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DEVELOPMENT OF INNOVATIVE VEHICLE SYSTEMS USING COLLABORATIVE TRAINING AND EDUCATIONAL TECHNOLOGIES

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ABSTRACT – Increase of competitiveness of automotive industry has a direct relation to the generation and gaining of novel engineering ideas. However, the creation of innovative technologies is not possible without the critical mass of highly skilled individuals and professional teams. Taking into account the complexity of modern technologies, automotive engineering professionals must have a deep interdisciplinary background that cannot be covered by conventional undergraduate and higher education only. To create such a background, advanced technologies for postgraduate education and lifelong learning are demanded. The presented paper introduces two case studies in this context. These studies disclose some mechanisms for research and development of new vehicle systems through industry-academia doctoral and post-doctoral projects. The work under discussion is based on results obtained within training schemes proposed by Marie Skłodowska-Curie Actions (MSCA) of European Commissions. The first case study presents the MSCA Innovative Training Network ITEAM. The ITEAM is mainly concentrated on PhD education and has the goal to establish and sustainably maintain the training network with high grade of interdisciplinarity. The target group covers future specialists skilled in research and development of novel technologies in the field of multi-actuated ground vehicles (MAGV). The training concept is based on intersectoral cooperation and covers domains of (i) basic research, (ii) applied research, and (iii) experimentations for three research clusters: "MAGV integration", "Green MAGV", "MAGV Driving Environment". The second case study relates to the MSCA Research and Innovation Staff Exchange project EVE - Innovative Engineering of Ground Vehicles with Integrated Active Chassis Systems. As differentiated from the previous case, the EVE involves not only early-stage researchers but also experienced researchers and management staff. The main technological target of EVE is to develop and validate novel integrated chassis system uniting decoupled brake control, active suspension elements, and dynamic tyre pressure control. This is being realized with intensive networking measures covering (i) knowledge transfer and experience sharing between participants from academic and non-academic sectors, (ii) professional advancement of the consortium members through intersectoral and international collaboration and secondments. Of special importance is the EVE training programme for testing of tyres and vehicle systems on several hosts in Europe, South Africa and USA.

The paper demonstrates detailed cooperation mechanisms for both case studies. A particular attention is given to organization of joint experiments in research laboratories and on proving grounds as key elements for efficient training of skilled professionals. Approaches proposed in the paper can be used by establishment of new educational and training schemes having the target to fill up the niche in private sector and automotive industry with researcher-practitioners.

TECHNICAL PAPER – In accordance with the Frost & Sullivan survey [1], several challenges can be expected to 2020 regarding educational policy and automotive industry:

- It is forecasted that the global growth rate of demand (+18.0%) of mechanical engineering graduates will be less the global growth rate of mechanical engineering graduate supply (+31,94%);
- At the same time, the skill sets and quality of the graduates may be not sufficient for OEMs;
- New paradigms in automotive industry, such as automated driving, connected vehicles and electric mobility, require extension of traditional skills of mechanical engineering graduates with strong interdisciplinary content (first of all, IT) allowing them a better understanding of the new market requirements.

There are only few mentioned challenges that cause the seeking for new approaches to educate professionals in automotive and transportation engineering. An analysis of up-to-date studies points to the fact that the academic sector initiates and proposes new education schemes aiming at the increase of interdisciplinary and intersectoral content of the study as a response to these challenges [2-5]. However, most of known innovative education approaches are addressing undergraduate or graduate levels. The post-graduate and doctoral level as well as continuous advancement of skills of established professionals are rarely taken into account. But exactly these learning areas should be of special focus of industry and research institutions in order to recognize and to train the most talented people, who will be able to make essential contributions to new generations of hi-tech products.

One of known programmes proposing specific training schemes for early-stage and experienced researchers and staff is Marie Skłodowska-Curie Actions of established by the European Commission [6]. The MSCA propose several instruments both for individual and institutional training to bring the necessary skills and international / intersectoral experience to the researchers for their successful academic and/or industrial career. The main instruments under discussion are

- *Individual fellowships* to support experienced researchers undertaking mobility between countries, optionally to the non-academic sector;
- *Research networks (ITN)* to support Innovative Training Networks including intersectoral training of PhD students;
- International and inter-sectoral cooperation through *the Research and Innovation Staff Exchanges (RISE)* to support short-term mobility of professionals at all career levels.

In framework of the presented paper, two case studies for ITN and RISE schemes will be introduced. Both case studies will illustrate how these programmes can contribute to the development of innovative vehicle systems through cooperation and networking of many academic and non-academic partners with inclusion of PhD training and advancement of staff skills.

CASE STUDY: DEVELOPMENT OF MULTI-ACTUATED GROUND VEHICLES IN INNOVATIVE TRAINING NETWORK

Motivation

Ground Vehicle Engineering, both as highly interdisciplinary research discipline and technological domain, receives a profound impact from increased demand on safe, environment-acceptable and user-oriented intelligent technologies. Nowadays there is a strong trend towards the transformation from traditional cars, trucks and other mobile machines to complex systems interconnected with environment, infrastructure and users through numerous information channels. It made possible emerging of a new technological cluster – multi-actuated ground vehicles (MAGV). A multi-actuated ground vehicle is a complex engineering system having a set of parallel subsystems requiring both individual and integrated control to secure simultaneously criteria of efficient dynamics, safety, and user- and environment-friendly operation. Essential features of the MAGV are (i) modularity and autonomy of embedded subsystems, and (ii) complex uncertainty of operational environment of motion. Examples in point are conventional, electric, semi-autonomous and autonomous vehicles with x-by-wire systems, as well as vehicles equipped with integrated chassis and powertrain modules.

It is apparent that skills demanded for the MAGV design are beyond the knowledge provided by the traditional mechanical or control engineering study and require a strong interdisciplinarity. Moreover, the complexity of the subject allows to suggest that the corresponding professionals have to be trained on the level of post-graduate courses. These arguments have motivated a consortium form several research institutions and industrial companies to establish a network for joint training of PhD students, who should able to make determinant contributions to next generations of multi-actuated ground vehicles. This interdisciplinary training network ITEAM has been created within the MSCA ITN programme, and its main components are explained in next sections.

Concept and Consortium

The main idea behind the ITEAM concept is the interaction of three research clusters. The research clusters define technical objects, where innovative outcomes are being expected: Cluster "*MAGV integration*" - Mechatronic subsystems for active and integrated chassis and powertrain control, in particular, brake, steering and stability control; Cluster "*Green MAGV*" - Energy-efficient and low-emission MAGV including electric vehicles; Cluster "*MAGV Driving Environment*" - Vehicles with elements of semi-autonomous and full autonomous driving; Solutions for driver assistance and human-machine interface. For these three clusters the network is recruiting fifteen early-stage researchers (ESR) with a task to perform in three years an individual research project at specific host. Simultaneously, each ESR has to be enrolled as PhD student at academic institutions of the consortium.

Taking into account the technical content of the clusters, the composition of the ITEAM consortium, Figure 1, is well-balanced between academic and non-academic sector from nine European countries:

- Three automotive OEMs - Volvo Car Group (VOLVO), Skoda Auto (SKODA), Jaguar Land Rover (JLR);
- Three suppliers / industrial companies with competence in automotive electronics, testing and simulation technologies - Infineon Technologies AG (IFAG), AVL List (AVL), IPG Automotive GmbH (IPG);
- Seven universities - Technische Universität Ilmenau (TUIL), Coventry University (COVUNI), Katholieke Universiteit Leuven (KUL), Università degli studi di Pavia (UNIPV), Université de technologie de Compiègne (UTC), Technische Universiteit Delft (TUD), The University of Liverpool (UOL);
- Three research institutions with different competences - Flanders Make (FMAKE), Das virtuelle Fahrzeug, Forschungsgesellschaft mbH (VIF), Institute of Information Theory and Automation at the Czech Academy of Sciences (UTIA).

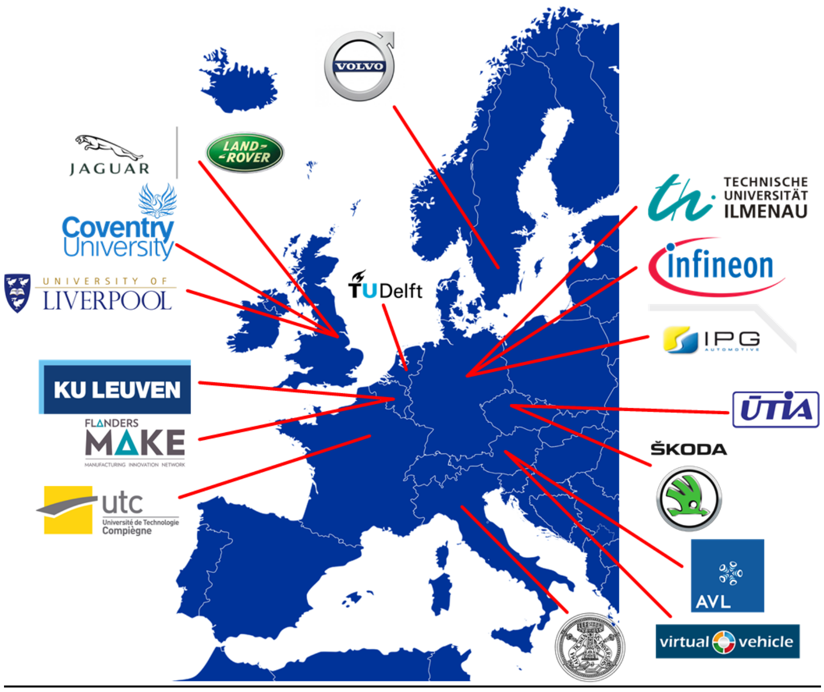

Figure 1: Geography of ITEAM consortium

Table 1: ITEAM clusters and individual projects

No.	Individual Project	Host	Co-supervisors
Cluster "MAGV Integration" (MI): (i) Control strategies for integrated powertrain and chassis subsystems; (ii) Software/hardware implementation of novel tools for modelling and experimental assessment of integrated MAGV subsystems; (iii) Design and testing of full-scale demonstrators of integrated subsystems			
MI1	Integrated design and simulation for active safety functions	VIF	IFAG, TUIL, TUD
MI2	MAGV development of virtual steering control and steering feel model reference	VOLVO	COVUNI, IPG
MI3	Validated MAGV virtual simulation environment for development and verification of chassis control soft-ware	VOLVO	IPG, TUIL
MI4	Robust wheel slip control in MAGV via sliding modes generation	UNIPV	JLR, UTIA
MI5	Fail-safe power electronics of integrated MAGV dynamics control	IFAG	AVL, UOL, VIF
Cluster "Green MAGV" (GM): (i) Subsystems and components responsible for improvement of energy efficiency and reduction of MAGV-related emissions; (ii) Technologies increasing performance of MAGV with electric propulsion; (iii) Development and experimental validation of on-board software tools and embedded systems for energy-efficient driver-assisting and automated driving operation of MAGV			
GM1	Optimization of autonomous driving functions targeting the overall energy efficiency improvement of MAGV	VIF	UTC, SKODA, KUL
GM2	Robust estimation of dynamics behaviour and driving diagnosis applied to an intelligent MAGV with electric powertrain	UTC	UOL, KUL, JLR
GM3	Driver assistance measures for low-emission MAGV	SKODA	IPG, UNIPV
GM4	Low-emission MAGV dynamics control	TUIL	AVL, FMAKE, UOL
GM5	On-boarded perception and sensor-based navigation applied to an intelligent MAGV with electric powertrain	UTC	KUL, FMAKE, IPG
Cluster "MAGV Driving Environment" (MD): (i) New methods for mathematical formulation, identification and observation of the driving environment parameters to be used in on-board controllers of driver-assisted, semi-autonomous and fully automated MAGV; (ii) On-board chassis and powertrain control systems as actuators of (semi-)autonomous MAGV			
MD1	Path planning methods for (semi-)autonomous MAGV with electric powertrains	FMAKE	UTC, KUL, SKODA
MD2	Traffic simulation for the optimization of autonomous driving	AVL	UNIPV, SKODA, TUD
MD3	ADAS functions for small electric vehicles	COVUNI	VOLVO, TUD
MD4	Model-based distributed sensor fusion for MAGV state and parameter estimation	KUL	SKODA, UTC
MD5	Identification of off-road driving environment for MAGV dynamics control	TUIL	JLR, UTIA, UNIPV

Research Content

The principles of the ITEAM network are as follows:

- Early-stage researcher is hosted for three years with a work contract at one of the consortium organizations to carry out an individual research project;
- Early-stage researcher is also enrolled for a PhD study, and the individual project of ESR is related to her/his PhD topic;
- During the project and PhD study, the researcher has several mobility periods (secondments) by different consortium participants for special training purposes;
- The secondments must have an obligatory international and intersectoral character;
- Individual ESR projects are attributed to three research clusters described above and contribute to the development of joint models, controllers, experimental tests and demonstrators, which are then accessible for the whole consortium.

The research content of the ITEAM network is summarized in Table 1. It should be mentioned that research activities have to be supplemented with intensive training of ESRs in order to prepare well-skilled staff with competence in different areas. The training aspects of the ITEAM network are introduced in next section.

Training Content

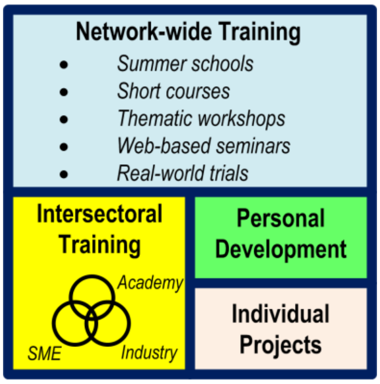

Figure 2: ITEAM training structure

The main training idea of the ITEAM network is that each early stage researchers has to be sequentially trained in three domains required for the full development cycle of new technical objects. *The first domain* of the training is connected with gaining advanced knowledge related to the basic research disciplines, in particular, control engineering and computational intelligence. This knowledge is a major requisite to enter the second stage of the training. *The second training domain* deals with applicative research and relevant disciplines, which have direct connection to different MAGV topics: vehicle dynamics, system engineering, and human machine interface. This training phase will lead to novel solutions requiring verification and validation. Such activities will imply the development of suitable virtual and real-world testing facilities for MAGV and their subsystems. Thus, the possibility of acquiring experience on test-beds, but also on how to develop appropriate experimental platforms for the class of systems under consideration, will be the major aim of *the third training domain* related to experiments in general. Additional training will be provided for transferable skills, where early-stage researchers are gaining knowledge in (i) patenting and intellectual property management, (ii) proposal writing for industrial and international grants, (iii) start-up business and business models for research and science, (iv) advanced skills in rhetoric and communications. The training structure is introduced on Figure 2 and discussed further in more details. An example of training time plan is given on Figure 3.

Network-wide training: The measures of network-wide training have a strong interdisciplinary content and cover Summer schools, Thematic workshops, Short courses, Web-based seminars, and Real-world trials. In accordance with ITEAM concept, all the events will relate to three training domains. The real-world trials are the crucial component of the ITEAM training programme. Because all the ITEAM individual projects have direct relation to real vehicle objects, three training events on automotive proving grounds are being performed on the latest stages of the to demonstrate effectiveness and applicability of developed engineering solutions in real-world conditions.

Intersectoral training: ESRs, finished training programme and individual projects within the ITEAM network, should be ready to take positions in different sectors as researcher-practitioners and visionary leaders. In this context, the consortium places a special emphasis on the intersectoral training. This kind of training is being organized through secondments and special workshops, dedicated to each ITEAM research cluster. Each ESR, hosted in a certain sector, has at least one secondment in another sector.

Personal development training: To favour the development of transferrable skills by recruited ESRs, the ITEAM network will organize the personal development training through (i) research projects and (ii) personal training seminars. Personal development training makes an essential contribution to help the ESRs in reaching the targets of their personal career development plans. Therefore, the ITEAM consortium proposes relevant measures on the highest professional level using recent technologies of human resource management for academic and non-academic sectors. Multidisciplinarity of the personal development training will concern not only disciplines related to the ITEAM research clusters but also elements of project management, entrepreneurship, IPR and IP management, psychology, and social responsibility.

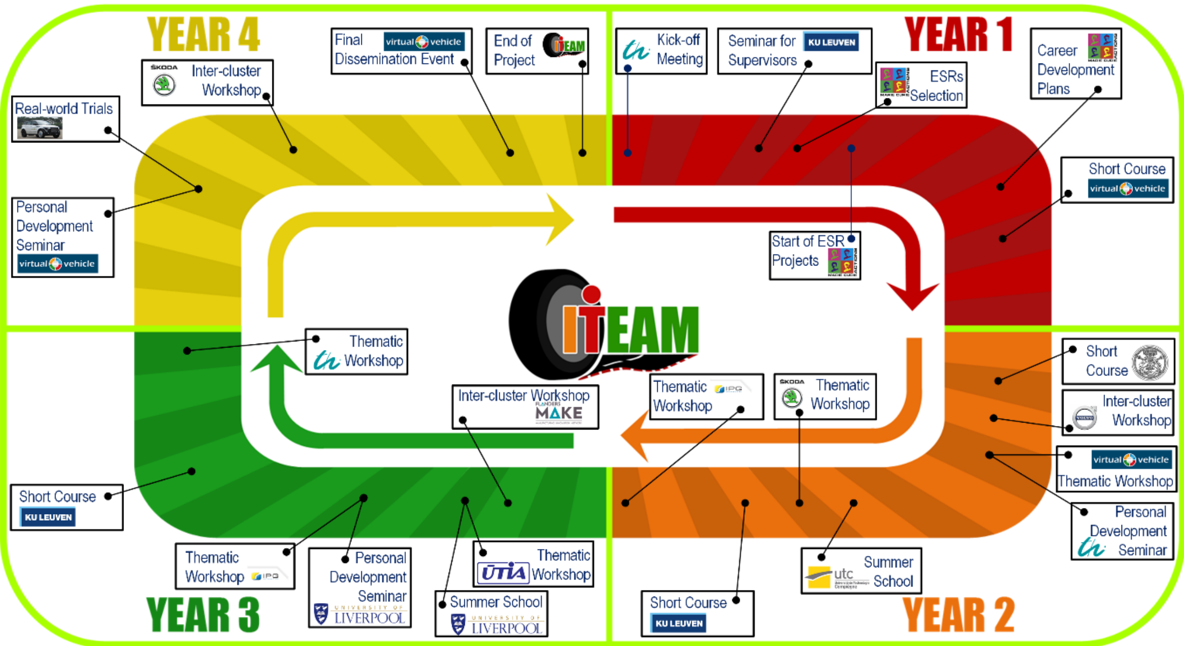

Figure 3: Example of training time plan

Hence, through exposure to different environments, recruited researchers are receiving excellent opportunities to develop their additional skills in research methods from different disciplines, experimentations, technology development, entrepreneurship, and management. The proposed partner's collaboration in each doctoral project, as indicated in Table 1, provides for recruited researchers a complete training environment that fulfils expectations from the academic and industrial sectors in the domain of MAGV. It guarantees that individual projects have a product-oriented character and ESRs will be provided with a valuable hands-on experience.

Benefits of ITEAM Programme

For all participating ESRs, the introduced research and training programme of the ITEAM network brings a number of following benefits.

- *Immediate benefits:* (i) New research experience connected with the fact that the proposed network topics have an increased grade of interdisciplinarity and orientation towards the multi-actuated vehicles and their systems as control objects with fundamentally new level of complexity; (ii) Close networking with partners from industrial and private sector in order to create an application side of performed scientific works and to open further career outlooks in parallel with academia.
- *Longer term benefits:* (i) Intensive works with students and young researchers from adjacent research groups at host organizations (and/or at organizations providing the secondment) with the possibility to establish unique schools of thought on the interface between abstract and engineering sciences; (ii) The development of new joint projects on the basis of the ITEAM network with participation of the network researchers as project coordinators or key persons.

All listed measures form in the aggregate a solid basis for sustainable progress of the researchers' career allowing them a good combination of such qualities as internationally recognized leading scientists and high-level research managers.

CASE STUDY: COLLABORATIVE DEVELOPMENT OF INTEGRATED ACTIVE CHASSIS SYSTEMS USING STAFF TRAINING

Motivation

Modern information technologies and mechatronic systems have a significant influence on ground vehicle engineering. This influence results in both an increasing degree of automation of systems employed in ground vehicles and emerging new concepts like integrated chassis control (ICC). Application areas of ICC relate not only to the traditional transportation sector of passenger cars and commercial vehicles but also to agricultural, mining, construction and forestry machinery. Of special importance is the fact that the integrated active chassis systems are also substantial components of semi-autonomous and autonomous vehicles, which have dartingly increased importance for the future transportation paradigm. In spite of existing engineering ICC solutions, wide intersectoral networking with an international dimension is missing and this can be considered as a tangible barrier for rapid development and market implementation of integrated active chassis systems. Moreover, bilateral training of researchers from academia and engineers and developers from industry is rarely observed in this field. The mentioned arguments point to strong demand for the consolidated research and innovation actions for ICC technologies. It motivated a consortium of partners from different sectors to implement the project through the following scheme:

- The consortium is being performed a regular staff exchange between the partners in order to be trained in skills required for the ICC development;
- Training through the staff exchange is supplemented with joint R&D, experimental and testing activities
- Training should bring to the development of joint demonstrator of ICC (concentrated around integration of active brake, suspension and tyre pressure control as one of promising solutions for simultaneous improvement of safety, energy-efficiency and driving comfort of ground vehicles).

These ideas are being realized in the project EVE – Innovative Engineering of Ground Vehicles with Integrated Active Chassis Systems – funded under the MSCA RISE scheme and introduced in next sections.

<u>Concept and Consortium</u>

The EVE concept is based on a number of objectives, and the most important of them from viewpoint of education are:

- Knowledge transfer and experience sharing between participants from academic and non-academic sectors to create innovative products in the field of ground vehicle engineering based on the know-how of partners in mechatronics, automotive control systems, vehicle dynamics and experimental techniques;
- Professional development of the consortium members through intersectoral and international collaboration and secondments to unique research environments exploring cutting-edge knowledge and technologies in ground vehicle and control systems engineering.

These educational objectives are connected with research and innovation objectives as:

- Development of reference tyre models for on-road and off-road conditions including database of experimental results
- Development of advanced models of ground vehicles and automotive subsystems for real-time control applications.
- Development of new hardware subsystems for brakes, active suspension and tyre pressure control for on-road and off-road mobility;
- Realization of remote distributed testing technology allowing cooperative experiments on test rigs situated at different hosts.

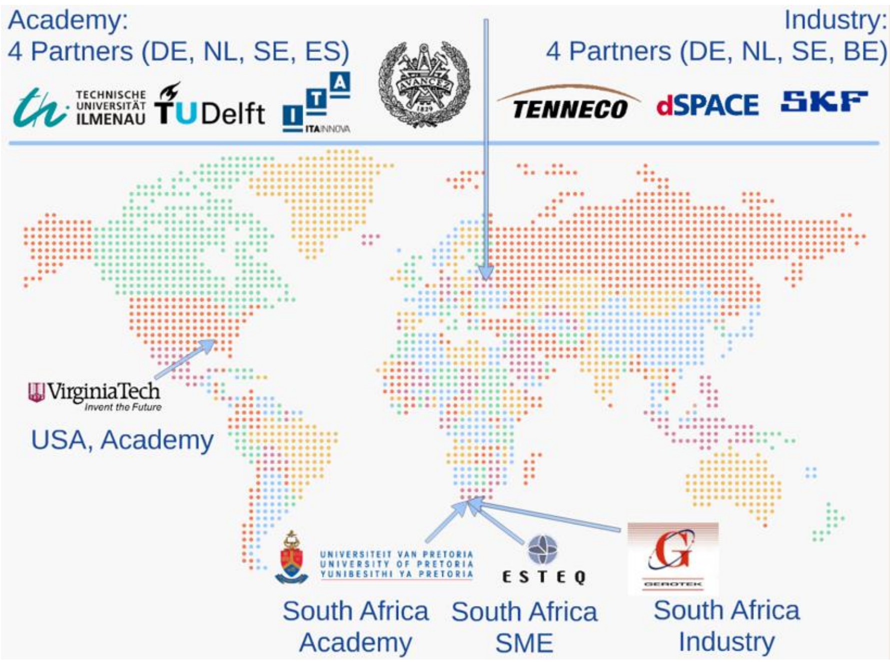

Figure 4: EVE Consortium

Hence, the listed objectives have a high grade of complexity and are related in general to the training of professionals having not only university education but also a certain professional experience. To address the objectives, the EVE consortium composition includes, Figure 4:

- Six research institutions – Technische Universität Ilmenau (TUIL), Technische Universiteit Delft (TUD), Instituto Tecnológico de Aragón (ITAINNOVA), Chalmers Tekniska Hoegskola AB (CHALMERS), University of Pretoria (UP), Virginia Polytechnic Institute and State University (VT);
- Six industrial organizations - Tenneco Automotive Europe BVBA (TENNECO), dSPACE Digital Signal Processing and Control Engineering GmbH (DSPACE), SKF Divisions in the Netherlands (SKF BV) and Sweden (SKF-AB), Armaments Corporation of South Africa (GEROTEK), ESTEQ Engineering (Pty) Ltd (ESTEQ).

<u>Interdisciplinary Training Content</u>

The educational activities and training in the EVE project have a strong interdisciplinary character expressed by combination of different areas of knowledge that will be brought by the consortium members. The interconnections of disciplines and project outcomes are illustrated in Figure 5.

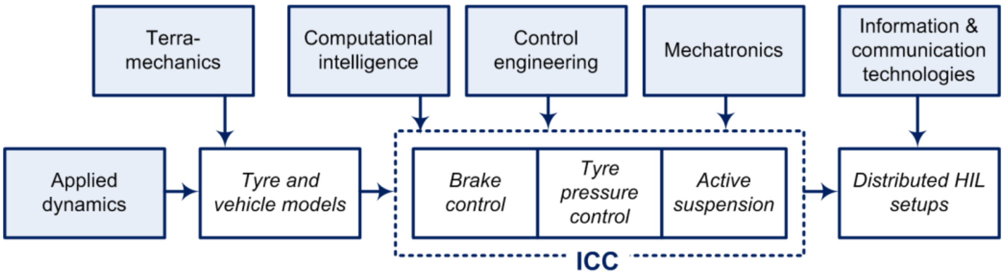

Figure 5: Interdisciplinarity of the project EVE

Specifically, the staff involved in the EVE project is receiving a consecutive training of the following skills:

- Development of tyre models for on-road and off-road conditions, terrain models as well as vehicle dynamics models using relevant mathematical instruments of terramechanics and applied dynamics;
- Control engineering methods necessary for formulation of control strategies for the active brake, suspension and tyre inflation systems;
- Methods of computational intelligence to handle the uncertainties in the definition of parameters for the operational environment of ICC;
- Mechatronic system design for ICC subsystems;
- Hardware-in-the-loop and vehicle experiments.

The EVE concept use simultaneously people-centric and information-centric approaches for knowledge sharing. *The people-centric approach* implies that each consortium member will allocate persons that are involved in running research and innovation activities at the host and will be responsible for knowledge exchange within the project. They will be in direct contact with nominated colleagues in partner organizations and contribute to transfer knowledge through participation of secondments, supervising and collaboration with visiting EVE partners. *The information-centric approach* is required due to the interdisciplinary character of the project EVE. The knowledge, collected and shared in course of the project communications and collaborative works, is classified to different domains like simulation techniques, controller design, mechatronic applications, design of experiments and other. The correspondingly classified information is stored in specified project databases and handled in thematic training events of the project.

Explicit and tacit knowledge sharing is being organized through secondments – individuals participating in the project are gaining knowledge during a set of mobility periods. In accordance with the consortium strategy, the seconded scientists / engineers should collect theoretical and practical experience from working in new research, technological and cultural environments. Some examples of knowledge sharing are graphically introduced on Figure 6.

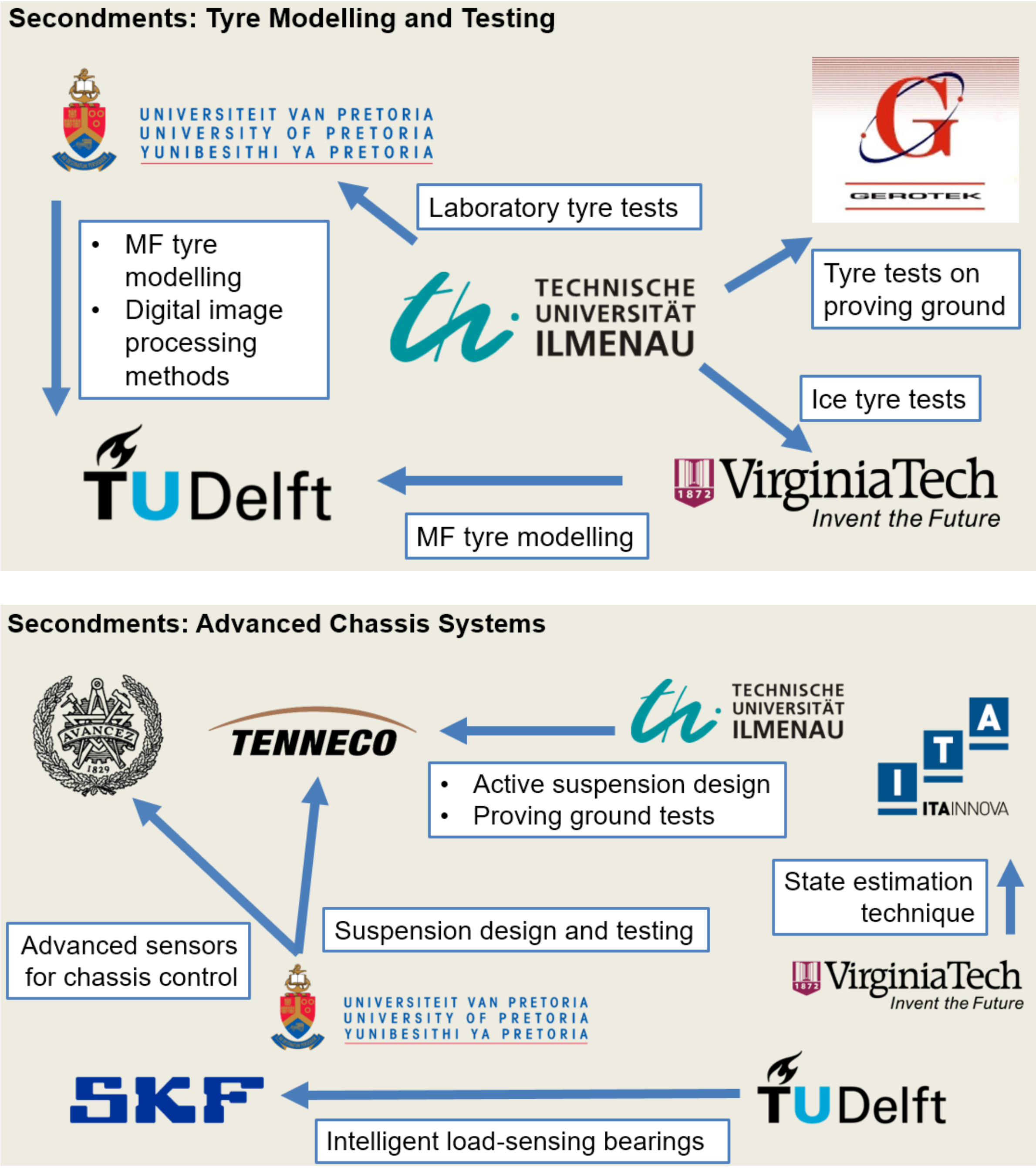

Figure 6: Examples of knowledge sharing through secondments

Benefits of EVE Concept

The training approach realized in the EVE project brings benefits for all participants through a valuable experience gained from interdisciplinary, intersectoral and international cooperation.

In accordance with the rules and goals of the MSCA RISE instrument, the individuals participating in the staff exchange have to be actively engaged in or linked to research and innovation activities at the sending institution for at least six months prior to the first period of secondment. After the secondment, the exchanged staff members should be reintegrated again into the sending organization. In this context, the EVE measures intend to transfer efficiently knowledge back to the sending hosts. In particular, the returned staff members are taking responsibility not only for ongoing research tasks of the EVE project but also for other research and innovation activities on host institutions to maximize the benefits from their newly acquired expertise.

CONCLUSIONS

Two case studies, introduced in the presented paper, are demonstrating different approaches to the post-graduate learning and training of researchers and professionals in the field of automotive engineering. These approaches show that intersectoral and international training programmes funded from public sources can bring essential benefits both to academic and industrial staff through strengthening of their career outlooks. In addition, the presented training concepts contribute to the development of complex engineering objects requiring strong interdisciplinary approach.

ACKNOWLEDGEMENT

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