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A Study of Maintenance-Related Education in Swedish Engineering Programs

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Abstract: Engineers of today require a holistic understanding of the lifecycle of products and processes, from conceptualization to operations. Maintenance and reliability are areas receiving increased attention due to the contribution to sustainable industry practices. The related literature describes ways to strengthen the education with respect to curricula and teaching, but studies on the extent and content of maintenance-related education in engineering programs are lacking. The purpose of this study is to describe the maintenance-related education content in Swedish engineering programs. The main objects of study are the curricula and courses of engineering programs in Sweden. In total, 123 Bachelor of Engineering and 119 Master of Engineering programs were studied, as well as 36 maintenance-related courses. It was found that 12% of the engineering programs include one or more maintenance-related course, either mandatory or elective. On the Master of Engineering level, only 4% of the programs include mandatory maintenance-related courses. The corresponding number for Bachelor of Engineering programs is 15%. The courses are typically of 6–7.5 credits, but as low as under one credit worth of maintenance-related content is seen, as well as two specialized programs offering up to 60 credits. Of the 36 courses, 20 have a distinct maintenance focus, 2 are degree thesis courses, and 2 are within reliability engineering, while the rest have a focus in other areas. The lack of maintenance-related education makes future engineers less prepared to make good decisions and judgments that might affect the operational phase of the product or system.

Keywords: engineering education; competence requirements; maintenance and reliability; maintenance engineering; maintenance management; system lifecycle understanding

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1. Introduction

The engineers of today require a holistic understanding of the conceptualization, design, implementation, and operation of products and processes. Consequently, engineering education should provide the possibility to acquire these kinds of competences in a comprehensive manner. However, it is claimed that the required industrial competencies are not adequately met in academia today [1]. This calls for the reformation of engineering programs and curricula, for instance by implementing problem-based learning (PBL) or the conceive-design-implement-operate (CDIO) syllabus [2], which both are systematic approaches to curriculum development. PBL provides students with real-life resembling experiences during the study time and trains the personal as well as interpersonal skills, such as critical thinking, teamwork, and communication [3]. The CDIO initiative is a collaboration between academia, industry, and students for the development of modern engineering education [4], and the CDIO syllabus is a support in building a curriculum that integrates competencies in depth (core engineering competencies) and width (personal and interpersonal competencies). Attempts to integrate different competence requirements on course level have been reported in the literature, such as in [5] where design is studied from an interdisciplinary and sustainability perspective or the PBL-based approach to learning Industry 4.0 through a product lifecycle management software environment in [6]. Moreover, several designs and redesigns of engineering curricula are found; see for instance [6–10]. Furthermore, according to CDIO [2,4], the engineering students should acquire basic knowledge in engineering fundamentals as well as the full product lifecycle, from the conceiving of an idea to the operations of the finished product. This includes the understanding of modification, operations, and maintenance, as well as how to assure safety, reliability, and availability of production.

Maintenance is an industrial area receiving increased attention due to the contribution to sustainable industry practices [11]. Nevertheless, maintenance is given a small role in mechanical and industrial engineering education according to the study in [12], and few-related studies are found within the area of maintenance-related training and education. A comprehensive literature review using the keyword combinations “maintenance engineering” and “competencies/syllabus/curriculum” resulted in fewer than 20 journal and conference articles. The findings reveal that previous studies mainly investigate competence requirements or describe program and course development within the maintenance area. Maintenance-related competence and training requirements are explored using the survey methods in [13–15]. The main conclusion from these surveys is a strong industrial interest in maintenance training and education. In [16,17], the competence requirements for persons working in hazardous environments are discussed, and a set of competencies are suggested for certification. In [18], the industry-collaborative work at Cranfield University with regards to training and education in hidden failure or no fault found (NFF) events is described. Examples of courses in the topics of fault diagnostics and condition monitoring are found in [19,20]. In [21], a course in software maintenance based on a reverse-engineering approach is described, and learning material for a maintenance course was developed and evaluated in [22]. Distance-based and PBL learning are often used in the courses, and hands-on experiences in the form of laboratories are perceived as important. The author of [23] describes a postgraduate education program on maintenance at University of Exeter, comprising teaching in mathematics of maintenance, maintenance analysis, reliability and safety, maintainability and supportability engineering, maintenance management and economics, design for maintenance, and maintenance integration and lifecycle engineering. The systematic work with conforming the Aircraft Maintenance Engineering degree program at Saint Louis University with ABET accreditation is described in [24]. The authors of [25–28] propose curricula for maintenance education in engineering. In [25], a curriculum for housing maintenance is suggested for the Chinese civil engineering education system. The authors want to strengthen the engineering education with new curricula, learning material, and increased practical teaching and suggest a National Housing Maintenance Technical Training Centre. A curriculum based on a PBL approach is proposed by [26] for engineering programs on the first cycle level. It includes basic engineering knowledge and specific subjects in maintenance, such as reliability, maintainability and safety, physical asset and lifecycle cost analysis, risk analysis, and human resources and knowledge-based management. In addition, knowledge of information and communication technologies is perceived as important for complying with requirements according to Industry 4.0. The digital transformation of industry is the main driver for the curriculum developed in [28], and a set of competence requirements for Maintenance 4.0 is suggested based on the international standard EN15628 Maintenance—Qualification of maintenance personnel. In [27], a curriculum for maintenance-related education in engineering programs is suggested based on the same standard and the CDIO syllabus, and a generic maintenance course for engineering programs is proposed.

While the literature highlights ways to strengthen the engineering education by distance-based teaching and modern technologies, PBL and practical understanding, interdisciplinarity and lifecycle understanding, and an integrated curriculum where personal and interpersonal competences are trained in parallel with learning the knowledge content, the reality might be quite different. Thus, there is a need to study the real-life context of engineering education and thereafter being able to propose possible future directions. The purpose of this study is to describe the maintenance-related education content in engineering programs both quantitatively and qualitatively. The quantitative perspective focuses on number of programs with maintenance-related content and estimated number of credits that are included. The qualitative perspective focuses on course content as well as on teaching and examination forms. The study is delimited to the conditions in Sweden.

2. Materials and Methods

2.1. Theoretical Framework

For the Swedish context, two main standardization bodies within the area of maintenance are of importance. The first is the European Committee for Standardization (CEN), which coordinates the national standardization bodies of European countries [29], and the second is the European Federation of National Maintenance Societies (EFNMS), which acts as an umbrella organization for the nonprofit National Maintenance Societies in Europe [30]. The standard EN15628 Maintenance—Qualification of maintenance personnel [31] defines nine competence areas of a maintenance engineer: (1) to ensure the implementation of maintenance strategies and policies; (2) to plan the maintenance tasks within his or her area of responsibility, defining and organizing the necessary resources; (3) to organize, manage, and develop the maintenance resources: personnel, materials, and equipment; (4) to ensure compliance with regulations and procedures related to safety, health, and environment; (5) to ensure technical and economic efficiency and effectiveness of maintenance tasks based on current state of technology; (6) to participate in the technical aspects of contracts and procurement process and manage the performance of the contractors; (7) to communicate to all necessary partners such as staff, contractors, customers, and suppliers; (8) to use their technical/engineering knowledge and the organizational tools to improve maintenance tasks and plant efficiency in terms of availability and reliability; (9) to fulfil organizational and economical obligations in the field of his undertaken tasks.

EFNMS has developed curricula for maintenance training for the maintenance technician as well as for the maintenance manager [32,33]. The curricula form the basis for the certification exams for the level of maintenance technician and maintenance manager, respectively. Moreover, an e-training platform has been developed for this purpose, see [34,35]. According to EFNMS, a maintenance manager should be skilled in the following main topics: Management, Reliability performance of production plants, Maintenance information systems, and Maintenance methods and techniques. The curriculum of EFMNS is based on the standard EN15628, but some differences do occur: the EN15628 covers competence requirements for three different roles, maintenance technician specialist, maintenance supervisor/engineer, and maintenance manager, while EFNMS only covers the roles of the technician and manager. In addition, competence requirements are expressed in EFNMS as a set of knowledge requirements while EN15628 define key competencies as well as essential knowledge, and different headings are used.

Both standards have previously been used as a basis for developing curriculum content of engineering programs, e.g., [14,27,28], and are seen as relevant for building the theoretical framework of this study. Table 1 summarizes the knowledge requirements of a maintenance engineer according to the standard EN15628 [31] and the maintenance manager according to the EFNMS certification as a European Expert in Maintenance Management [32]. The knowledge requirements are divided into ten main knowledge categories: (1) Terms and standards, (2) Maintenance concepts, tools, and methods, (3) Management and organization, (4) Maintenance planning and logistics, (5) Maintenance information systems, (6) Maintenance contracting and economics, (7) Asset management /lifecycle engineering, (8) Reliability engineering, (9) Heath, safety, and environment, and (10) Others. The knowledge categories form the theoretical basis for the investigation carried out in this paper.

Table 1. Knowledge requirements according to [31,32].

Category	EFNMS (1998)	EN15628 (2014)
Terms and standards	Actual European standards within maintenance Maintenance terms in the English language	Legislation and technical standards
Maintenance engineering	Maintenance Methods and Techniques -The theory of the failure patterns -Types of wear and tear -Improvement techniques (aiming at reducing failure rates and down times) -Preventive techniques -Inspection techniques -Condition monitoring techniques -Methods of life extensions -Measurement methods -Control systems -Performance improvement techniques -Repair techniques The mathematical and statistical formulas to be used in the specifications and for verifications	Maintenance methods and technologies Maintenance and diagnostic techniques Materials and equipment technologies Maintenance and diagnostic techniques Methods and tools of engineering maintenance Principles, logic, and parameters ofoperation and utilization of assets and items Principles and techniques of design, construction, and maintainability Legislation and technical standards
Management and organization	Goals, strategy, and result -How to set up a company management policy in order to be able to participate in its definition as far as maintenance is concerned -How to formulate the maintenance policy within a company -How to formulate the maintenance goals -Different maintenance strategies and how to choose the right strategy -How to specify the requirements for the maintenance activities -How to measure and analyze the results of the maintenance activities, e.g., efficiency and economy Economy -How to define the future maintenance needs of a company Organization, competence -How to organize the maintenance activities, how to choose a suitable organization and assure the right competence within the organization -How to determine the human and material resources in order to implement the organization -How to define and implement human resources development policy	Maintenance strategies and policies Methods and techniques of organization Principles, logic, and parameters of operation and utilization of asset and item in combination with wear and damage mechanisms Business job descriptions and roles Business objectives Legal constraints related of the management of resources, equipment and tools Skills of employees Training and coaching techniques and methods Tools and techniques for technical, organizational, and economic monitoring Technical training and coaching Concepts/methodologies, techniques, and tools of continuous improvement Process re-engineering techniques Organizational responsibilities Productivity measurement and improvement methodsMethodologies and tools to develop fit-for purpose organizations Management tools to conduct combined teams of own and third party forces
Maintenance planning and logistics	Logistics support, material and store handling, methods for spare part calculations Supportability	Procedures Methods and techniques of organization, planning and project management Principles, logic, and parameters of operation and utilization of asset and item Standards and operational methods of work
Maintenance information systems	Maintenance Information Systems -Maintenance management information systems -Technical documentation/information systems -Technical process control systems -Expert systems -Basics concerning the computer support for the topics above	Fundamentals of data acquisition and control management Features and capabilities of computerized maintenance management systems and tools Documentation and knowledge management

Table 1. *Cont.*

Category	EFNMS (1998)	EN15628 (2014)
Maintenance contracting and economics	How to develop and use key-figures for the economical control LCC/LCP techniques/methods	Maintenance contracting -Methods and policies for the procurement of materials, materials and spare parts logistics, and the management of materials and warehouses -Contractors policies and management systems -Contractual general conditions and technical specifications Economical decision options Cost calculation methods and schemes
Asset management /lifecycle engineering	The maintenance activities in the development and procurement of new production equipment The essential contribution from the maintenance activities to achieve good product quality and good production performance Quality assurance	Quality management system
Reliability engineering	Reliability Maintainability Supportability Availability Improvements of the availability performance Human reliability Production safety Risk analysis Laws and regulations (technical aspects)	Reliability analysis methods and techniques
Heath, safety and environment	How to assure (by maintenance activities) the health and safety and the right environment conditions (inside and outside the company) Production safety Risk analysis	Legislation, technical standards and integrated management systems for safety, health, and environmental protection Techniques and methods for risk assessment Sustainability principles
Others	Laws, regulations -Laws and regulations regarding labor, liability, guarantee environment, energy, etc.	Basic principles of the communication -Sound capability of customers language, needs and requirements -Negotiation techniques -Communication and presentation Techniques Problem-solving methods

2.2. Study Design

The main objects of study are the curricula and courses of engineering programs in Sweden. Swedish higher education follows the Bologna structure [36]: first cycle comprises years 1–3, second cycle years 4–5, and third cycle years 6–9. For engineering education, however, there are differences in the national system with regards to the Bologna structure, see Figure 1.

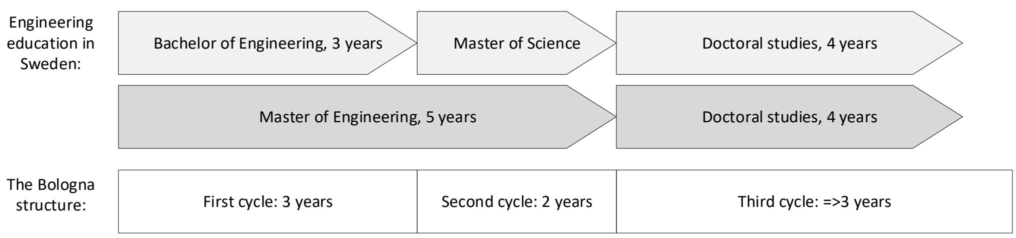

Figure 1. The Swedish higher education system for engineering sciences.

One year of study corresponds with 60 credits, which equals 60 credits worth of studies according to the European Credit Transfer System (ECTS). However, as the Swedish grading system differs from the ECTS-grading system, the terminology of the Swedish academic credit system is used in the paper to avoid confusion. Academic merit is thus referred to in terms of "credits". In Sweden, most engineering students undertake either a three year program resulting in a Bachelor of Engineering, or a five year program resulting in a Master of Engineering. These programs have different entry requirements, whereas the prerequisites especially in mathematics are higher for the five year program. The program contents are regulated in one curriculum for the Bachelor of Engineering and one for the Master of Engineering [37]. Students with a Bachelor of Engineering degree could enter a one year or two year program on the second cycle, earning a Master of Science. The Master of Science and Master of Engineering are not equivalent, even if the number of study years are the same. The curricula as well as knowledge content differ, as the outcomes for the "three plus two" path follow the curriculum for Bachelor of Engineering plus a general Master of Science, while the five-year path follows the Master of Engineering curriculum.

The universities are responsible for the establishment of programs and courses. The programs and courses are formally regulated in program and course syllabuses stating the prerequisites, objectives, and content. For courses, the teaching methods and reading material is often mentioned in the syllabus as well.

For collecting information regarding available Swedish engineering programs in this study, the search engine provided by Swedish Council for Higher Education at *antagning.se* [38] was used. Antagning.se is the official website for admission to higher education in Sweden. The search engine is an integrated part of the national admission system, with content regularly updated by the universities. Consequently, it is an accurate source for searching available programs and courses but also convenient, as the search could be delimited, e.g., to specific degrees. The search engine was used for finding available engineering programs starting in the autumn semester 2019. Two searches were conducted in June 2019, one delimited to Bachelor of Engineering programs, and one delimited to Master of Engineering programs. This resulted in a list of totally 242 programs; 123 within Bachelor of Engineering and 119 within Master of Engineering; see Figures 2 and 3. The education programs in Figures 2 and 3 are sorted by main subject area. Multidisciplinary programs, covering two or more main areas, and specialized programs are found under the rubric "Other engineering". At the bachelor's level, *Computer Engineering*, *Civil engineering*, and *Mechanical Engineering* are the top programs, while *Computer Engineering*, *Engineering Physics,* and *Industrial Engineering* are top programs at the master's level. The master's level contains a higher number of specialized programs as well.

The official university web pages were thereafter visited in September 2019 for the collection of program and course specific information. The program syllabuses were identified and downloaded, and a first text search within the program syllabus was made using the key words "maintenance", "availability", and "reliability" (In Swedish, "underhåll", "driftsäkerhet", and "tillförlitlighet"). Searching the full documents ended up in 55 hits. The hits were located to general program descriptions as well as to specific courses within the program. It could be noted that a total of 66 maintenance-related courses were identified, spanning from program courses to elective courses and industrial training courses. Further, only the courses directly connected to an engineering program either as mandatory or elective course were investigated. The courses accounted for in Figures 2 and 3 are thus courses that were found in the program syllabus.

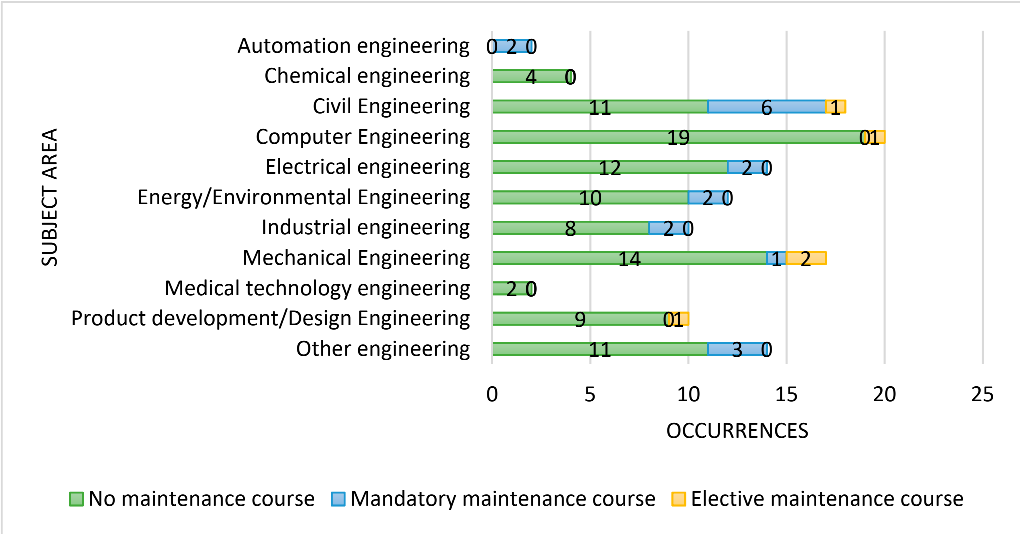

Figure 2. Bachelor of Engineering programs included in the study (programs starting in autumn 2019).

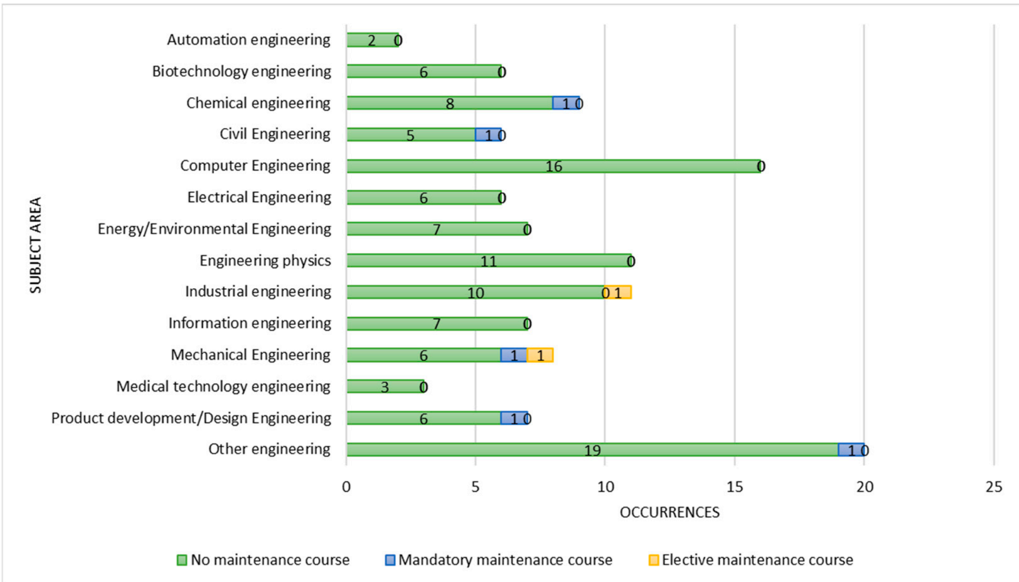

Figure 3. Master of Engineering programs included in the study (programs starting in autumn 2019).

In total, 30 programs (of 242) included courses within the maintenance area. Of these, 23 included mandatory courses, and 7 included elective courses; see Figures 2 and 3. The number of unique courses identified were 36. These programs are mostly found within *Civil Engineering*, *Mechanical Engineering*, *Industrial Engineering*, and *Other Engineering*. In the category Other Engineering Programs, two Bachelor of Engineering programs were found with specialization in maintenance. According to the first program description, the program is developed in close collaboration with industry and gives the students the opportunity to work with real-life problems, such as how industry could reduce its climate impact. The program provides knowledge in technology and production maintenance that is needed to develop safe and long-term sustainable production. The second program highlights the technological industrial advancements, such as artificial intelligence, sensors, and big data. According to the program description, the education provides foundations and tools in maintenance engineering, so that the students could be part of the journey toward a sustainable industry and infrastructure.

The course syllabuses were retrieved from the university web pages and downloaded locally to create the main study database. Moreover, a search on the university web pages using the key words mentioned above was made for identifying relevant single-subject courses. Further investigation by inquiring the program responsible through phone or mail was conducted in case a program syllabus claimed that students after taking the program would acquire knowledge in the maintenance area, but no maintenance-related courses were listed in the course list.

Basic data regarding the 36 courses were first extracted: name, level, credits, subject area, forms of teaching, forms of examination, program type and level, and whether the course was obligatory or elective. This information is found in Appendix A. Thereafter, the course content was mapped with respect to the categories in Table 1 using conceptual content analysis. The courses were also classified according to whether the course was a general maintenance-related course or a course within a specific maintenance domain.

3. Results

It was found that 12% of the engineering programs include one or more maintenance-related courses, either mandatory or elective, as seen in Figures 2 and 3. Mandatory maintenance-related courses are found in 23 out of 242 programs, or 9.5% of the total programs. These courses are more common at the Bachelor of Engineering level, at 19%, of which 15% are mandatory. By contrast, only 6% of the Master of Engineering programs include maintenance-related courses, of which 4% mandatory.

Of the 36 courses in total, 33 are first-cycle courses, and three courses second-cycle courses, as seen in Table 2. There is no direct correlation between course level and program level; two of the second-cycle courses are mandatory in the Bachelor of Engineering programs. Similarly, five of the six courses offered at Master of Engineering programs are first-level courses. The typical length of a course is 7.5 credits, which corresponds to 1/8 of a year full-time study. Looking at the number of credits within a program, the span is 6–60 credits. The main part of the programs includes one course of 6 or 7.5 credits. Some programs offer two courses or longer courses of 10–15 credits. Two Bachelor of Engineering programs are specialized in maintenance engineering, and these programs comprise 57 and 60 credits, respectively (out of 180 credits in total). The number of credits does not fully reflect the maintenance-related content that is taught, as some courses combine maintenance topics with other topics. We are going to discuss this matter under the Discussion section. Of the 36 courses in total, 20 are courses with distinct maintenance focus, 2 are degree thesis courses, and 2 are within reliability engineering, while the rest (12 courses) have a main focus in other areas, such as facilities management or quality management but with maintenance-related content.

Longer courses are project courses or degree courses, with two exceptions: one course of 10 credits covers both quality and maintenance subjects, and one 15 credits course is mainly in the area of facility management, where maintenance planning forms a smaller part. The subject area of the course corresponds to high degree with the program in which the course is taken. For example, the course *Building Services and facility management* is within the subject area Civil Engineering and is taken by the students at the Bachelor of Science Program in Civil Engineering, and the course *Maintenance Technology* with subject area Mechanical Engineering is read by students in the Mechanical Engineering, Industrial Engineering and Management, and Automation Engineering programs. Most courses are based on traditional teaching in the form of lectures, exercises, and laboratories and are assessed with written examination, assignments, and exercises. Two courses use a flipped classroom approach and are offered as distance-based alternatives. Some courses include project work in addition to traditional teaching methods, and a few are entirely project based.

Table 2. Summary of the conceptual content analysis.

Course #	Level	Classification	Terms and Standards	Maintenance Engineering	Management and Organization	Maintenance Planning and Logistics	Maintenance Information Systems	Maintenance Contracting and Economics	Asset Management/Lifecycle Engineering	Reliability Engineering	Heath, Safety, and Environment
1	First cycle	Infrastructure (Buildings)	x	x		x	x				
2	First cycle	Production systems		x							
3	First cycle	Production systems		x	x			x	x		x
4	First cycle	General								x	
5	First cycle	General	x	x	x			x			
6	First cycle	Infrastructure (Wastewater)		x							
7	First cycle	Infrastructure (Roads)		x							
8	First cycle	Infrastructure (Roads)		x							
9	Second cycle	Infrastructure (Roads)		x			x	x			x
10	First cycle	General		x		x	x	x			
11	First cycle	Infrastructure (Buildings)				x					
12	First cycle	Infrastructure (Buildings)			x	x					x
13	First cycle	General (Hydropower)	x	x	x	x	x	x	x	x	x
14	First cycle	General		x	x	x	x	x		x	
15	First cycle	General								x	
16	First cycle	Infrastructure (Roads, Wastewater)		x				x			
17	First cycle	Software systems		x	x				x		
18	First cycle	Production systems		x							
19	First cycle	General		x			x		x	x	
20	First cycle	General (Building, Road)	x	x	x	x	x	x		x	
21	First cycle	Chemical systems		x							
22	First cycle	Production systems		x						x	x
23	Second cycle	General		x		x	x	x		x	
24	First cycle	Production systems		x	x						x
25	First cycle	Production systems		x		x				x	
26	First cycle	General		x	x	x	x	x		x	
27	First cycle	Production systems									
28	First cycle	Production systems					x				
29	First cycle	Production systems		x			x				
30 [1]	First cycle	Production systems									
31	First cycle	General	x	x				x		x	
32	First cycle	General (Production)		x	x				x		
33	First cycle	General								x	
34	First cycle	General		x							
35	Second cycle	General		x			x				
36 [1]	First cycle	General									

[1] Degree course.

The content analysis showed that 33% of the courses covered only one maintenance knowledge category; see Figure 4 and Table 2 for details. These courses are found in the categories of *Maintenance engineering*, *Maintenance planning and logistics*, *Maintenance information systems*, and *Reliability engineering*. In most of these courses, the maintenance-related content forms a minor part of the total course content. The typical content is maintenance connected with the specific subject area, such as: "Conduit maintenance (renovation, renewal and improvement)", "Road and street operation and maintenance", and "Maintenance of roads, streets and bridges", or basic maintenance and reliability knowledge, expressed, e.g., as: "Basic (concepts in) maintenance technology, Preventive and corrective maintenance", "Maintenance planning", "Total Productive Maintenance", and "Reliability engineering: definitions, theories, tools, methods, models and concepts".

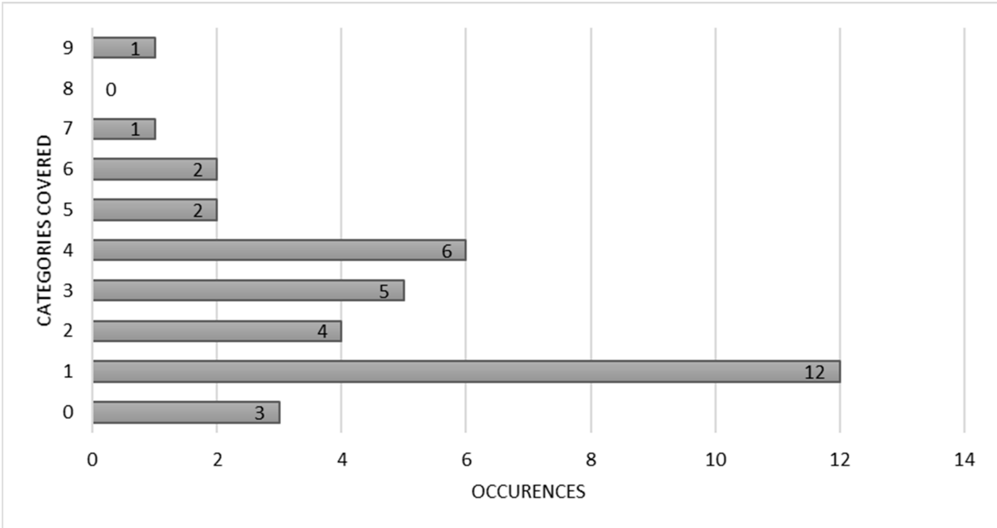

Figure 4. Knowledge categories covered.

This is also seen in the classification of the maintenance-related content in the courses: the courses are either general, i.e., teach general maintenance knowledge, or specialized with respect to the system to be maintained, such as infrastructure systems, production systems, software systems, or chemical systems. The three courses did not cover any of the knowledge categories, which is explained by their nature: two are degree thesis project courses and one a project course, where the topics are chosen individually for each project. An interesting observation is that one course covered all knowledge categories. This is a mandatory course for students at two Electrical Engineering programs at a bachelor's level. The course name indicates that it is specialized for hydropower, but the course content is expressed in general terms except for the formulation: "Maintenance within hydropower, for example inspection routines".

In Figure 5, the frequency of knowledge categories is displayed. The knowledge category *Maintenance engineering* is covered in 75% of the courses. *Reliability engineering* and *Maintenance information systems* are topics covered in 33% of the courses. Less frequent topics are *Terms and standards*, *Asset management/Lifecycle engineering*, and *Health, safety, and environment*. From Table 2, the most frequent topic combinations for each knowledge category could be extracted. The category *Terms and standards* is mainly combined with Maintenance engineering and Maintenance information systems. *Maintenance engineering* is combined with Management and organization, Maintenance information systems, Maintenance contracting and economics, and Reliability engineering. This correlation is double directed, i.e., the topics of *Management and organization*, *Maintenance information systems*, *Maintenance contracting and economics*, and *Reliability engineering* are mainly combined with Maintenance engineering. In addition, *Health, safety, and environment* is also mainly combined with Maintenance engineering. *Maintenance planning and logistics* is combined with

Maintenance engineering, Maintenance information systems, and *Asset management/lifecycle engineering* is combined with the topics Maintenance engineering and Management and organization. Maintenance engineering is thus a common denominator when a topic is combined with other topics, with one exception. The exception is a course named *Management and Maintenance of Buildings* that covers the knowledge categories Management and organization, Maintenance planning and logistics, and Health, safety, and environment. The course is within property management, covering methods and tools, guidelines, and standards in the area of property management as well as planning, implementation, and follow-up of the condition assessment of buildings. It includes a major project work where the student develops a plan for the management and maintenance of a building.

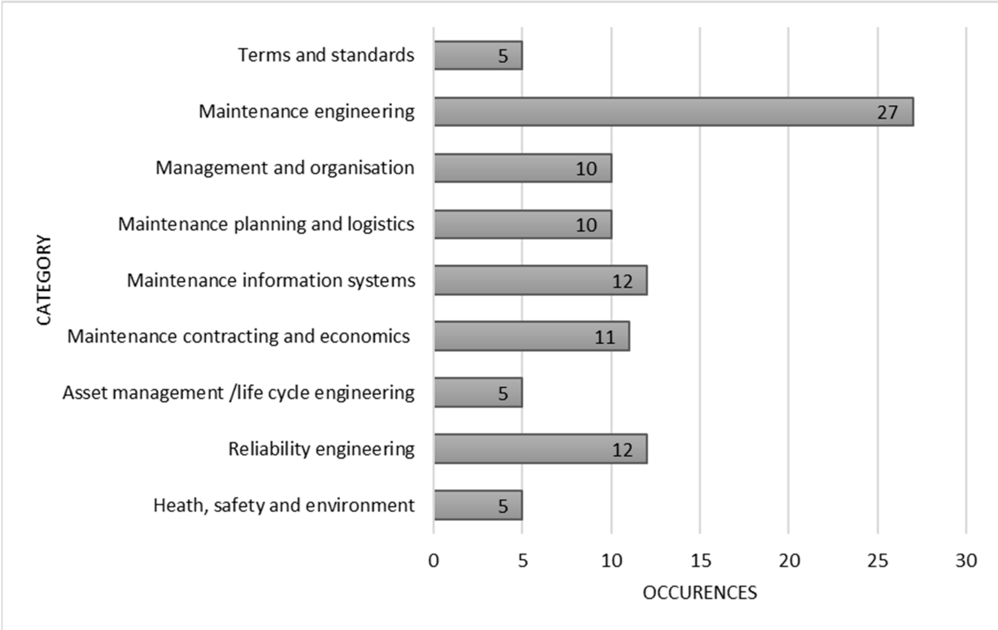

Figure 5. Frequency of categories covered.

The knowledge coverage of the two Bachelor of Engineering programs with a specialization in maintenance is rather good according to the content in the course syllabuses, as seen in Table 2 (the courses within the two programs with specialization in maintenance engineering are #24–30 and #31–36, respectively). The first program has good coverage in both engineering and management-related topics but lacks content regarding *Terms and standards* and *Asset management and lifecycle engineering*. The other program covers engineering topics to a high degree but lack content in the areas of *Maintenance planning and logistics* and *Health, safety, and environment*. It should be noted that these are results based on the formal content of the course syllabuses, while the knowledge content could be implicitly included in one of the courses or found in other courses taught in the program; see the next section for a discussion.

4. Discussion

According to the course syllabuses that comprise the education programs, only around one-tenth of the programs include maintenance-related topics. The percentage is somewhat higher for three year Bachelor of Engineering programs, while only about 5% of the five year Master of Engineering programs include maintenance-related topics. Computer engineering, electrical engineering, chemical engineering, and product development engineering programs are examples of programs with limited or no maintenance-related elements. The difference between the Bachelor of Engineering and Master of Engineering programs in Sweden is sometimes expressed in terms of future work roles. While a Bachelor of Engineering often obtain positions at a supervisor level, a Master of Engineering often ends up in a managerial position. From this perspective, it is quite unfortunate that the Master of Engineering students do not retrieve basic knowledge regarding the maintenance of assets, as they will be responsible for decisions regarding the assets.

The total amount of teaching in maintenance-related topics for a single student is somewhat hard to estimate as the maintenance-related content does not conform with the total number of credits in a specific course. By estimating the content distribution from the course content descriptions, some students acquire as low as less than one credit's worth of studies within maintenance-related topics, while others have 7.5 credits, with a mean of around four credits (not taking into account the two programs specialized in maintenance). According to [4], all engineers should retrieve a basic understanding of the different phases in the lifecycle of a product or a system. Moreover, engineers have a driving role in the development and innovation of the industry and society. Therefore, understanding how this development impacts the societal, enterprise, and individual levels forms part of the core engineering competence requirements, namely engineering ethics [39]. The lack of maintenance-related education makes the future engineers less prepared to make good decisions and judgements that might affect the operational phase of the product or system.

The knowledge categories covered in the 36 courses are mainly core maintenance or reliability engineering topics. As seen in the analysis of topic combinations, maintenance engineering forms a basis and is often combined with knowledge of planning, economics, information systems, or reliability engineering. The courses thus tend to be either technical or managerial in nature. Typical technical courses cover maintenance and reliability engineering topics, while managerial courses cover maintenance engineering topics in combination with knowledge regarding maintenance planning, contracting and economics, or information systems (for the management of maintenance). Moreover, the course content is often correlated with specific subject areas, such as the maintenance of infrastructure, production systems, or energy systems. Engineering education in Sweden has strong focus on industry collaboration, employability, and sustainability; see for instance [40,41]. In the context of this study, this is seen in the two Bachelor of Engineering programs aimed at educating maintenance engineers and asset experts, which are both developed in cooperation with industry fulfilling regional needs, as well as national needs [42]. The two programs have both a strong focus in advanced technology and sustainability. The technology focus is clearly reflected in the courses within maintenance and reliability engineering; the first program has one course dedicated to condition-based maintenance, sensor technology, and maintenance-related information systems, and another course within the topic of Industry 4.0 and its applications. The second program includes a project course in sensor technology, condition monitoring, and data analysis, and a course in eMaintenance covering the whole process from data acquisition to decision making. The latter covers contemporary topics such as big data management and cloud computing. The sustainability aspect is, in the first program, covered in several courses, both general and related to different topics such as production economy and maintenance. Sustainability is covered in several courses in the second program but as noted in the results above, not explicitly in the maintenance-related courses. From a maintenance competence perspective, the two programs offer good coverage either in the specific maintenance-related courses or in other courses that are included in the programs.

Offering specialized programs is one way to strengthen the maintenance-related engineering competencies, but for the main part of the engineering programs, other means are required. One reason to the poor coverage of maintenance-related training and education could be the lack of resources and competence [12]. More support is needed for maintenance-related education, for instance in the form of syllabuses, teaching material, and textbooks. For the Swedish context, this could be strengthened by providing teachers with easy-to-use or easily accessible material. Basic textbooks in the native language and online courses that could be incorporated into the engineering programs without the necessity to hire teachers with specific maintenance competences are two examples of such material. Another option is industry collaboration, for instance using the experiences and knowledge of maintenance engineers as basis for lectures and seminars or creating industry-related projects that give the students the necessary knowledge and competence.

In this study, the program curricula and course syllabi that explicitly include maintenance-related content was explored using a theoretical framework based on industry standards. Using the industry standards in the higher education leads to benefits as well as drawbacks. The standards reflect the industry needs for specific knowledge and skills, which ensures that relevant competencies are covered. The main drawback is the potential that the standards operationalize the knowledge content on too detailed of a level or cover areas that are less relevant in the higher education context. To handle this issue, the standards EFNMS and EN15628 were used to create relevant categories of coding for the content analysis, rather than for mapping on a detailed level. The nine categories used are all directly related with maintenance and reliability topics and thus are relevant for the purpose of the study. However, several categories could be seen as general topics put into the specific context of maintenance and reliability. Engineering economics, for instance, might cover lifecycle costs, and the topic of health, safety, and environment might be covered in courses within sustainable development. With a strong emphasis on sustainability and sustainable development in Sweden, several engineering programs include courses in sustainability topics. It could be argued that generic knowledge of this kind could be transferred into a specific context. This logic assumes that the students have gained the basic understanding of maintenance and reliability, and according to the findings, few programs offer this. Although several programs, especially within civil engineering and energy engineering, mention that the program aims at providing knowledge and skills covering the whole-system lifecycle, from conceptualization to operation and maintenance, they do not include a specific course in maintenance and reliability. The knowledge of maintenance might be included in one of the core courses, such as building technology or energy technology. To explore this further, a survey study would be appropriate.

As the number of similar studies is limited, it is hard to do a thorough comparison of the findings in an international context. The study of industrial engineering and mechanical engineering programs in Sweden and Finland reported in [12] found that less than 15% of the programs offered maintenance courses, i.e., similar findings as in this study. In [14], a nonsystematic review of maintenance-related education in mechanical engineering, industrial engineering, and production engineering fields of study is found, focusing on course content, and not on the extent of maintenance education offered. The results in [14] correspond with the findings of this study with respect to knowledge categories covered but differ with respect to frequency of categories covered, in that most courses covered three or more categories. A cross-case analysis of maintenance-related education, e.g., in the European context would be an interesting extension of this study.

The focus of this study is maintenance-related education in Swedish engineering programs, and therefore, the implications are valid beforehand within the study framework. However, some generic conclusions could be drawn upon the study design. (1) The program curricula and course syllabi were comprehended as relevant sources for the study, as they reflect the content as well as the intentions of the programs. This approach could be applied for other areas of education than engineering, and for studies of education content in other countries, allowing for crosscase analysis. (2) Finding relevant coding categories when conducting deductive content analysis is important, and the available standards provide a good basis. Several studies use either industry standards and certifications, or national and international standards in specific educational contexts as the theoretical basis, e.g., [7,16,21,28]. However, if industry standards are used for the purpose of content analysis, the fitness-of-use for the level and type of education has to be taken into account when developing the coding categories.

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Appendix A

Course #	Level	Credits	Subject Area	Forms of Teaching	Forms of Examination	Program Type	Bachelor or Master	Obligatory or Elective
1	First cycle	7.5	Civil and Environmental Engineering	Lectures, literature studies, seminars, exercises, and tutorials	Project work	Civil Engineering	B	O
2	First cycle	7.5	Industrial Engineering	Lectures, exercises and written assignments	Written examination, individual assignments	Energy/Environmental Engineering	B	O
3	First cycle	7.5	Mechanical engineering	Lectures, lessons	Written examination, written assignment	Mechanical Engineering, Industrial Engineering, Automation Engineering	B	O
4	First cycle	7.5	Industrial economics	Lectures, seminars, labs and project work	Written examination, laboratory, project work	Industrial Engineering	B	O
5	First cycle	6	Industrial Engineering	Lectures, group assignments	Written examination, written assignment	Other Engineering	B	O
6	First cycle	6	Building Technology	Lectures, exercises	Written examination	Civil Engineering	B	O
7	First cycle	6	Building Technology	Lectures, exercises	Written examination, exercises	Civil Engineering	B	O
8	First cycle	7.5	Building Technology	Lectures, exercises, laboratory work	Written examination	Civil Engineering	B	O
9	Second cycle	7.5	N.a.	Lectures, exercises, laboratory work, project work	Project reports, oral examination, written examination	Civil Engineering	B	O
10	First cycle	7.5	Energy Technology/Chemical Engineering	Lectures, study visits, project work	Web based examination, written assignment, study visit	Automation Engineering, Energy/Environmental Engineering	B	O
11	First cycle	15	Civil Engineering	Lectures and tutoring in connection with laboratory work, group work andprojects	Exercises, presentations, written examination	Civil Engineering	B	O
12	First cycle	10	N.a.	Lectures, seminars, workshops, study visits, major project work, tutoring	Participation in study visits and seminars, assignments, written and oral presentation of project assignments	Civil Engineering	B	O
13	First cycle	7.5	Maintenance Engineering	Lectures, case study, assignments, study visit	Written examination, assignments	Electrical Engineering	B	O
14	First cycle	7.5	Mechanical engineering	Lectures, seminars, exercises, individual-/group-based work	Written examination, practical exercises/laboratory, project work	Industrial Engineering, Mechanical Engineering	B	O/E
15	First cycle	7.5	Mechanical engineering	Lectures, exercises, seminar	Written examination, assignments	Industrial Engineering	B	E
16	First cycle	7.5	Technology	Lectures, exercises	Written examination, exercises	Civil Engineering	B	E
17	First cycle	7.5	Technology	N.a.	Report, exercises	Computer Engineering	B	E

Course #	Level	Credits	Subject Area	Forms of Teaching	Forms of Examination	Program Type	Bachelor or Master	Obligatory or Elective
18	First cycle	7.5	Industrial Management, Mechanical Engineering	Lectures, laboratory sessions, study visits, case studies, seminars	Written examination, literature seminars, laboratory sessions, assignments, case report	Mechanical Engineering	B/M	E
19	First cycle	6	Technology	N.a.	Written examination, exercise, project work	Mechanical Engineering	M	O
20	First cycle	7.5	Maintenance Engineering	Lectures, group discussion and homework	Written examination, Group work/assignment report	Civil Engineering	M	O
21	First cycle	7.5	Chemical Engineering	Lectures, study visits, tutoring, laboratory work	Project work, oral presentation, laboratory report, written examination	Chemical Engineering	M	O
22	First cycle	10	Mechanical Engineering	Lectures, hands-on exercises, laboratory	Written examination, assignments	Other Engineering	M	O
23	Second cycle	7.5	Mechanical Engineering	Lectures, seminars	Home examination, assignments	Product development/Design Engineering	M	O
24	First cycle	6	Technology	N.a.	Assignments, written examination, exercise	Other Engineering	B	O
25	First cycle	6	Technology	N.a.	Project work, written assignment	Other Engineering	B	O
26	First cycle	7.5	Technology	N.a.	Assignment, laboratory work, project work, written examination	Other Engineering	B	O
27	First cycle	7.5	Technology	N.a.	Project work, exercise	Other Engineering	B	O
28	First cycle	7.5	Technology	N.a.	Assignment, seminars, written examination	Other Engineering	B	O
29	First cycle	7.5	Technology	N.a.	Assignments, seminars	Other Engineering	B	O
30	First cycle	15	Technology	N.a.	Thesis project	Other Engineering	B	O
31	First cycle	7.5	Maintenance Engineering	Recorded lectures, discussion sessions (flipped classroom)	Written examination, assignments	Other Engineering	B	O
32	First cycle	7.5	Maintenance Engineering	N.a.	Written examination, assignments	Other Engineering	B	O
33	First cycle	7.5	Maintenance Engineering	Recorded lectures, discussion sessions (flipped classroom), study trip	Written examination, assignments	Other Engineering	B	O
34	First cycle	15	Maintenance Engineering	Decide on a case by case basis	Project report	Other Engineering	B	O
35	Second cycle	7.5	Maintenance Engineering	Lectures, lessons, practices and laboratory work, project work, tutoring	Assignments, laboratory work	Other Engineering	B	O
36	First cycle	15	Maintenance Engineering	Degree project, tutoring	Written and oral presentation	Other Engineering	B	O

Courses within the two programs with specialization in maintenance engineering are #24–30 and #31–36, respectively.

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