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Abstract

European Automotive Industry is suffering from a skill gap between engineering graduates and industry practices. This paper introduces a collaborative research aiming at establishing a certified automotive engineering design curriculum which shall serve as a springboard to highly qualified engineering design jobs in the automotive industry. Based on the European AQUA sector skills alliance, this research brings together major players from industry and higher education. Integrated design education with a clear ECTS-ECVET evaluation scheme plays a key role in this curriculum, since most of the modern skill challenges in automotive are related to interdisciplinary design optimization of quality and costs.

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1. Introduction

Nowadays electronics and software control more than 70% of a modern car's functions, and several studies predict this share to grow to more than 90% in the future [1]. This leads to a level of complexity that has not been experienced before – for both the system "car" and its development processes. There is a strong common agreement in the sector that an interdisciplinary expertise is the absolutely indispensable fundamental basis for being able to tackle this complexity under the heavy pressure of shorter development and innovation cycles. Moreover, this demand is reinforced by the necessity of mastering essential horizontal topics such as product and process quality, reliability, and functional safety.

International standards considering Development Quality (Automotive SPICE®, ISO/IEC 15504), Functional Safety (ISO 26262, IEC 61508) and Six Sigma (production and process quality) form the backbone of the modern automotive and supplier industry. These standards make possible the smooth coupling of the different companies along the supply chain, and enable the successful integration of all parts and subsystems. In order to be eligible for OEMs, suppliers have to implement and master all these standards. This applies equally well to big companies as to small and middle-sized ones.

The holistic nature of these quality requirements and the ever growing need for shortening development cycles imply that the topics linked to quality aspects have to be addressed in a totally integrated way. Furthermore, the capability of suppliers to master this integration is increasingly a subject of rigorous assessments demanded by OEMs [2]. This strong requirement, however, is confronted with a lack of qualified specialists and even more so of interdisciplinary "all-rounders" that can act as the links between different expert groups. Practitioners also experience a huge gap between the knowledge provided within the higher education and industry

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practices, especially when it comes to integrated development topics. The research presented here addresses this lack by identifying the essence of the specialist topics linked to modern integrated engineering design of automotive quality, and explaining them in a compact and modular certified and e-learning enabled training program that is especially targeted towards higher education institutions. The “essence” is considered to be the very share of the knowledge that is vehicular, i.e., that can drive the integration of related stakeholders within existing organizations [3]. This initiative is driven by the AQUA Sector Skill Alliance, which unites representatives of international automotive industry with VET training providers and higher education institutions with the objective to develop focused sector-specific qualification programs [4].

This paper explains the essence of the research objectives (section 2), the applied research methodology with integrated validation (section 3), as well as key results obtained so far (section 4) and a case study highlighting two particular key concepts (section 5). Section 6 concludes the paper and gives an outlook on further research and valorization activities.

2. Target description

The CIRP community has an outstanding research track in the area of stakeholder integration in product, service, and system design [5]. The work presented here is complementary to this research in that it investigates the integration of stakeholders who are somehow concerned with quality and risk for the purpose of mastering both product-level and process-level quality and risk better than organizations do today. Beyond the “why” and “what for”, it deals with the essential question of “how” to achieve this integration challenge on an organizational level using the lever of qualification for vehicular knowledge on a broad level.

The core objective of our research program is to qualify automotive engineering designers to achieve the integration of development process and product quality according to Automotive SPICE®, Functional Safety and Design for Six Sigma. This is achieved thanks to a compact and modular e-learning enabled education and training program.

3. Methodology

The core idea is to identify vehicular bricks of knowledge about essential quality- and risk-related activities in the product creation process (i.e., design, development, and production), and to explain them in the context of the three target domain experts’ points of view. Departing from this, we have established a complimentary integrated view, which does not assume any specific boundaries that have historically grown between the expert domains. The identification of such bricks was done systematically by the analysis of the following sources:

1. The standards relevant to the respective three areas.
2. Published experience reports about best practices in the implementation of these standards.
3. Unpublished results of expert working groups (German and French industry and university representatives) around the topics quality, reliability, and functional safety.

The key criteria for a term to be considered vehicular are that

1. It represents a notion that has an essential meaning in all three expert areas.
2. It is used with same or different wordings in at least two of the three areas.
3. It contributes essentially to the systemic quality and risk and/or reliability aspect of the product, service, and related processes.

The results will be compiled into an EQF-compliant [6] skill card which describes the competency requirements to a quality integration expert in a hierarchical manner: on the top level there are the skill units which contain skill elements characterized by performance criteria. This initial skill card has been reviewed systematically by several experts from various automotive clusters with respect to specific qualification needs, in particular those of tier-1 and tier-2 suppliers. It provides the basis for the definition of the training program, the elaboration of the training material, as well as the certification process. The strong need for such an interdisciplinary certified training program has also been confirmed by several automotive clusters [4]. Furthermore, the positive impact of targeted qualification on company’s quality management maturity has been shown in scientific research [7].

Another key methodological step was to come up with an architectural concept that allows both trainers and trainees to capitalize on existing training programs in the three expert areas while providing them a convenient and understandable access to the core vehicular knowledge that links those together [3]. Based on existing established programs in the areas Automotive SPICE®, Functional Safety, and Six Sigma, some specific “linking elements” have been defined. For each of these elements (e.g. life cycle, requirements, etc. in Figure 1), new training modules have been developed, explaining the relevance of key terms related to the respective element, and how they relate to the specific (vernacular) terms used in the three expert areas. Thanks to this modular architecture, it is easily possible for universities to assign ECTS to each module and integrate the complete program or only part of it into their specific curricula. Companies can compose trainings that correspond to their specific needs in terms of building up capacities fostering the integrated treatment of quality and risk aspects in their respective organizations.

4. Results

Table 1 shows selected results of the authors’ research in the form of skill units and elements with only a few selected vehicular key items that are the subject of the corresponding training materials and examination. The meaning of the table’s columns is the following:

1. Learning Elements: name of the skill elements related to the skill unit shown in the respective line.
2. Integration: integrated view on the learning element and its vehicular knowledge items.

Table 1
Vehicular knowledge items arranged in the form of a skill set (Note: the content in each cell is non-exhaustive, and shows only selected key subjects)

Learning Elements	Integration	Automotive SPICE®	Functional Safety	Design for Six Sigma
UNIT 1: Introduction				
U1.E1 Standards, Norms and Guidelines	Scope and limitations of each domain standard, integrated view on the standards in the development process	ISO 15504, VDA 6.1, Automotive SPICE®	ISO 26262, IEC 61508	ISO 13053 Six Sigma Roles and Skill Profiles
U1.E2 Organisational Readiness	Multifunctional teams, integration of domain experts	Quality managers, independent quality assurance	Safety engineers and managers, presumes quality management	Champions, Green & Black Belts, TQM
UNIT 2: Product Development				
U2.E1 Life cycle	Integration of all the life-cycle views based on the V-model	V-model for system- and software development	W-model for system-, software- and hardware development, safety life-cycle, Development Interface Agreement (DIA), safety plan	DMAIC, DMADV/IDOV
U2.E2 Requirements	Integration of all requirements elicitation and management methods based on the V-model	Customer-, system-, software-, hardware-, mechanics requirements, full bi-directional traceability between requirements	Functional and technical safety requirements on system-, software- and hardware-levels, Functional/Technical Safety Concept (FSC/TSC)	VOC, CTQ Flowdown
U2.E3 Design	Integrated view on all the design issues based on the V-model, Failure in Time (FIT) rate as a key vehicular figure	System and software architecture, CPU load, memory consumption	System-, HW-, SW-, reference architectures, PFD, PFH, freedom from interference, Hardware-Software Interface (HSI), ASIL decomposition	Transfer functions, DoE, Yield, DPMO, CpK
U2.E4 Test and Integration	Integration based on the V-model	System-, integration-, software unit tests, traceability of tests to the requirements, test coverage	Release levels, fault injection tests, equivalence class tests, and other special test methods to validate safety integrity	Reliability, preliminary capability, DoE tests
UNIT 3: Quality and Safety Management				
U3.E1 Capability	Holistic notion of capability (development, manufacturing)	Capability levels, maturity levels, rating scale profile	SIL and ASIL, balance between hardware reliability and software diagnostic coverage	Process Capability (CpK), Process Performance (PpK)
U3.E2 Hazard and Risk Management	Holistic risk management framework	Re-use and risk management on process/project level	SIL and ASIL, FMEDA, Hazard & Risk Analysis, risk management on process and product level	Design FMEA
U3.E3 Assessment and Audit	Integrated assessment approach	Process management	Safety audit	Internal and external audits
UNIT 4: Measure				
U4.E1 Measurement	Aggregated dashboard, experience values	Requirements-, test coverage, trend analysis	Requirements, diagnostic, test coverage, resource usage	Measurement system analysis MSA, internal CTQs
U4.E2 Reliability	Deriving reliability requirements from hazards and risks and availability requirements (dependable design)	ASIL classification and diagnostic measures	SIL and ASIL, special design and process requirements for each SIL/ASIL level	Hazard, life distribution. function, failure in time, MTTF, accelerated life testing, failure rate curve

3. Automotive SPICE®: selected vernacular knowledge items specifically related to the respective skill element and Automotive SPICE®.
4. Functional Safety: selected vernacular knowledge items specifically related to the respective skill element and functional safety according to ISO 26262 (Functional Safety for Road Vehicles).
5. Design for Six Sigma: selected vernacular knowledge items specifically related to the Design for Six Sigma principles.

6. Case Study

The concept shall be explained using the example of the skill elements "Life Cycle" and "Requirements" (Figure 1). In the context of integrated product development, the term "life cycle" signifies all the phases that a product runs through over a cycle from the initial product idea to usage and "revival" through re-cycling, re-manufacturing, and/or re-use [8]. From the viewpoint of the Automotive SPICE® software process quality experts and standard based on ISO 15504, the same term signifies the V-model [9], which has been shaping industrial software and systems development processes over years, and is still the predominant reference model in the automotive industry. It may be considered as an extension of the waterfall model relating the phases of design (from system level down to component level) to the phases of testing, verification, and validation (from component level to system level). The horizontal and vertical axes represents time or project completeness (left-to-right) and level of abstraction (coarsest-grain abstraction uppermost), respectively. One of the most essential key characteristics of Automotive SPICE® is that it demands the proven establishment of full bi-directional traceability over the whole V-cycle from the top-level requirements to the validation tests. The entire Automotive SPICE® implementation and assessment assumes a V-cycle based development methodology, although it does not stipulate any particular development process.

Experts for functional safety in road vehicles have coined the safety life cycle which according to the recent standard ISO 26262 denotes the entirety of phases from concept through decommissioning of the safety item, which in the standard's terminology signifies the particular safety-critical system to be designed (e.g. ABS, E-gas, ESP, etc.). These phases are reflected in the W-model shaped structure according to which the standard has been designed. The W-model is a more recent extension of the V-model for mechatronic systems that contain electric/electronic hardware and software subsystems and components. This model presumes one V-cycle for hardware and one for software development, with requirements elicitation, architectural design, as well as system verification and validation spanning over both V's.

In Design for Six Sigma, although no clear notion of a life cycle is given, there are a few essential concepts that refer to an overall cycle. DMAIC (Define, Measure, Analyze, Improve and Control) refers to a data-driven improvement cycle used for improving, optimizing and stabilizing processes and designs. For new processes, or optimized processes that do not meet the required level of (customer) expectations, DMADV (Define, Measure, Analyse, Design, Verify) replaces DMAIC as the core tool. Likewise, IDOV is one popular methodology of designing products or services to meet six sigma standards. IDOV signifies a four-phase process (Identify, Design, Optimize, Verify) which parallels the four phases of the traditional Six Sigma improvement methodology, MAIC.

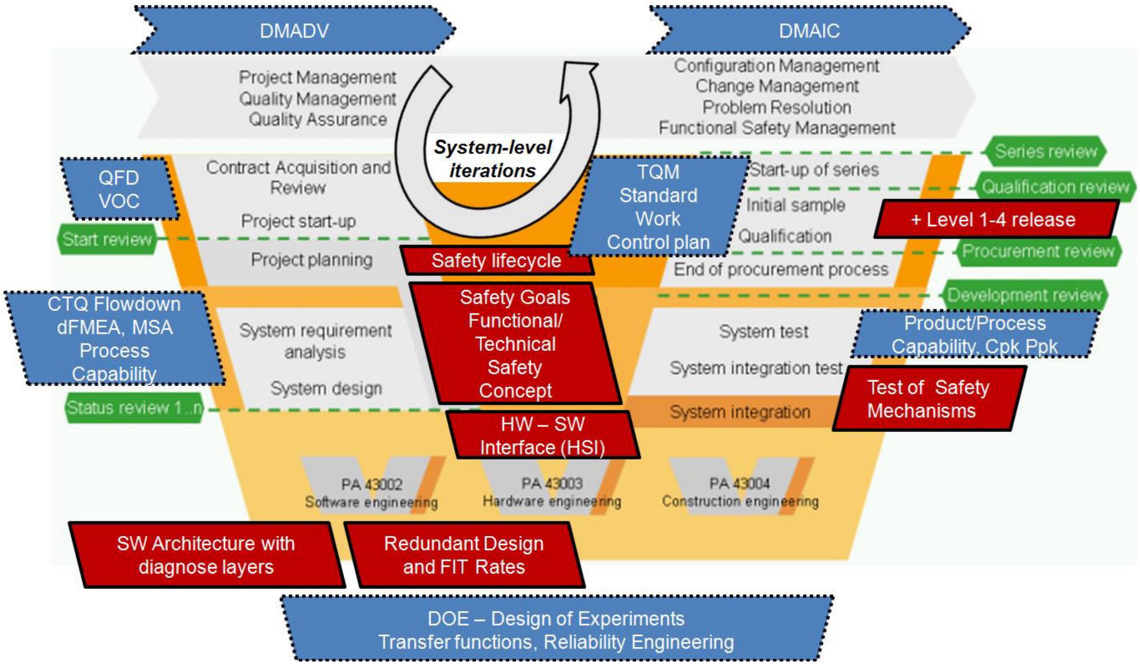

Figure 1. Integration of requirements methods along the life-cycle.

In order to demonstrate the necessity and added value of an integrated view on the different life-cycle notions, Figure 1 shows the integration approach chosen to relate activities, process outcomes, and tools used in the three different quality expert domains to one another as well as to their relevance for the underlying product creation process. The figure elements without a black frame constitute the product development life cycle of a renowned German tier-1 automotive supplier with integrated Automotive SPICE®. It does not explicitly take into account neither functional safety nor production, and it is very much focused on electrics/electronics and software components. Representative for a lot of other companies in this and other sectors, functional safety, production, and mechanical development have been considered in separate processes for a long time. However, there is growing awareness and pressure to integrate these processes in order to implement a holistic and integrated design and quality management. In Figure 2, elements in red and solid black frames indicate selected activities, tools, and process outcomes needed to integrate requirements related to functional safety in the process. Blue elements with a dotted frame relate to selected tools from Design for Six Sigma that are relevant to the requirements management activities carried out in the development process. Interestingly enough, despite the immediately visible synergies among the different activities related to requirements management, the three expert areas are mostly completely separated in industrial organizations, which compromises the success of horizontal activities such as overall quality management. One practical example where the three disciplines have clear interfaces in the creation process is the calculation of reliability figures of hardware parts (sensors, actuators, etc.) used in safety-critical systems and subsystems. These figures are needed by system architects and functional safety developers in order to find the good compromise between costly high-quality hardware (i.e., with a low FIT rate, FIT = Failure in Time) and software diagnose functions making up for less expensive hardware in order to achieve a required SIL (Safety Integrity Level). As the calculation of such figures requires statistical tools and knowledge that functional safety experts in general do not have, the latter use manufacturer catalogues to look up the required values. Such catalogues, however, are often inconsistent and/or outdated. Collaborating with a reliability expert mastering statistical methodology and tools from the Design for Six Sigma toolbox would be much more efficient and effective.

Thanks to the results of our research, those experts can learn about such synergies, as well as about ways of exploiting them for the sake of globally better results in quality management.

5. Conclusion and Perspectives

The need for organizations, methods and tools for the integration of different expert groups and departments has been widely documented in the research community over several years. Also, the importance of intensive industry-university collaboration to tackle this challenge has been emphasized by representatives of both parties. Our research addresses these challenges for the topic of integrated quality and risk engineering in automotive essentially via the terminology lever in that it has developed a sophisticated and worldwide unique training architecture around the principal vehicular terms and subjects in the area of quality in development and production of mechatronic systems and subsystems. The approach has been proven successful with automotive suppliers in Austria, Czech Republic, Germany, France, and Slovenia. It is now being transferred to leading universities in these countries in order to contribute to reducing the reportedly big skill gap between university education and industry practice.

Given the huge challenges that organizations have been facing with the realization of integrated product creation concepts, we believe that our research results can be considered a significant contribution to the research question of how such integration concepts can actually be driven, leveraged, and deployed in existing industrial environments without changing the complete organization and central processes (as changing these takes a long time and huge investments). Many organizations have learned the lesson that integration of stakeholders does not just happen, but can only be the result of much targeted specific actions and strategies aiming at enabling stakeholder communication and collaboration on all organizational levels. In the presented approach, the main lever is a very specific targeted interdisciplinary training program based on a sophisticated modular architecture allowing the focused investment of companies in the acquisition of vehicular knowledge by a large number of concerned stakeholders. In order to help them maintain these investments at a reasonable level while at the same time making the training accessible to as many concerned employees as possible, the training is supported by fully-blown e-learning facilities. Moreover, a Europe-wide certification by the ECQA (European Certification and Qualification Association) assures the high level of both the recognition of the program and its quality and continuous improvement und update.

Future research activities include the assessment of several indicators obtained by the actual deployment of the training program in several companies in terms of efficiency, effectiveness, influence of the training lever on the organizations' integration capabilities, etc. These figures, in combination with further experiences and feedback collected during the trainings will enable progress in judging the relative importance of the explicit presence and support of vehicular knowledge in an organization in order to leverage stakeholder integration for a very specific objective.

Additionally the transfer of the knowledge to the students from different countries (Austria, Czech Republic, France and Slovenia) will be done with the focus on students of different study direction, with different knowledge background (mechatronics, electrical and computer engineering). This will be an opportunity to test the concept on a wide audience and adjust it to their needs as well as abilities.

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