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Article

Smart Automotive E-Mobility—A Proposal for a New Curricula for Engineering Education

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Abstract: Automotive engineering is an area of great value and development. Lately, it has evolved rapidly because of autonomous vehicles. The development of smart mobility will be crucial in the coming years. Related research and companies related to intelligent transportation require trained and capable engineers. It is essential to generate an updated and specialized academic program that provides state-of-the-art technologies and related areas with smart mobility. This paper presents a novel two-year graduate academic program focused on smart electromobility. Programs around the globe were analyzed to find opportunity areas related to autonomous and electric vehicles, and smart mobility. Multi- and transdisciplinary courses were designed, according to the findings, on areas related to computer science, mechanical and electric engineering, law, marketing, and public policy. The proposed program fulfills the needs of a graduate student who will later work in a smart electromobility environment. The program offers a balanced curriculum that includes technical, business and social courses. Virtual and physical labs are proposed to develop a high-quality educational experience. This proposal can be used as a model for upcoming and related programs in other universities.

Keywords: smart mobility; electromobility; autonomous vehicles; automotive engineering; mechatronics; artificial intelligence

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1. Introduction

The continuous and innovative developments related to autonomous vehicles (AV) during the last decade have had an economic, educational, industrial, political, and social impact. It is likely that this trend will continue in the upcoming years. As happened in previous industrial revolutions, the development of AVs will likely generate a paradigm shift. Consequently, the job market will change. The number of jobs that could be lost because of poorly qualified professionals is estimated to be greater than four and a half million [1–3]. However, the number of new jobs related to AVs is expected to outnumber the ones lost. Continuous and high-quality training can mitigate and prevent unemployment. Automotive workers are expected to have a broader and more flexible set of skills. University and open-education programs are required to provide means to facilitate personal and professional development [3–5]. The offered curricula should be improved and enhanced in areas related to smart, autonomous electromobility (SAEM) [6,7]. This work presents a graduate program with a balanced curriculum focused on SAEM areas. Program alumni are expected to develop the necessary skills for the upcoming job market through selected courses and topics.

Smart mobility (SM) is closely related to new environments such as smart cities, energy management, and employment generation. The growth in automotive and technology companies relies on highly skilled professionals capable of developing and integrating new systems [8]. Designers, engineers and computer scientists must work together to develop new vehicles that comply with the needs of the future for efficient, sustainable and safe operation [9]. Computer scientists and software engineers will focus on creating algorithms and efficient code that enables AVs to successfully navigate diverse environments. Electrical engineers should work on sensor performance and architecture, user experience, and system integration. Designers and mechanical engineers must focus on designing and improving manufacturing processes to achieve ecofriendly, modular, robust, and lightweight vehicles [10,11].

The SM ecosystem does not only consist of AVs. Companies and professionals outside the SM design and development areas are also required to ensure the adoption of all involved actors [12–14]. Business management, marketing, and communication are responsible for highlighting the benefits of the SM ecosystem. Their work enables the creation of new markets and the engagement and adoption of the related technology. Public and private companies should focus on using reliable automotive platforms that cover the diverse needs of all types of users who do not need to own a vehicle [15]. Current laws and regulations must be enhanced and modified to allow the adoption of AVs. Proper norms and standards should be created to determine the reach and responsibilities of every actor in the ecosystem. Likewise, AV companies must ensure the proper performance of their vehicles, to comply with mandatory regulations [16]. These, and other complementary roles, are necessary to consolidate the SM environment.

From an educational perspective, curricula in engineering are constantly changing. Integrating new technologies into academic programs is key to keep up with industry- and research-related trends [17–19]. Topics related to industry 4.0 and engineering education are highly important, to ensure flexibility and capability in SAEM engineering undergraduate or graduate students [20–23]. Framework proposals to improve mobility in smart cities as part of industry 4.0 consider industrial, research and educational models [24–27], and logistics strategies for better practices in sustainability and smart mobility [28–30].

As a consequence, smart education (SE) [31–34] seeks to integrate trending technologies such as the internet of things (IoT) [35,36]. Intelligent transport systems (ITS) and electric and autonomous vehicles have been the main topic of SE platforms that foster technical and social skills in students [37–45]. These platforms include large-scale vehicles that can be used to transport goods or people [42,46]. Digital twins or simulation platforms have been developed with this same objective, allowing the emulation of hardware and dynamic models of the different modules that are integrated within a vehicle [47–50]. Related works depict physical SM micro-ecosystems oriented for research and training [51,52]. These environments are focused on the production and manufacturing of AVs and electric vehicles [53,54], autonomous driving-assistance systems (ADAS) [55,56], or software development for automotive applications [57,58]. Engineering students are likely to deride the relevance of humanities, and ethics. These fields are highly important for an integral education. A broad perspective empowers human beings to evaluate the impact of their developments [59,60].

1.1. Automotive-Engineering Graduate Programs

Specialized graduate university programs offer online, hybrid or face-to-face master's degrees centered on specific topics related to automotive design, manufacturing or driver-assistance technology. We searched and compared the most academically impactful programs and the most up-to-date academic curricula from various universities on these specific topics. We analyzed top master's degree programs in automotive engineering from prestigious institutions. The selected courses are listed in Table 1. Additionally, we classified the curricula of the programs in Table 1 into eight course categories:

1. *Advanced Driver-Assistance Systems (ADAS)* includes innovative topics on modern approaches to navigation and visual perception for self-driving vehicles. These topics include machine and reinforcement learning, neural networks and other artificial intelligence (AI) approaches.
2. *Chassis* considers topics regarding vehicle dynamics and control in all the relevant degrees of freedom. Aspects regarding instrumentation and measurements are also included in this category.
3. *Electrical engineering and communications (EE&Comms)* deals with digital and embedded systems that enable the execution of control and AI tasks. Real-time operating systems are also covered.
4. *Product design* accounts for industrial design, interior design and ergonomic aspects. It also foresees aspects of production management, quality control and sustainable materials.
5. *Powertrain* includes topics regarding propulsion technologies—internal combustion engines or electric machines—together with their management and control.
6. *Energy* deals with aspects of energy storage, management, and optimization.
7. *Numerical* simulation courses in the relevant physical domains are included. They subsume both lumped-parameter and finite-element techniques.
8. *Safety* for passengers, pedestrians and other drivers is covered in this category. Regulations and policy are also paramount.

We propose these categories as the topics with the greatest current impact on SM and automotive engineering. They will also be part of the fundamental base of the topics of the curricula proposed in this work.

The radar maps shown in Figure 1 summarize this classification for the programs of fourteen institutions in these eight course categories. Each radar depicts the total academic offer (core and optional curricula) of each graduate school. In each program, the units and/or hours (depending on the institution) of each course were classified, then each category sum was divided by the total hours and/or units of the program to obtain the radar map scale. In the cases where multiple programs were offered, radar maps were superimposed in the same chart. This classification shows that most programs rarely provide an integral overview of the opportunity areas in technical and social fields. Furthermore, when programs show a balanced curricula, this is usually not attained by the students, as many courses are elective.

Table 1. Selected academic university SAEM programs comparison (FF = face to face).

Master's Course Name	University or Company	Mode	Country/Language	Duration [months]
Automotive Technology	Eindhoven University of Technology	FF	Netherlands/English	24
Automotive Engineering	University of Leeds	FF	UK/English	12
Automotive Engineering	RWTH Aachen University	FF	Germany/English and German	18
Automotive Engineering	Polytechnic University of Turin	FF	Italy/Italian and English	24
International Automotive Engineering	Royal Melbourne Institute of Technology	FF	Australia/English	24
Automotive Engineering	University of Michigan	FF/online	USA/English	24
Global Automotive and Manufacturing Engineering	University of Michigan	FF/online	USA/English	24
Mobility engineering	Chalmers University of Technology	FF/online	Sweden/English	24
Electromobility	Politechnic University of Catalonia	FF	Spain/Spanish	24
Motors and Mechanics	Politechnic University of Catalonia	FF	Spain/Spanish	24
Connected Vehicles and Assistive Driving	Politechnic University of Catalonia	FF	Spain/Spanish	24
Automotive Engineering with Electric Vehicles	Oxford Brookes University	FF	UK/English	12
Racing Engine Systems	Oxford Brookes University	FF	UK/English	12
Electric Vehicle Engineering	University West	FF	Sweden/English	12
Autonomous Vehicles	University West	FF	Sweden/English	12
Future Vehicle Technologies	Aston University	FF	UK/English	22
Advanced Automotive Electronic Engineering	Bologna University	FF	Italy/Italian and English	24
Advanced Automotive Engineering	Universities in Emilia Romagna	FF	Italy/Italian and English	24
Master of Science in Computer Control and Automation	Nanyang Technological University	FF	Singapore/English and English	24
Masters in Mechanical Engineering	Hong Kong Unviersity	FF	Hong Kong/English	24

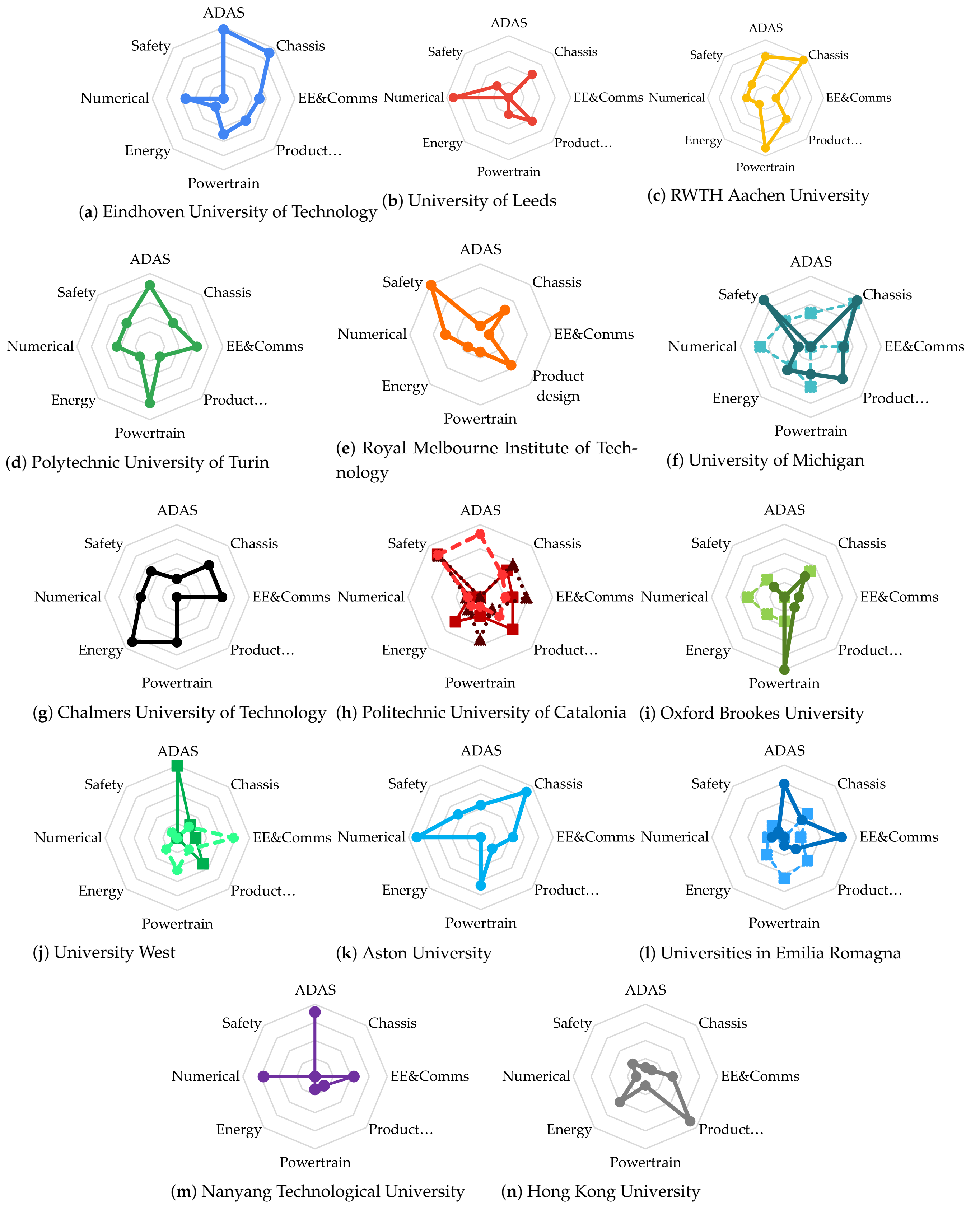

Figure 1. Radar maps for core curricula in SAEM-related master's programs in selected universities.

Each program in Tables 1 and Figure 1 specializes in a specific SM area. Eindhoven University of Technology covers almost all the basic topics related with AVs except vehicle-to-everything (V2X) communications, public policy and social topics. Programs offered by RWTH Aachen University or the University of Michigan have a complete curricula. Their only weaknesses are V2X communications and narrow driving-automation topics such as high-level ADAS. The Polytechnic University of Catalonia focuses on automotive engineering and provides an overall insight into the SM environment. However, their program is only taught in Spanish. Aston University offers a very attractive program, including internships in relevant firms. Nevertheless, topics related to automation in autonomous driving, automotive design, and non-technical issues are briefly covered. Italian universities such as the Polytechnic University of Turin and the Universities in Emilia Romagna have very extensive and complete curricula, but a vast majority of their courses are elective, which leads to very specialized engineers lacking in alternative areas. Online programs are constantly updated. They cover a wide variety of trending areas related to AVs. Their most important disadvantages are the theoretical bases around electric vehicles and automotive mechanics. Therefore, these online courses are highly recommended as refreshers and complement undergraduate or graduate programs.

The analyzed face-to-face programs focus their courses on specific and traditional topics such as automotive and mechanical design, logistics, and transportation engineering. Programs based on AVs or SM use simulators. Practical skills and physical implementations are skipped or limited. Some programs focus exclusively on technical bases and omit the legal, social, political, or economic aspects of EM. Lastly, other programs analyze logistics, standards, or social impacts, excluding technical bases. Face-to-face programs tend to be more traditional, with strong theoretical bases, whereas online programs are more specialized and trendy, but shorter and shallower.

1.2. Contributions

Previous works have attempted to cover the enhancement of graduate curricula in the described context [61,62]. Efforts have been partial or specialized in a single subset of engineering skills [63,64]. Therefore, the SAEM core curricula can be considered an evolution and integration of "classic" academic plans in automotive engineering, ITS, mobility and logistics, mechatronics, robotics, and communications. This paper proposes a curricula for engineers dedicated to designing, developing and integrating AVs in diverse SM ecosystems. It aims to balance core and optional courses that focus on the development of technical, practical, social and personal skills [65].

The present curriculum proposal is structured as follows: the required skills for an SAEM engineer are stated and analyzed (Section 2). A detailed SAEM curricula is presented and detailed. The curricula covers technical, social, and public-policy related topics (Section 3). Finally, challenges, areas of application, and conclusions are presented (Section 4).

2. Smart Automotive Electromobility Engineering

The proposed curriculum is intended for professionals aiming to join the smart city environment. Potential students can come from mechatronics, electronics, mechanics, robotics, or software areas or should be experienced in the automotive field. The graduate school candidate must have strong mathematical foundations that would be measured by a standardized admissions exam. The undergraduate curriculum of each candidate will be carefully examined to validate compatibility with the SAEM program. Computational skills will be tested in a face-to-face practical exam. The program is proposed to be taught in English to encourage the enrollment of international students. A minimum of a B2 level (CEFR) or equivalent in IELTS and/or TOEFL exams will be required. Potential students will be interviewed by a faculty member to verify the English language requirements.

The SAEM program aims to develop practical, technical, social and personal skills. These skills will help the program alumni to perform in the diverse technological, industrial, and governmental sectors that are part of the SM environment. The SAEM graduate will be capable of generating and implementing optimal, effective and suitable solutions related to transportation and mobility. The graduate will be able to work in research and development positions related to the technologies that surround SM, such as software, mechanics, robotics, design, logistics or project management, in this field. With this, the graduate has the ability to integrate and meet SM needs in manufacturing, as well as being able to shape the electromobility ecosystem as a product or service for the benefit of smart cities. The proposed program is based on intelligent transportation, EM, automotive mechatronics, digital communications, robotics, social, economic, political, and legal topics. Figure 2 depicts the SAEM program.

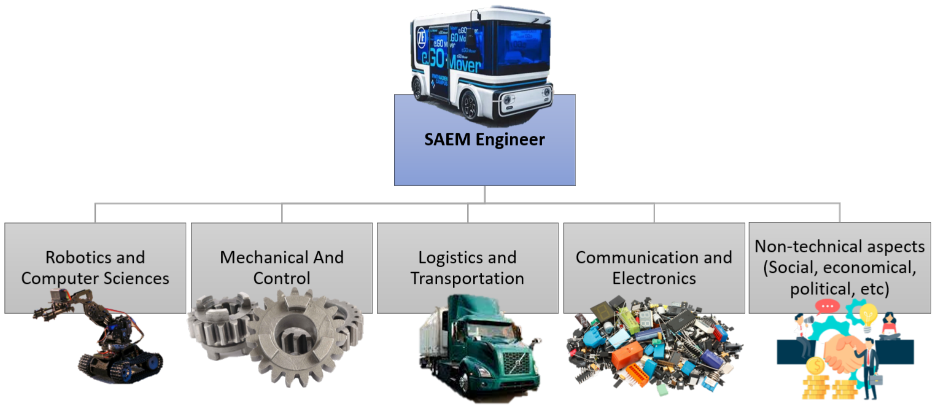

Figure 2. Main bases that constitute an SAEM Engineer.

The SAEM curricula is more balanced than the ones offered by other graduate school programs. This approach provides the alumni with a general panorama of the trending smart-mobility environment. This property allows young alumni to easily join any of the studied areas. On the other hand, experienced professionals will obtain an environment overview.

We generated a general comparison in Table 2 regarding the topics of navigation, software development, sensors and instrumentation, propulsion and powertrains, dynamics and kinematics, electronics and communication, protocols and standards, modelling and simulations, logisitics, a social and legal overview, and management. These topics are the foundational proposed submodules for the SAEM curricula. The engineering programs that offer these topics are mechatronics, robotics, software, automotive mechanics, transportation, and electrical engineering. This general comparison was made by extracting the focus topics and courses of the various "traditional" engineering programs in the selected universities seen in Section 1 and our university. As seen in Table 2, Mechatronics engineering covers most areas proposed by SAEM. However, it does not include vehicle or transportation modeling. Similarly, automotive mechanical engineering has several strengths, but it has several loopholes in essential AVs and SM areas such as programming and electronics. Robotics engineering is complemented by the shortcomings of automotive engineering, which generally lacks focus on larger-scale propulsion vehicles. The other engineering programs have a specific focus. Electronics, software, and transportation engineering work will be on specialized modules that will be undertaken later by an SEAM engineer. As can be noted, the SAEM engineer is completely focused on the design, development, creation, and optimization of technologies for electric and AVs. With this, a comprehensive curricula is proposed that constitutes the basis to specialize an engineer in all the aforementioned areas.

Table 2. General engineering programs and topics comparison.

	Mechatronics Engineer	Robotics Engineer	Software Engineer	Automotive Mechanics Engineer	Transportation Engineer	Electronics/ Com. Engineer	SAEM Engineer
Navigation Algorithms	◑	●	○	○	◑	○	◕
Software Development	◑	●	●	○	○	◑	◑
Sensors and Instrumentation	●	◑	○	◑	○	●	◑
Propulsion and Powertrain Knowledge	◑	○	○	●	◑	○	◕
Vehicle Dynamics and Kinematics	◑	◑	○	●	◑	○	◑
Electronics and Communications	◑	◑	◑	○	○	●	◕
Vehicle Protocols and Standards	◑	◑	○	●	◑	○	◑
Vehicle Model Simulations	○	●	◑	●	●	○	◕
Transportation Logistics	○	○	○	◑	●	○	◕
Social, Economic, and Political aspects	◑	○	○	○	◑	○	◑
Engineering Management	◑	○	○	◑	◑	○	◑

● = very strong foundations, ◕ = strong foundations, ◑ = medium foundations, ○ = weak foundations.

Methodology

The presented program includes trending topics that are the main focus for industry and academia. The proposed methodology is the creation of modules that generate better theorical and practical knowledge in these specialized topics. These topics and modules were selected after the analysis and comparison of the engineering programs of the selected universities in Sections 1 and 2. Each module has a focus area with specialized topics. The electromobility-ecosystem module will have a greater theoretical load than practical, while the autonomous-navigation, vehicle-communication, propulsion and power systems modules will focus on practical development in laboratories or specialized spaces. The load of the contents will be distributed over the duration of the study plan to generate a better balance between theory and practice. Each module will be evaluated with a practical and theoretical examination. At the end of each module, the engineer will present a final evaluation and at the end of specialization, a final project that integrates all the knowledge acquired will be presented. Industry partners will provide case studies for the students to work on. Graduate-SAEM professionals will be encouraged to perform internships or apply to open positions in cutting edge companies such as Waymo, Voyage, ZF, Cruise, Ouster, Zoox, Tesla or any transportation company that is developing electric vehicles or those with a certain level of driving automation or assistance.

The following section details the proposed curricula with their study bases, hours of work, and study topics.

3. SAEM Curricula

The SAEM curricula considers the required skills of an engineer to work in an EM ecosystem. The program takes traditional and trending elements to give broader knowledge and understanding by harmonizing technical, social, and practical activities. The program is considered to last two years. Individual courses are taken in specialized spaces and laboratories equipped with appropriate software and hardware platforms. Flexibility and project-based learning are important elements to ensure a memorable learning experience. The main modules of the programs are Autonomous Navigation Systems, Propulsion and Power Systems, Communications, and Electromobility Ecosystems. Each module lasts 36 h, in which theoretical content will be covered and applied in lab sessions. Figure 3 depicts the modules of the SAEM program.

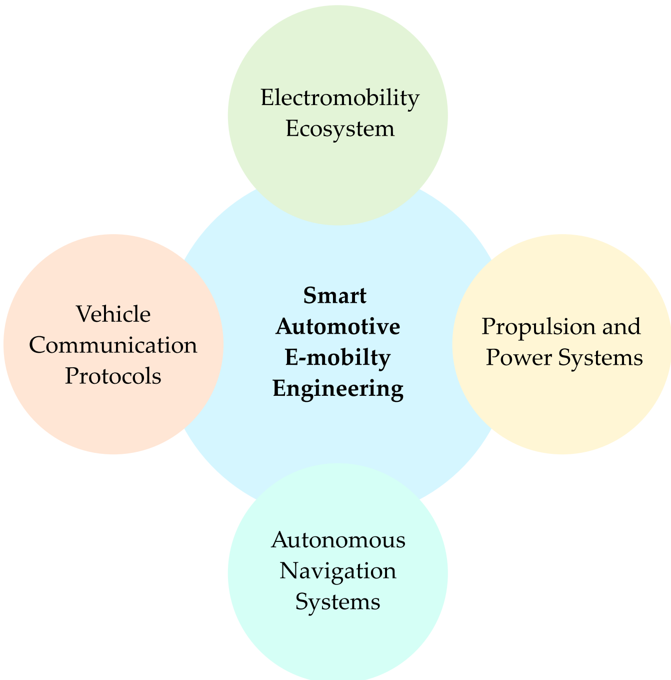

Figure 3. Main modules of the proposed major curricula.

1. *Autonomous Navigation Systems*. This module is based on computer science, software engineering, electronics, and robotics. The most relevant high-level algorithms related to sensor reading and fusion, classical and modern control, path planning and scheduling are covered to achieve semi- or autonomous navigation in vehicle environments.
2. *Propulsion and Power Systems*. The module gives a mid- and low-level overview of the systems in a vehicle. The module includes the basics of dynamics, actuators, energy management and storage, powertrain systems. Special attention is paid to optimization processes to achieve the better performance of the vehicle to ensure the comfort of a user.
3. *Communications*. This module focuses on the protocols a vehicle needs to communicate with internal systems and external actors. Communications are key to achieving smart vehicles. The applications of these systems are infotainment, cloud computing, transportation logistics, scheduling, and V2X communications.

4. *Electromobility Ecosystems*. Local and international, social, economical, political, legal, and educational topics are analyzed and discussed. An ecosystem requires multidisciplinary work that ensures the successful implementation of SM.

In the following subsections, information of each module will be given, along with the required software and hardware tools.

3.1. Autonomous Navigation Systems

This module is organized into six submodules that provide the required knowledge and basics of path planning and autonomous systems, applied to current trends in AVs. The topics that need to be covered are vehicle architecture and its kinematic and dynamic models, embedded operating systems for simulation and in-system operation, navigation, localization, mapping, and the control algorithms applied to these platforms. The submodules and their duration are presented in Figure 4.

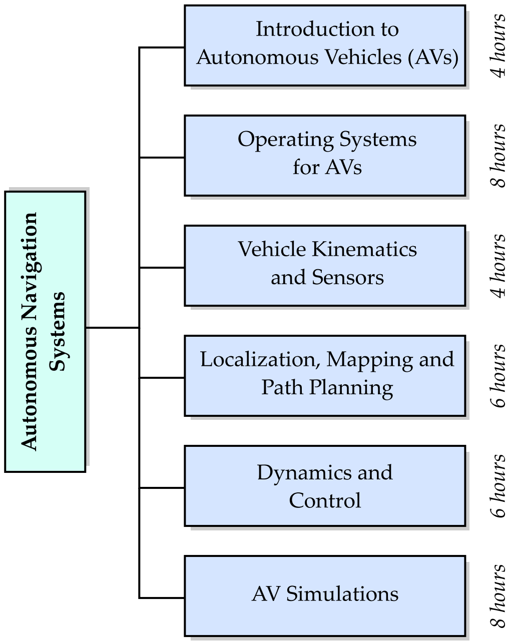

Figure 4. Submodules for Autonomous Navigation Systems.

Each of the submodules lasts between 4 to 8 h. Lectures will cover theoretical and practical activities using state-of-the-art software and hardware tools. The content of each block is as follows:

1. *Introduction to Autonomous Vehicles (AVs)*. The main components of an AV are detailed: sensors, actuators, processing units, and communication elements. The main classification of autonomy is taught with clear examples of vehicle software and hardware architecture, its evolution, and current trends. Research- and business-opportunity areas are discussed and presented.
2. *Operating Systems (OS) for AVs*. This submodule covers the trending operating systems for commercial and research purposes. RTOS and Linux distributions are covered, accordingly. The basics of the Robot Operating System (ROS) are taught. Scheduling, planning, and resource management topics are covered.
3. *Vehicle Kinematics and Sensors*. The kinematic models of a vehicle (direct and inverse), the Jacobian matrices, and homogeneous transforms are presented along with basic mathematical notation related to a vehicle. The behavior of sensors for the perception of a vehicle and their theoretical foundations are covered.
4. *Localization, Mapping, and Path Planning*. State-of-the-art algorithms are covered in this submodule, including sensor-fusion techniques for estimation and filtering. Sensor architectures are analyzed to review their performance. Local and global

path planning is reviewed from classical and deep-learning perspectives of different scenarios.

5. *Dynamics and Control*. The dynamic and control models for a vehicle are introduced. They cover classical control techniques such as the proportional integral derivative (PID) and novel algorithms such as model predictive control (MPC). Longitudinal and lateral control are reviewed from the space-state perspective. Optimization is studied to balance the AV performance.
6. *AVs Simulation*. The last module grounds the previous knowledge in a practical and simulated way. For this, an introduction will be given to the most popular simulators that can be used (open-source and proprietary) to generate these vehicles. Hardware-in-the-loop (HIL) and software-in-the-loop (SIL) architectures will be presented too, as part of the integration in a vehicle.

Lecturers for this module should be experts on theoretical and applied mobile robotics and autonomous navigation. This module requires programming, physics, and mathematical skills. The labs are to be developed on simulators, and with scale or full-size platforms. Scale platforms such as the ones presented by MIT or UPenn can be employed, as they have a similar architecture to full-scale vehicles [66]. These platforms use Linux distributions and ROS as a workbench. The platforms are equipped with LIDARs, cameras, inertial measurement units (IMU), and high-performance processing units. The platform has been previously used, with successful results.

Simulations can be run on MATLAB, CARLA, Nvidia Drive or similar platforms. They can be linked with other development toolkits focused on dynamics, control, perception, planning, manufacturing, etc. Even so, the use of other simulators (such as LGSVL Simulator, rFpro Simulator, Opal-RT, AirSim, SUMMIT, and others) and the use of frameworks such as Apollo and Autoware, are not ruled out.

3.2. Propulsion and Power Systems

In this module, the energy requirements of a vehicle are analyzed. Six submodules aim to develop competencies in autonomous mobility, as illustrated in Figure 5. A proper energy assessment requires a thorough model-based approach to describe a vehicle. It should include aspects of dynamics in all relevant degrees of freedom and powertrain elements. In addition, the analysis and diagnosis of vehicle-energy-storage systems is mandatory to understand power transfer limitations and energy capacity. Ultimately, these two features will determine the autonomy of a vehicle and its transient performance.

These elements constitute the basis for defining a target plant, which can be controlled by employing energy-management strategies to yield specific performance figures. Benchmarking can be executed through standardized driving cycles to assess autonomy and vehicle performance. With this background, students will have sufficient elements to optimize dynamics, powertrains, storage systems, and control, to ultimately improve vehicle behavior.

As seen in Figure 5, each submodule lasts between 4 and 8 h of theoretical and practical lessons. The contents for each submodule are detailed as follows:

1. *Introduction vehicle dynamics*. The first submodule introduces the key dynamic models governing the automotive chassis. These models are presented and the relevant parameters are introduced for practical and realistic dynamic behavior, both at low and high speeds.
2. *Vehicle operative cycles*. This submodule introduces a vehicle's operating cycles, such as the modal, transient, and random cycles. The student will grasp knowledge of standardized approaches to the different benchmark subsystems of a vehicle and their diagnostics.
3. *Energy-performance simulations*. The third module addresses the simulation of a vehicle's energy requirements. To this end, the concepts of power, energy, and torque (instantaneous, average, and maximum) will be introduced and associated with a vehicle's specific design and performance requirements.

4. *Energy storage systems*. For this submodule, energy storage and management systems are presented. State-of-the-art solutions, such as batteries (lead and lithium), fuel cells, and supercapacitors, will be covered. Then, lessons will target the battery bank and the energy management systems necessary for different vehicle uses.
5. *Handling and traction components*. In the fifth submodule, electrical traction and handling components are studied. Electric and combustion engines are explained, as well as power electronics and power-switching systems for a vehicle. Relevant handling models are presented to study the improvement in a user's driving experience.
6. *Mathematical modeling*. The last submodule presents the mathematical modeling for cost optimization in a hybrid proposal. The models for the theoretical and practical efficiency of a vehicle are also detailed.

The Propulsion and Power Systems module will lay foundations in automotive engineering, focusing on electric vehicles. It provides solid multidomain support for medium- and large-scale electric vehicles. Specialized software and hardware are required to reinforce theoretical knowledge. To blend theory and practice, the use of a power-systems laboratory is necessary for its development.

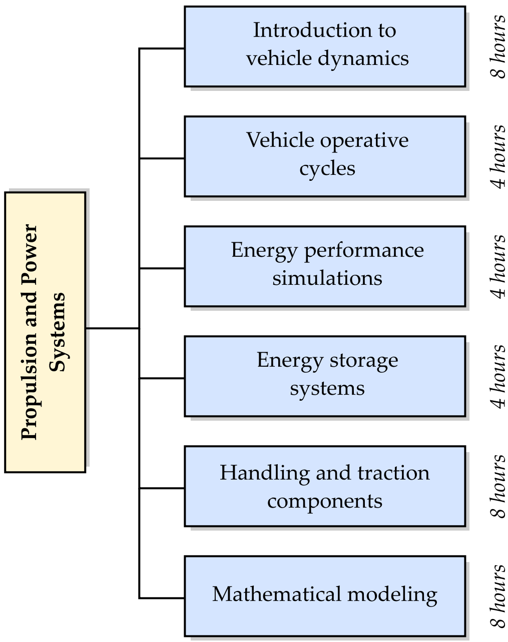

Figure 5. Submodules for Propulsion and Power Systems.

Instructors for this module should be experts in electrical engineering, mechanical engineering or mechatronics. Industry experience would be desirable in the automotive or automation field. These courses require the use of numerical tools, such as MATLAB/Simulink^{TM} for multidisciplinary model-based approaches, and CarSIM^{TM} for vehicle-dynamics simulations. For more specific analyses, other multiphysics tools, such as GT-SUITE^{TM} or AMESim^{TM}, could be helpful to evaluate energy flow across components in a realistic way. Specialized courses could require finite-element-based tools such as COMSOL Multiphysics^{TM}, to study the particular behavior of a single part or a reduced set of components.

From a hardware perspective, validations could occur at a component level with specific prototypes that require the student's attention. Electric motors, mechatronic actuators, battery arrays, and power converters are some of these systems. Although limited to a single component, the study could be extended to full-vehicle models through hardware-in-the-loop approaches. Modern embedded systems supported by automatic code generation represent an affordable yet powerful solution for students. Solutions by TI^{TM}, ST^{TM}, and ATMEL^{TM} are well-known for these possibilities. In systems where control strategies are more complex, the same approach can be adopted through more powerful hardware, such as dSpace™ MicroLabBox / MicroAutoBox or NI LabVIEW™ solutions, such as CompactRIO.

3.3. Vehicular Communications

This module is organized into four submodules that analyze the internal and external communication systems in a vehicle. The module analyzes the different protocols for communicating electronic control units (ECU) and emerging technologies for V2X and V2V. Requirements and challenges for new ECUs are discussed, as well as network SM infrastructure. The submodules and their duration are presented in Figure 6.

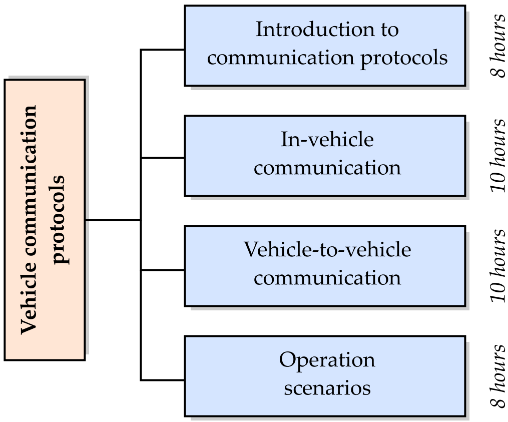

Figure 6. Submodules for Vehicular Communication protocols.

Each submodule lasts from eight to ten hours. Theoretical and practical activities are scheduled. The module is structured as follows:

1. *Introduction to communication protocols*. The first submodule introduces what the ECUs are and their importance in a vehicle.
2. *In-vehicle communication*. This submodule focuses on in-vehicle communication protocols such as the control area network (CAN), the local interconnection network (LIN), media-oriented systems transport (MOST), and others. The definition, specifications, variants, and applications of each one are given.
3. *Vehicle-to-vehicle (V2V) communication*. The submodule exposes communication protocols used among vehicles. The radioelectric spectrum, bidirectional wireless telecommunications, vehicular ad hoc networks (VANET), regulatory bodies, and standards are explained. The 802.11p, 4G LTE, and 5G standards are discussed.
4. *Operation scenarios*. The last submodule presents the operating strategies of these protocols, such as V2V, vehicles to infrastructure (V2I), and other V2X communications. Some of the most-used current applications are also explained.

This module will provide the bases for internal and external vehicle-communication protocols, and the layers of an automotive protocol. It implies knowing the limitations, advantages, and disadvantages of the protocols most used in the automotive industry for a vehicle's internal communication. The correct understanding of the radioelectric spectrum will lead to generating high-capacity data transmission, whether for entertainment use, data analysis, localization, or assistance in data processing for driving. Furthermore, this module will explore the role of vehicles in smart cities. Data analysis can be performed on traffic flow, fuel usage and optimization, driving preferences, incident location, infrastructure state, vehicle-autonomy patterns and charging. Details regarding vehicle-to-grid interactions (V2G) will also be covered.

The lecturer for this module must be an expert in vehicle-to-infrastructure, industrial and high-frequency wireless communications, and telecommunications or electronics that can be applied to automotive platforms. Open-source or licensed software will be used to simulate and generate scenarios with this type of protocol, such as MATLAB™, NetSim™, Veins™, OMNET™, SUMO™, Vergilius™, VECTOR™, and others. Platforms that use the 802.11p, 4G LTE, and 5G standards, CAN, LIN, and MOST are recommended: DSpace MicroAutoBox™, NI CAN tool, Nordsys WaveBEEhive V2X, LocoMate V2X solutions, Cohda V2X, Unex Rohde-Schwarz CAN and V2X tools, and others. Several of these options are used for research and development purposes at various automotive companies and universities.

3.4. Electromobility Ecosystem

The last module is the least-technical of the proposed curricula. It is organised into three submodules that constitute an innovation ecosystem applied to mobility. Socio-technical aspects that have to do with legal, cultural, social, and security aspects are included. In the module, skills are developed in innovation ecosystems where academia, government, industry, entrepreneurs, and investors trigger economic development by transforming urban mobility. The impacts on different production chains are covered. The objective of this module is to provide the SAEM engineer with knowledge in the aforementioned non-technical areas for the effective integration of an electromobility ecosystem in large cities. All these aspects will be seen from a national and international point of view, to gain knowledge of the limitations and capacities that each country has in relation to SM. The submodules and their duration are presented in Figure 7.

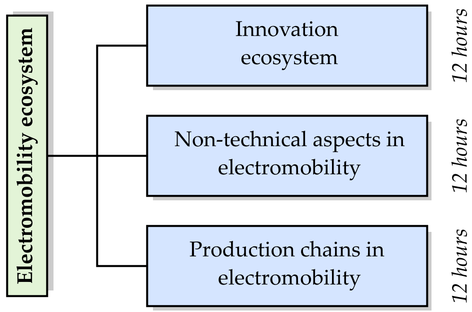

Figure 7. Submodules for EM Ecosystem.

Each submodule lasts 12 h. Theoretical content and case analysis constitute the main approaches of the module. Each submodule is detailed below:

1. *Innovation ecosystem*. The first submodule presents the innovation ecosystem with its different components, study cases, application to EM, and disruptive-innovation development.
2. *Nontechnical aspects in EM*. The following submodule exposes nontechnical issues, such as legal, social, cultural, and safety aspects. Those topics will help the effective integration of smart EM in society.
3. *Production chains in EM*. The last module is based on EM production chains, analyzing study cases of current transformation, new business models, and the study of possible future scenarios nationally and internationally.

Instructors for this module should be industry-involved experts and practitioners in business, information technology, entrepreneurship or industrial engineering. Experience in the development and logistics of technological projects and their effective integration into society is desirable. Knowledge or experience of industrial standards in the automotive environment, especially in ITS, is also recommended.

The module is structured such that engineering problems can be analyzed from a nontechnical point of view. This way, the legal, cultural, social, and security aspects of the ecosystem are employed to model new production chains within the framework of disruptive innovation and the proposal of new business models. These issues will be supported by presenting ISO and other important standards, such as ISO 26262 (Functional safety in road vehicles), ISO 22737 (Requirements and test procedures for ITS) and other standards for intelligent transport systems [67] and electric vehicles [68]. Specialized software such as Llamasoft Supply Network Design, JDA Network Design, or SAP APO Supply Chain Engineer can be used to analyze and model supply and transportation chains. For this module, no specialized hardware is considered as a requirement, only computer equipment with the proposed software licenses is required.

This module completes the integration of the four base blocks that make up the proposed curricula. In each block, technical and nontechnical aspects are taken into account to generate the knowledge and specialization of an SEAM engineer in the SM field. The objective of the proposed curricula is the generation of human capital suitable for the effective integration of SM technologies into what are called smart cities.

4. Concluding Remarks

The present study aimed at generating a feasible curriculum for future EM engineers. This work was a particular case study for Tecnologico de Monterrey, Mexico. To yield a balanced combination of the disciplines to cover, curricula from prestigious international institutions were analyzed. This study considered the most relevant and vital issues, in technical and nontechnical areas, to developing electric and AVs.

After analyzing key areas, a final SAEM engineer profile was created. Thus, modules in four key areas were proposed. Our proposal enabled the development of the required modules together with the associated processes, spaces and tools. In addition, a general layout for new specialized study plans on smart mobility was proposed. This study considered the relevant issues necessary to train personnel towards improvement and development in mobility in large cities. Another objective of the curricula was to promote and accelerate the development of these technologies with qualified and specialized personnel in EM. Moreover, the implementation of this program could potentially lead to the simultaneous improvement in mobility in large cities. The radar map of our curricula can be found in Figure 8; this was generated using the same course classification in Section 1.2. A more balanced curricula can be observed in the different classification categories on the radar map.

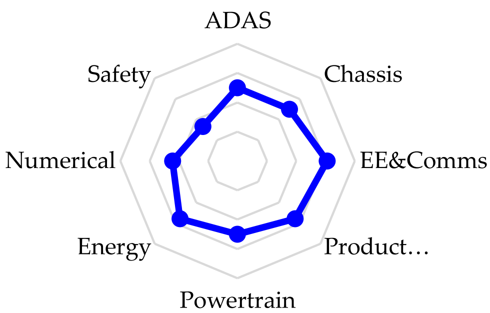

Figure 8. Radar map for SAEM proposed curricula.

The syllabus for each module and specific topics in SAEM are yet to be defined. Then, laboratories, simulators, and the platforms required to teach these modules will be presented. A first attempt to deliver this curricula is intended to be implemented in Tecnologico de Monterrey. They are considering the infrastructure required to make such a proposal possible for the next generations of students looking for the cutting-edge competency skills needed for the near future. The authors believe that the academic development of engineers in smart mobility will be necessary for the coming years, due to the growth in this area of global development. This background was analyzed through a state-of-the-art review. More importantly, opportunity areas in current trends were highlighted. In this context, we offered curricular modules that blend the technical and nontechnical elements of the electromobility ecosystem. The dynamics of the proposed curricula are based on innovative learning–teaching techniques, training and practical methods in specialized spaces with state-of-the-art technology.

4.1. Areas of Application and Challenges

The proposed program seeks to train qualified and specialized personnel who can apply their knowledge to improve and develop new routes and means of mobility. They mainly focus on medium- and large-scale sustainable electric vehicles. The proposed SAEM program faces challenges in different areas. A 24-month agenda is limited to specific learning hours, where risks of shallowly covering some topics are present. As such, students from heavily focused programs,such as some of the other universities', might present better knowledge in very specific areas. This is important to mention, because more or less specialized programs generate these advantages and disadvantages depending on each case. Our proposal is committed to a program that is less-specialized in certain areas but broader in the topics that impact SM and AV directly. Nonetheless, the core of SAEM provides a general and sufficient overview of a vehicle, its technologies and the surrounding smart environment.

Another important limitation regards the initial investment for hardware, software and infrastructure. When compared to other engineering programs, SAEM's requirements might exceed the available budget for its initial implementation. However, existing infrastructure from other undergraduate and graduate programs can be shared to absorb this initial cost.

4.2. Future Work

The development of smart mobility will be crucial in the coming years; this makes it necessary to continuously update study plans in the areas of specialization that embrace the concept of smart electromobility. For this reason, the curricula will be implemented in future works to develop spaces in which engineers are trained in smart mobility. The aforementioned spaces will be equipped with the proposed software and hardware platforms to provide the necessary tools for this specialization.

In this scenario, a case study will be generated at Tecnologico de Monterrey, Mexico, on its main campuses. The main objective is to develop what the authors call Smart Electromobility laboratories. These spaces will evaluate and validate the case study through student learning and the impact that this may have on the improvement of knowledge. Local industry will also play a major role in enabling applied academic and research topics in the field of mobility. Likewise, projects to improve regional mobility in cities will be integrated, as they will take the first actions to push significant changes in this context. The curricula should be adapted depending on the city or country where it is implemented, but the basic modules that are proposed should be fulfilled.

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Abbreviations

The following abbreviations are used in this manuscript:

ADAS	Autonomous driving assistance system
AV	Autonomous vehicle
CAN	Control area network
CEFR	Common European Framework of Reference
Comms	Communications
ECU	Electronic control unit
EE	Electrical engineering
EM	Electromobility
FF	Face to face
HIL	Hardware in the loop
IMU	Inertial measurement unit
IoT	Internet of things
ISO	International standard organization
ITS	Intelligent transport system
LIDAR	Light detection and ranging
LIN	Local interconnection network
MOST	Media-oriented systems transport
MPC	Model predictive control
PID	Proportional integral derivative
ROS	Robot operating system
SAEM	Smart automotive electromobility
SE	Smart education
SIL	Software in the loop
SM	Smart mobility
VANET	Vehicular ad hoc networks
V2X	Vehicle to everything
V2G	Vehicle to grid
V2I	Vehicle to infrastructure
V2V	Vehicle to vehicle

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