUE) Siep Weiland (TUE) Thea de Kluijver (UT) Maarten Korsten (UT)
17:00 - 17:45	**Meeting with Alumni (English)**	Anil Kunnappillil Madhusudhanan (TUD) Ashgard Weterings (TUD) Emilia Silvas (TUE) Edgar Martinez (UT)

Day 2, 13 April 2012

08:15 - 08:30	**Arrival of committee**	Sven Laudy Peter Heuberger
08:30 - 09:15	**Round tour facilities / meeting with programme director**	Stefano Stramigioli (UT)
09:15 - 10:15	**Committee meeting behind closed doors + skype meeting with one thesis supervisior**	
10:15 - 11:00	**Concluding meeting with management (Dutch)**	Hans Hellendoorn (TUD) Peter Heuberger (TUD) Paul van den Hof (TUD/TUE) Robert Babuška (TUD) Rick de Lange (TUE) Jan Willem Polderman (UT)
11:00 - 13:30	**Committee meeting behind closed doors + lunch**	
13:30 - 14:00	**Oral presentation on first impression by committee (Dutch)**	Everybody invited
14:00 – 14:30	**Reception**	

Appendix 7: Theses and documents studied by the committee

Prior to the site visit, the committee studied the theses of the students with the following student numbers:

Delft University of Technology:

1092715
1278509
1327917
1380664
1218239
4039440
1344919

Eindhoven University of Technology :

621487
620166
607524
569370
729602
560253
619136

University of Twente:

1018426

During the site visit, the committee studied, among other things, the following documents (partly as hard copies, partly via the institute's electronic learning environment):

- Subject-specific reference framework;
- Learning outcomes of the programme;
- Overview of the curriculum;
- Outline description of the curriculum components [stating learning outcomes, teaching
- method(s), attainment targets, assessment methods, literature (mandatory/recommended),
- teacher and credits;
- Teaching and examination regulations;
- Allocated staff with names, positions, scope of appointment, level and expertise;
- Overview of the contacts maintained with the professional field;
- Reports on consultations with relevant committees/bodies;
- List of the final projects of the past two years;
- Reference books and other learning materials;
- Summary and analysis of recent evaluation results and relevant management information;

Appendix 8: Declarations of independence

nvao
nederlands-vlaamse accreditatieorganisatie

DECLARATION OF INDEPENDENCE AND CONFIDENTIALITY

TO BE SUBMITTED PRIOR TO THE ASSESSMENT OF THE PROGRAMME

THE UNDERSIGNED

NAME: JOOS VANDEWALLE

HOME ADDRESS: BRAINESTRAAT 35
3052 BLANDEN
BELGIE

HAS BEEN ASKED TO ASSESS THE FOLLOWING PROGRAMME AS AN EXPERT / ~~SECRETARY~~:

Master Systems and Control

APPLICATION SUBMITTED BY THE FOLLOWING INSTITUTION:

3TU

HEREBY CERTIFIES TO NOT MAINTAINING ANY (FAMILY) CONNECTIONS OR TIES OF A PERSONAL NATURE OR AS A RESEARCHER / TEACHER, PROFESSIONAL OR CONSULTANT WITH THE ABOVE INSTITUTION, WHICH COULD AFFECT A FULLY INDEPENDENT JUDGEMENT REGARDING THE QUALITY OF THE PROGRAMME IN EITHER A POSITIVE OR A NEGATIVE SENSE;

nvao
nederlands-vlaamse accreditatieorganisatie

HEREBY CERTIFIES TO NOT HAVING MAINTAINED SUCH CONNECTIONS OR TIES WITH THE INSTITUTION DURING THE PAST FIVE YEARS;

CERTIFIES TO OBSERVING STRICT CONFIDENTIALITY WITH REGARD TO ALL THAT HAS COME AND WILL COME TO HIS/HER NOTICE IN CONNECTION WITH THE ASSESSMENT, INSOFAR AS SUCH CONFIDENTIALITY CAN REASONABLY BE CLAIMED BY THE PROGRAMME, THE INSTITUTION OR NVAO;

HEREBY CERTIFIES TO BEING ACQUAINTED WITH THE NVAO CODE OF CONDUCT.

PLACE: Delft DATE: 13-4-2012

SIGNATURE:

nvao
nederlands-vlaamse accreditatieorganisatie

DECLARATION OF INDEPENDENCE AND CONFIDENTIALITY

TO BE SUBMITTED PRIOR TO THE ASSESSMENT OF THE PROGRAMME

THE UNDERSIGNED

NAME: René Boel

HOME ADDRESS: Vliegpuit 3
B9830 Sint-Martens-Latem
België

HAS BEEN ASKED TO ASSESS THE FOLLOWING PROGRAMME AS AN EXPERT / SECRETARY:

Ma Systems and Control

APPLICATION SUBMITTED BY THE FOLLOWING INSTITUTION:

3TU

HEREBY CERTIFIES TO NOT MAINTAINING ANY (FAMILY) CONNECTIONS OR TIES OF A PERSONAL NATURE OR AS A RESEARCHER / TEACHER, PROFESSIONAL OR CONSULTANT WITH THE ABOVE INSTITUTION, WHICH COULD AFFECT A FULLY INDEPENDENT JUDGEMENT REGARDING THE QUALITY OF THE PROGRAMME IN EITHER A POSITIVE OR A NEGATIVE SENSE;

1

nvao
nederlands-vlaamse accreditatieorganisatie

HEREBY CERTIFIES TO NOT HAVING MAINTAINED SUCH CONNECTIONS OR TIES WITH THE INSTITUTION DURING THE PAST FIVE YEARS;

CERTIFIES TO OBSERVING STRICT CONFIDENTIALITY WITH REGARD TO ALL THAT HAS COME AND WILL COME TO HIS/HER NOTICE IN CONNECTION WITH THE ASSESSMENT, INSOFAR AS SUCH CONFIDENTIALITY CAN REASONABLY BE CLAIMED BY THE PROGRAMME, THE INSTITUTION OR NVAO;

HEREBY CERTIFIES TO BEING ACQUAINTED WITH THE NVAO CODE OF CONDUCT.

PLACE: Delft DATE: 12 april 2012

SIGNATURE:

DECLARATION OF INDEPENDENCE AND CONFIDENTIALITY

TO BE SUBMITTED PRIOR TO THE ASSESSMENT OF THE PROGRAMME

THE UNDERSIGNED

NAME: Jasper Boomer

HOME ADDRESS: Jozef Israëlsstraat 45A
9718 GC, Groningen

HAS BEEN ASKED TO ASSESS THE FOLLOWING PROGRAMME AS AN EXPERT / SECRETARY:

S&C

APPLICATION SUBMITTED BY THE FOLLOWING INSTITUTION:

3TU

HEREBY CERTIFIES TO NOT MAINTAINING ANY (FAMILY) CONNECTIONS OR TIES OF A PERSONAL NATURE OR AS A RESEARCHER / TEACHER, PROFESSIONAL OR CONSULTANT WITH THE ABOVE INSTITUTION, WHICH COULD AFFECT A FULLY INDEPENDENT JUDGEMENT REGARDING THE QUALITY OF THE PROGRAMME IN EITHER A POSITIVE OR A NEGATIVE SENSE;

HEREBY CERTIFIES TO NOT HAVING MAINTAINED SUCH CONNECTIONS OR TIES WITH THE INSTITUTION DURING THE PAST FIVE YEARS;

CERTIFIES TO OBSERVING STRICT CONFIDENTIALITY WITH REGARD TO ALL THAT HAS COME AND WILL COME TO HIS/HER NOTICE IN CONNECTION WITH THE ASSESSMENT, INSOFAR AS SUCH CONFIDENTIALITY CAN REASONABLY BE CLAIMED BY THE PROGRAMME, THE INSTITUTION OR NVAO;

HEREBY CERTIFIES TO BEING ACQUAINTED WITH THE NVAO CODE OF CONDUCT.

PLACE: Delft

DATE: 12/04/2012

SIGNATURE:

DECLARATION OF INDEPENDENCE AND CONFIDENTIALITY

TO BE SUBMITTED PRIOR TO THE ASSESSMENT OF THE PROGRAMME

THE UNDERSIGNED

NAME: F. Sperling

HOME ADDRESS: Hagelkruis 6
5674 RE Nuenen
the Netherlands

HAS BEEN ASKED TO ASSESS THE FOLLOWING PROGRAMME AS AN EXPERT SECRETARY:

Ma Systems & Control 3TU OW.

APPLICATION SUBMITTED BY THE FOLLOWING INSTITUTION:

~~QANU~~ 3TU

HEREBY CERTIFIES TO NOT MAINTAINING ANY (FAMILY) CONNECTIONS OR TIE OF A PERSONAL NATURE OR AS A RESEARCHER / TEACHER, PROFESSIONAL C CONSULTANT WITH THE ABOVE INSTITUTION, WHICH COULD AFFECT A FULI INDEPENDENT JUDGEMENT REGARDING THE QUALITY OF THE PROGRAMME EITHER A POSITIVE OR A NEGATIVE SENSE;

HEREBY CERTIFIES TO NOT HAVING MAINTAINED SUCH CONNECTIONS OR TIES WITH THE INSTITUTION DURING THE PAST FIVE YEARS;

CERTIFIES TO OBSERVING STRICT CONFIDENTIALITY WITH REGARD TO ALL THAT HAS COME AND WILL COME TO HIS/HER NOTICE IN CONNECTION WITH THE ASSESSMENT, INSOFAR AS SUCH CONFIDENTIALITY CAN REASONABLY BE CLAIMED BY THE PROGRAMME, THE INSTITUTION OR NVAO;

HEREBY CERTIFIES TO BEING ACQUAINTED WITH THE NVAO CODE OF CONDUCT.

PLACE: Nuenen

DATE: 10-apr-12

SIGNATURE: Frank Sperling

DECLARATION OF INDEPENDENCE AND CONFIDENTIALITY

TO BE SUBMITTED PRIOR TO THE ASSESSMENT OF THE PROGRAMME

THE UNDERSIGNED

NAME: Jan Willems

HOME ADDRESS: Van Diepenbeeckstraat 10/02
2018 Antwerpen België

HAS BEEN ASKED TO ASSESS THE FOLLOWING PROGRAMME AS AN EXPERT / ~~SECRETARY~~:

Master programme Systems & Control

APPLICATION SUBMITTED BY THE FOLLOWING INSTITUTION:

3TU

HEREBY CERTIFIES TO NOT MAINTAINING ANY (FAMILY) CONNECTIONS OR TIES OF A PERSONAL NATURE OR AS A RESEARCHER / TEACHER, PROFESSIONAL OR CONSULTANT WITH THE ABOVE INSTITUTION, WHICH COULD AFFECT A FULLY INDEPENDENT JUDGEMENT REGARDING THE QUALITY OF THE PROGRAMME IN EITHER A POSITIVE OR A NEGATIVE SENSE;

HEREBY CERTIFIES TO NOT HAVING MAINTAINED SUCH CONNECTIONS OR TIES WITH THE INSTITUTION DURING THE PAST FIVE YEARS;

CERTIFIES TO OBSERVING STRICT CONFIDENTIALITY WITH REGARD TO ALL THAT HAS COME AND WILL COME TO HIS/HER NOTICE IN CONNECTION WITH THE ASSESSMENT, INSOFAR AS SUCH CONFIDENTIALITY CAN REASONABLY BE CLAIMED BY THE PROGRAMME, THE INSTITUTION OR NVAO;

HEREBY CERTIFIES TO BEING ACQUAINTED WITH THE NVAO CODE OF CONDUCT.

PLACE: Delft

DATE: 13/4/2012

SIGNATURE:

DECLARATION OF INDEPENDENCE AND CONFIDENTIALITY

TO BE SUBMITTED PRIOR TO THE ASSESSMENT OF THE PROGRAMME

THE UNDERSIGNED

NAME: Daan de Lange

HOME ADDRESS: Catharijnesingel 56
3503 RA Utrecht

HAS BEEN ASKED TO ASSESS THE FOLLOWING PROGRAMME AS AN ~~EXPERT~~ / SECRETARY:

Systems and Control

APPLICATION SUBMITTED BY THE FOLLOWING INSTITUTION:

3TU. Federatie

HEREBY CERTIFIES TO NOT MAINTAINING ANY (FAMILY) CONNECTIONS OR TIES OF A PERSONAL NATURE OR AS A RESEARCHER / TEACHER, PROFESSIONAL OR CONSULTANT WITH THE ABOVE INSTITUTION, WHICH COULD AFFECT A FULLY INDEPENDENT JUDGEMENT REGARDING THE QUALITY OF THE PROGRAMME IN EITHER A POSITIVE OR A NEGATIVE SENSE;

HEREBY CERTIFIES TO NOT HAVING MAINTAINED SUCH CONNECTIONS OR TIES WITH THE INSTITUTION DURING THE PAST FIVE YEARS;

CERTIFIES TO OBSERVING STRICT CONFIDENTIALITY WITH REGARD TO ALL THAT HAS COME AND WILL COME TO HIS/HER NOTICE IN CONNECTION WITH THE ASSESSMENT, INSOFAR AS SUCH CONFIDENTIALITY CAN REASONABLY BE CLAIMED BY THE PROGRAMME, THE INSTITUTION OR NVAO;

HEREBY CERTIFIES TO BEING ACQUAINTED WITH THE NVAO CODE OF CONDUCT.

PLACE: Delft

DATE: 12 April 2012

SIGNATURE: