Future technologies in the EU transport sector and beyond: an outlook of 2020-2035

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Abstract. The aim of this paper is to deliver a brief synopsis of the transport research landscape by conducting a review of the transport projects across the four modes of transport on European level (FP7, H2020). This synoptic review identifies dominant technology themes (i.e. small electric urban vehicle design, battery materials and design, cleaner conventional engines, Automated Driver Assistance System, cleaner and quitter aviation engines, developments of Computer Engineering tools, morphing aircrafts, cleaner multifuel maritime engines, new freight wagon design, satellite positioning for rail Train Control & Management System). Future recommendations and conclusions are also provided.

Keywords: EU transport research, future transport innovation, EU transport projects

1 Introduction

According to the Paris Agreement, the reinforcement of innovative transport technologies and innovation should be a priority in the policy agendas. It is particular important to collect, analyse and disseminate information on technology development to support action on transport and climate change [1]. At a time of economic crisis, major demographic changes and increasing global competition, Europe's competitiveness, depends on its ability to drive innovation [2]. This is why innovation has been placed at the heart of the Europe 2020 strategy. It is also best means of successfully tackling major societal challenges, which are becoming more urgent by the day: Increased demand in transport, Dependency on oil, Congestion, Ageing, Travel optimisation using Information and communication technology (ICT) and satellite based technologies, Cutting edge technologies/ focus on Research and Technology Development (RTD), Better infrastructure (completion of the TEN-T) and Security [3-4]. The European transport companies are leading innovators with an increased RTD

share over the last year on the automobiles sector [5]. Based on scientific breakthroughs in recent years, the explosion in the knowledge on transport systems is set to deliver a continuous stream of new applications [6]. The aim of this paper is to deliver a brief synopsis of the transport research landscape by conducting a review of the transport projects on European level (FP7, H2020) and presenting the technologies that are being researched. In addition the paper presents some further innovative enabling technologies that are expected to become dominant in the near future. The overall aim is to produce future recommendations for research directions.

2 Methodology

The methodology followed in this research is based on a systematic review of 354 EU transport related research projects, funded under FP7 and H2020 programmes, with their main focus on technology development and innovation (Research and Innovation Action and Innovation Action types of projects). The initial step was to identify such transport projects from EU research databases like Cordis and TRIMIS using key word search terms and filters that the two databases offer. Specifically, the key terms that were used were road transport, air transport/aviation/ aeronautics, rail transport, maritime/waterborne transport. In addition, for the Cordis database the "programme FP7- transport" filter was used while for H2020 projects "transport", "energy", "environment", "infra", "industrial leadership", "security" filters were applied. In the TRIMIS database, projects were already available in modes i.e. air, road, urban, rail, water and multimodal transport and can be filtered by funding programme (FP7, H2020). After obtaining a list of projects that was built from the search results of the two databases, additional criteria were applied. Specifically, only projects from 2010 until currently were selected, assuming that further technology advancement would have been carried out on the topics that were researched earlier. The project reviews that were carried out, are based predominantly on the final reports, "results in brief" and periodic reports that are available on the two aforementioned databases depending on whether a project has been completed or is ongoing.

3 EU transport research projects

The following section presents a segment of the technology themes that are being researched or have been researched by the various EU transport projects.

3.1 Road transport

The shift towards cleaner Electric Vehicles (EVs) is evident in market shares of EVs which are constantly growing and could account for 25 to 40 percent of new vehicle registrations worldwide until 2030 [7]. The EC's focus on electrification is evident by the amount of projects funded to work on this subject while a special interest in small urban lightweight vehicle designs has been identified (WIDE-MOB, ALIVE,

AMBER-ULV, ELVA, EPSILON, SAFEEV, URBAN-EV, BEHICLE, STEVE, DEMOBASE, RESOLVE, ESPRIT). Electric trucks and vans with modular structural architecture were also the main themes for freight related projects (OPTIBODY, DELIVER, CONVENIENT, V-FEATHER). In the field of vehicle technologies, autonomous driving systems are currently one of the major trends emerging on a large scale. The progresses made over the past decades in the development of various kinds of driving assistance systems represent important milestones towards automated transport systems in the future [8]. Although autonomous driving would already be technically possible, non-technical issues such as lagging legal framework conditions inhibit currently a breakthrough of this technology [9]. The CITYMOBIL2 project is a good example were autonomous buses were pilot tested under real city conditions.

Development of new lightweight materials for vehicle structures such as Fibre Reinforced Polymers, or advanced metal materials (aluminium, magnesium, and high strength steel) is part of the research relevant to developing new more energy efficient lightweight vehicles while retaining crashworthiness (ALIVE, AMBER-ULV, E-LIGHT, PLUS-MOBY, EPSILON, BEHICLE, QUIET). Projects like H2ME, H2ME 2, HIGH V.LO-CITY, HYTRANSIT, HyTEC and CHIC are all major fuel cell vehicle demonstrators on passenger transport that included the deployment of refueling infrastructure, while taking in consideration hydrogen production on site.

Cleaner engine design is one of the most important themes in the road sector due to the significance it will play in the short and perhaps longer term, until EVs become more dominant. Some of the main themes that have been researched were advanced low emissions Spark (SI) or Compression Ignition (CI) engines; Downsized engines for hybrid EVs; Electric forced induction; Ultra lean combustion; Dual fuel engines for trucks and Waste heat recovery (GASTone, CORE, POWERFUL, ORCA, EAGLE, GasOn, COLHD, HDGAS, REWARD, ECOCHAMPS and UPGRADE). Integrated emissions control is not a new technology, yet there is room for improvement in the way air pollutants are captured before leaving the vehicle. Projects like CORE, HCV, EAGLE, GasOn and UPGRADE studied the development of Advanced Selective Catalytic Reduction (SCR); Integration of the advanced SCR catalysts onto a Diesel Particulate Filters (SCR/DPF); AdBlue processors; Gasoline particulate filters and three way catalysts without precious metals; Electrified (DPFs).

Although, electrification of vehicles is one of the major developments that is currently influencing the industry, several constraints remain concerning the overall eco-balance of EVs. An example is the production of a single Tesla battery that accounts to 17.5 tons of CO_2 [10]. Projects like GreenLion, OSTLER, SMARTBATT, HCV, DEMOBASE, ECAIMAN, iModBatt, EVERLASTIN, GreenLion, EUROLIS, EASYBAT, EuroLiion researched battery modularity and how the batteries should be integrated into the vehicle design rather the other way around including new battery materials. Development of electric motors is a way forward for road electrification. The most interesting concepts were delivered by projects that looked into Magnet free Switched Reluctance Motors (SRM) and Permanent Magnet Assisted Synchronous Reluctance Motors that do not use rare earth material (SYRNEMO, ARMEVA, Re-FreeDrive and ModulED).

Advanced driver assistance systems (ADAS) projects (COVEL, GENEVA, CITY MOVE, ERSEC, ADAS&ME, VI-DAS, ROBUSTSENSE) took various directions in the implementation of such systems with more focus on accurate satellite positioning, collision avoidance, advanced sensors, machine learning and cloud data integration.

In the course of digitalization, Intelligent Transport Systems (ITS) are rapidly developing. ITS-technologies optimize traffic flows and the use of infrastructure by intelligently managing and directing the different traffic elements. The following types of communication can be differentiated within ITS-technologies: Vehicle-to-Infrastructure (V2I), Infrastructure-to-Vehicle (I2V) and Vehicle-to-Vehicle (V2V) [11], examples of such projects are SMARTFUSION, ELVITEN, SAFESTRIP, INTERACT and HIGHTS. Further emerging innovations is truck platooning, where several trucks are connected together through V2V-communication or collective/swarm intelligence, where specific actions of individuals evoke intelligent behaviors in the community through communication and networking activities [12]. A relevant example project is COMPANION.

Furthermore, several new mobility products and services have emerged in recent years. According to a recent study, more than 20 million vehicles could be removed from urban roads in the future, given the predicted growth in new mobility solutions (e.g. ride-sharing, on-demand systems, etc.) [13]. One of the main trends that can be observed are sharing systems, which are based on a fundamental rethinking in the ownership of mobility products, turning from ownership of transport modes to the use of transport modes [9]. Especially in mature economies and societies, a shift towards shared economies is evolving especially, for younger generations where car ownership in general is highly affected by new attitudes and behaviors [14]. Another trend is the growing range of Mobility as a Service (MaaS) (STEVE project). Several MaaS projects are currently running in Europe and cities such as Helsinki have already announced their intention to eliminate the need for privately owned cars by 2020 only through implementing a wide range of MaaS offers [15]. On-demand systems - a specification of MaaS - are transport services that are ordered individually and on demand. Autonomous operations of on-demand systems could offer a huge potential to lower individual travelling costs for mobility users in the future [16].

3.2 Aviation

Future aircraft design is one of the most dominant themes in the EU aviation research sector with many projects introducing designs that will improve energy efficiency of the aircrafts. Innovative concepts like Blended Wing Bodies, C shaped wings, supersonic designs have been researched by various projects (ALaSCA, AHEAD, ATLLAS II, HEXAFLY-INT, DIsPURSAL, Ce-Liner, WASIS). Morphing concepts, the idea that parts of the aircraft like wings, fuselage, wingtips, trailing edges can adapt their shape based on the operational environment, have been investigated by NEVEMOR, SARISTU and SABRE. Aerodynamic design of wings and fuselages has concentrated in methods of controlling air flow and reducing turbulent flow by plasma actuators and Turbulent boundary layer control (MARS, AFDAR, TFAST, DRAGY). Computer Aided Engineering (CAE) tools such as Computational Fluid

Dynamics (CFD) or Finite Element Analysis (FEA) and other simulation tools will require further development in order to provide more accurate and real test-like results, thus minimizing cost of development (IDIHOM, MAAXIMUS, EXTREME, AEROGUST and DAEDALOS).

Materials development will be crucial for future aircraft designs. Examples of such materials are nanomaterials, composites, advanced alloys, ceramic matrix materials and high temperature materials for hypersonic speeds (ELECTRICAL, SARISTU, CERFAC, TICOAJO, ATLLAS II, HEXAFLY-INT). In addition, additive manufacturing methods like Selective Laser Melting (SLM), Laser Metal Deposition (LMD) and Electron Beam Melting (EBM) have been further developed by projects like MERLIN, Bionic Aircraft, AMOS, MMTech and AMATHO.

Noise from aviation is a major issue that can impede the future growth of the sector. Its control and mitigation have been covered extensively by research projects NINHA, ORINOCO, RECORD, ENOVAL, ARTEM and IMAGE through methods of studying engine noise and how engine stages interact with each other.

Engine and engine components development will be key enabling technology themes for future aviation. Projects like LEMCOTEC, FACTOR, IMPACT-AE, SOPRANO, ULTIMATE, SHEFAE 2, DREAM, and FIRST have worked in the development of ultra-high pressure ratio compressors, lean combustion and combustor design, interaction between combustor and turbine in order to improve engine efficiency and reduce emissions. Hybrid electric propulsion has also been studied by projects like MAHEPA, AHEAD, ASuMED and DIsPURSAL.

3.3 Rail transport

The EU rail sector will need to become more attractive for the customers, while remaining environmentally sustainable, increase its high-speed network and offer modal shift for goods transported by road while also offering connectivity with ports and airports. Wagon design was been a considerable technology theme with projects like CAPACITY4RAIL, VIWAS, HERMES and VEL-WAGON all offering their own design for modular lightweight freight wagons. Project Marathon has proposed an innovate concept of coupling two trains together with a slave locomotive in the middle of the convoy, which proved to offer considerable fuel savings during the trials. Project such as ACEM-Rail, ROBO-SPECT, SAFTInspect, DTD SYSTEM 2, SAFT, INTERAIL developed solutions for inspecting rail infrastructure with advancements in non destructive testing methods such as remote robotic systems, ultrasonic inspection and eddy current methods. Within a similar context projects MAXBE, AUTOMAIN, DIAG-PANTOGRAPH, WARNTRAK, INNOWAG developed solutions that can monitor health/ condition of train components.

Reducing noise emissions from the rail sector remains a high priority and potential growth impediment factor. Projects like QUIET-TRACK, RUN2RAIL, FFL4E, FINE1 and RIVAS have all studied solutions ranging from on board noise & vibration monitoring, noise simulations and human perception of noise and noise mitigation methods for tracks.

Train Control Management System will play a greater role in the control in the input/output of information regarding position of train, train operation, traffic management and communications. The integration of GNSS and EGNSS satellite positioning into various aspects of TCMS has been the subject of many projects (SMART RAIL, GRAIL-2, SATLOC, X2RAIL-2, ASTRail).

3.4 Maritime transport

The EU maritime industry remains competitive offering high value added products, rapid innovation, high safety standards and a leading position in terms of green technologies [17]. Project MUNIN, studied the development of a smart and autonomous or remotely operated cargoship. Such vessels will also require V2V and V2I systems including onshore infrastructure of remote control. Other projects like E-Ferry and SEABUBBLE, BB Green, GFF worked on the development of electric ferries and small electric boats for passenger transport. The design, manufacture and assembly of ships will also require change. CAE tools assist engineers in the design process of the vessels and various components, including the ship building process. Projects like PerSEE, No-Welle, SMARTYARDS, FIBRESHIP carried out research based on more accurate tools for CFD, FEA of ships including shipyard assembly simulation.

Integrated emissions control seems to also affect considerably the maritime transport sector, due to the emissions control impacting the vessels. Project like DEECON, RETROFIT, TEFLES worked on the further development of 2nd generation scrubbers for reducing SO2 and Particulate Matter (DEECON, RETROFIT, TEFLES) while other projects worked on SCR and DPF (HERCULES-C, HERCULES-2, JOULES). The innovative use of a Non-Thermal Plasma Reactor and Electrostatic seawater scrubber for reducing PMs, SO2, NOx, VOCs and CO was tested by DEECON.

Research on resistance and propulsion issues such as trim monitoring control, propeller design, ship stability, use of combinators and podded propulsion, was carried out by project like RETROFIT, TRIPOD, TARGETS TEFLES, STREAMLINE. In addition, multifuel engines using 1) LNG/Diesel, 2) Fuel flexible two stroke and four stroke engines, 3) Compressed Natural Gas (CNG) and/ or Liquified Natural Gas (LNG) as an alternative hydrocarbon fuel to Heavy Fuel Oil (HFO) or 4) LNG-Liquified Petroleum Gas (LPG)/Diesel were developed under RETROFIT, JOULES, HELIOS and HERCULES-2. Projects like HERCULES-C were one of the major projects in terms of engine development and optimization for ships. The electrification of secondary energy converters on board such as fuel cell generators, waste heat recovery, electric motors and hybrid propulsion are technologies that can offer potential energy savings (JOULES, INOMANS²HIP, H2MOVE, TARGETS, TEFLES, Auxilia, MARANDA). Furthermore, the integration of renewable energies such as wind and solar into propulsion has shown to be innovative concepts that will require further future research (ULYSSES, JOULES, SeagateSail, TARGETS, Rotor-DEMO, INOMANS²HIP).

In addition, ports are begging to increasingly use renewable energies into their port equipment such as Rubber Tired Gantry Cranes or trucks. Such initiatives were stud-

ied by the GREENCRANES project while RETROFIT, INOMANS²HIP and TEFLES investigated the use of Alternative Maritime Power.

4 Conclusions

The transport system is under transformation leading to a fundamentally new system and frame-conditions for mobility in the future. The European Union has been investing on RTD in the transport sector in order to prepare its transport system for the future challenges of decarbonization, retaining a competitive advantage over developing economies, while meeting changing societal needs in a global scale. The main technology themes that have been identified under this paper were the following: **1) Road transport:** Lightweight EV design, autonomous vehicles, hydrogen fuel cells, engine design and integrated emissions control, batteries and electric motors' development, ADAS, ITS and MaaS systems. **2) Aviation:** Aircraft design and morphing concepts, aerodynamics, CAE, new advanced materials for engines and structures, efficient and quiet engines including electric hybrid propulsion. **3) Rail transport:** Train design and modularity, inspection and testing for infrastructure and vehicles, health & condition monitoring of trains components, noise and vibration of trains, train control systems and satellite positioning. **4) Maritime transport:** CAE tools, autonomous vessels, Integrated emissions control, electric propulsion and secondary energy converters and integration of renewable energies, Alternative Maritime Power, greening of port equipment and operations.

Although, new technologies have been identified, their adaptation by the industry or the market itself, does not always occur. An example is the design of small urban vehicles as identified. Regardless, such vehicles are only a portion of automakers' available models. Furthermore, strategies of policy, planning and research are required. There is a need for new mobility paradigms to deal with both 1) the options arising from new technologies, mobility solutions and systemic change, and 2) the negative side effects of transport. Thus, to deal with burdens of increasing mobility demand, mobility has to be decoupled from aspirations for economic competitiveness, wealth and quality of life. This should lead to qualitative development of the transport system instead of growth. Especially a resource efficient organisation of given infrastructure via new technologies, selective amendments of the system and the realignment of strategies to principles of green and circular economy by using developments of industry 4.0 are essential in this context. People's mindset including those of companies will need to change towards future technologies. Finally, demonstrator initiatives could help the penetration of future technologies into markets by making people more familiar with technologies and increase attractiveness of the products.

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