Evolution of technology and users' requirements of factory communication systems from the 3rd to the 4th Industrial Revolution

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***Abstract*—The last 40 to 50 years' history of factory automation based on electronics and computer technology had given experiences on successes and failures. The author's personal carrier has touched several areas of technology and networking aspects of this progress domain. Telecommunication networking for industrial cyber-physical systems, IIoT and the automotive sectors are investigated.**

***Keywords*—CIM, ISO-OSI, MAP-TOP, standardization, User groups, Technology Platforms, INDUSTRY4.0, global networking**

I. INTRODUCTION

The history of factory automation based on electronics and computer technology had started around 4 or 5 decades ago, basically when the solid state components replaced the magnetic-mechanical switches within machine control circuits. Nowadays, when we deal with cyber-physical products and production systems [1] we declare the present as the birth and outbreak of the 4th Industrial Revolution, - the 1st being the emergence of the steam-power; the 2nd being accepted as the introduction of the mass-production technology, the 3rd industrial revolution was along the introduction of computer (and IT) technology at the shop floors. [2]

This paper highlights the key milestones of the evolution of shop-floor communication technologies with the industrial user requirements and points out the networking elements along the decades.

The term networking has two areas worth to differentiate: (1) when telecommunication channels get more advanced than just point-to-point interconnection; (2) when groups and communities share and jointly discuss, evaluate, generate harmonized opinions, prepare standards, debate, vote or agree on joint initiatives, regulations, etc.

In this paper the author reflects to gained experiences in several networking scenarios, covering industrial networking topics throughout the 4 past decades.

Sections of this paper will recall the General Motors' MAP initiatives, [3] the global networking efforts to gain applicable international standards, international CIM pilots, emergence of the European international EUREKA initiative, the Technology Platforms within the EU, the national TP-levels, the INDUSTRY 4.0 German, -EU, -GLOBAL networking.

While 4 decades ago the targeted industrial communication application field consisted of connecting a couple of controllers (PLCs, CNCs, Process Controllers, Robot-controllers, shop-floor terminals), by now, with the advent of IoT (Internet-of-Things) and IIoT (Industrial IoT), the task is not just a multiplication factor (quantity) issue, but quality-complexity issue too.

The paper will refer to the vast area of IoT, highlighting the relative small sub-domain of INDUSTRY 4.0 being addressed for the manufacturing and robotics applications. [4]

Due to its very timely issue, the paper highlights the present-day's industrial communication requirements within the automotive industry. The need for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2X) communication solutions is a prerequisite for the autonomous driving era already being asked for. The paper ends with commenting on the reals needs, and services to be applicable, finally will show the plans of the Hungarian test field for the autonomously driven vehicles.

The concluding part could be interpreted to be both optimistic and/or pessimistic. Though technological developments has introduced excellent techniques, the present user needs seems to be very close to the requirements of the 1980's, as if 40 years had almost solved none of the initial tasks.

II. HOW IT STARTED FROM THE LATE 1970'S?

The innovative technical directors at General Motors formed a "MAP TASK FORCE", to set a long-term technology leap for connecting industrial controllers and computers applied in the factories of the company. By 1980, the "MAP – Manufacturing Automation Protocol had been declared to be a future set or "stack" of standards, mostly planned (later on based) on the ISO-OSI 7-layer model. At the time of the definition, declaration, no such products were available at all. The user requirements were simple: Layer 1-2 were stable, allowing the options for Token-bus 802.4, or CSMA/CD 802.3 9 and newly defined layer 7 protocols had to be developed, defined and implemented at various HW-SW platforms. At the Application layer 7, FTAM, X500 directory service, Network management and the most novel MMS (Manufacturing Messages Standard) were defined for implementing general industrial tasks at the factory level.

IBM, DEC, Hewlett-Packard, FANUC and AllenBradley Honeywell computers and controllers were the first set of node-devices. The MAP version 1.0 was soon reworked for 2.0 and 2.1 versions during 1985-86, while the MAP/TOP 3.0 version was demonstrated in both UK and USA.

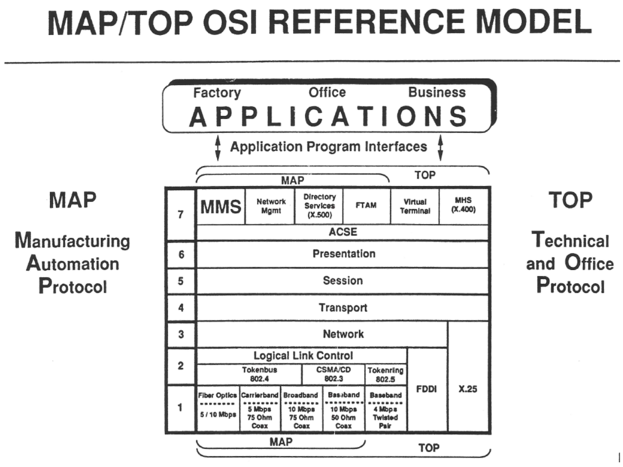

Fig.1. MAP/TOP Reference Model

The GM Task force soon realized that the harmonized solution must be a stable, and global answer to the user's needs and requirements. To gain acceptance, not only technology-demonstration events (fairs, expositions, demos) are needed, networking is also fundamental to involve experts and real users-vendors. Thus following demos, user groups were formed, like North-American MAP/TOP Users Group, European MAP Users Group, Australian and Japanese. By 1988, the Munich located SYSTEC exhibition demonstrated the operational, partly European, partly American products based implementations.

III. ESPRIT Project for CIM Design Rules

By 1990 an ESPRIT project report was published on the Design Rules for CIM Systems [10]. The project team summarized the state of the art for industrial communication, and for a generalized CIM environment collected 14 strategy points (rules or directives) to be considered in planning and designing factory communication systems. These points can still be considered valid today, and are still part of the present day's university lectures.

IV. Need for East-European MAP/TOP Users Groups

The IEEE 803 set of OSI standards had to be developed for ISO-acceptance, it means the international standards ISO committees had to accept or reject proposals from IEEE 803.xx versions. The World-Federation of MAP/TOP Users Groups decided to open the consultations with the East-Europeans, including the Soviet Union. The author was offered to help this process by setting up the Hungarian Group (HMUG) and promoting the regional East-European Interest Group that could work in harmony with the EMUG and the World Federation. A significant result of the HMUG was to set up a MAP training Centre, and for many years this laboratory served as a teaching factory for CIM students. Robot-controllers, PLC-controllers and CNC machine controllers were networked with FLEXCELL and similar Cell Controllers, as a development of MTA SZTAKI, managed by the author. Results were proudly demonstrated within the SYSTEMS and SYSTECH international exhibitions in Munich. [5]

V. What Were the Failures?

The North-Americans, pushed by the GM key players, were unalterable on the inclusion of Ethernet, CSMS/CD protocol for real-time applications. For them the deterministic status of the Token-bus protocol was their first priority. They were seconded by the Japanese and also supported by the Australians.

EMUG opinion was for Ethernet due to its very affordable price (almost zero, since most computers and controllers contained them as default interface), while the cost of a Token-bus interface was comparable to the price of the devices planned to get connected. There were several other obstacles, why companies did not buy MAP solutions:

- the standard came out late (just 1 or 2 years later, then planned),
- end-users needed fast solutions,
- end-users preferred cheaper solutions, other Field-bus, Profibus, MODBUS, or other bus versions,
- "not-invented here" excuse for other options,
- the interface for Token was unacceptably expensive, due to the limited need of the products,
- individual sensors or actuators were not reasonable to get connected directly,
- no support from engineering communities,
- end-users did not need all the functionalities,
- a Gartner-Group declaration against MAP-acceptance.

In spite of their failures we can show up lessons to learn:

- user groups are essential to speed up technology-debates,
- Aa good engineered, sound technology base is a must for long-term, stable standard,
- the MMS functionalities were taken up and partially implemented in most other Application-networking standard at layer 7.

The most forward-looking features and services of the MMS were:

- the Virtual Manufacturing Device Support,

- Domain, Program Invocation, Variable Access,
- Environment and General management,
- Semaphore and Event management,
- Journal management,
- Operator I/O and File transfer.

By systematic planning the network of a whole enterprise, including inter-continental distributed factory sets could be covered by the network-segments with full functionalities. The MMS became the connecting glues from the company's management and office levels down to the real-time zone of controllers and field devices.

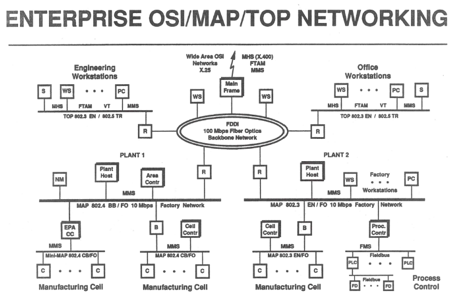

Fig.2. Enterprise network with MAP/TOP by EMUG

VI. TEN YEARS LATER, NETWORKING IN A NEW ERA

Dozens of industrial networking solutions were designed and implemented, since technology developments allowed newer and newer chips, interfaces and protocol-versions to address sector-specific requirements. CAN bus for the automotive sector, Bitbus, Modbus, PROWAY, Interbus, HART and PROFIBUS, dedicated versions for home or building environments, FIELDBUS versions, FIELDBUS FOUNDATION standards emerged with many subsets from the MAP's MMS. SERCOS network was again a specific application area for drives to be controlled with real-time synchronization.

The drive to extend the services has increased, and isochronous channels also needed to be involved. Multimedia requirements used ISDN and other available media before higher bandwidth and G3, G4 technologies offered more solutions.

Some far-ahead-looking scientific experts with good engineering expertise had the chance to suggest a European (EUREKA) level initiative based European Commission decision: to care for the next generation of efficient European manufacturing solutions. The idea was soon enlarged, and the European ManuFuture Technology Platform was established [6] as a bottom-up initiative to give scientific-technical suggestions to the EC and the EP for preparing a better Europe. This voluntary based group worked on a harmonized Europe-wide vision, followed by a consensus-based list of research needs (Strategic Research Agenda) and concluded by a RoadMap, how the visions could be reached with the given resources. There are a number of European Technology Platforms, each having dedicated technology domains, areas of interest, while some (e.g. 10) work as a sub-platform of ManuFuture ETP.

The EC understands the power behind the sectors involved, and treats the ManuFuture ETP and a key partner to set the goals for the research Framework Workprogramme and basic decisions regarding technology advances.

VII. GIVING LEGAL ENTITY TO MANUFUTURE ETP

To be able to deliver industrially operational research results the EC supported the establishment of the EFFRA, the EUROPEAN FACTORY-OF-THE-FUTURE RESEARCH ASSOCIATION. [7] The EFFRA is an open group of enterprises, research institutions, academic or university departments that can form consortia to make and deliver results.

EFFRA finances the projects based on the EC decisions, matching the PPP (Public-Private-Partnership) concept. EFFRA is open for any European partnership, but its main focus is on SMEs, as a grand challenge for Europe to raise SME involvement on high-tech.

The ManuFuture ETP with the business power of EFFRA has been working on the also high-priority European Grand-Challenge: *the digitization of the industry*.

In the EU countries each government had committed itself to a harmonized and nationally supported, pushed action: besides raising digitization at all governmental and other sectors agreed to give special focus to the digitization of the industry.

The German Prime Minister Angela Merkel, when received a briefing on the possible positive aspects of the connected, digitalized industry, suggested and actively supported that Germany should be the forerunner in it. Other countries and regions also had and have similar ideas, but the German version was the very first phrase for the 4^{th} Industrial Revolution: INDUSTRIE 4.0. [8]

All around Europe and by now also in all other regions, INDUSTRY 4.0 is the strong symbol of harmonized, standards-based efforts to use interconnected IT solutions in the industry. In the USA the terms Connected Industry or networked industry are rather applied.

VIII. IN THE PAST 5 YEARS: CONNECTING IOT & SENSORS

Advances in IT and communication technologies opened the research fields of internet-of-things. Combining with the new sensory elements data processing subsystems became very important. BigData, CouldComputing, DeepLearning are examples of newly adoptable technologies. The vast universe of IoT can be devoted to specific technology and specific application domains. The figure 3 points out the selected part of IoT that is reflected in the German INDUSTRY4.0. [4], [8].

IX. NETWORKING FOR INDUSTRY4.0

As the German initiative got governmental support and push, other nations within the EU decided to set up national task force groups. Hungary also declared its commitment at the level of Secretary of State to push the digitization of our industry at a very steep, fast scenario. The National Technology Platform IPAR4.0 had been initialized already in Spring 2016, and 7 working groups had been formed to care for strategy, education, pilot implementations, test sites, standards, and legal entity development. More and more companies are eager to join and learn on advancements, benefits, chances of the platform.[9] A mayor topic is the readiness level of SME-s.

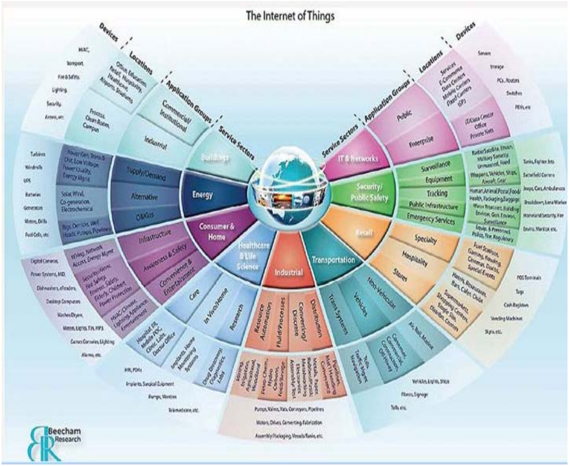

Fig.3. The areas of IoT, and the domain for INDUSTRY4.0. in red color [4]

Networking at international level is also important. EU Commissioner had pointed out the need for national-level projects with national government commitments in each and every EU member-state. The Commission intends to generate EU-wide joint harmonized actions in this specific area of interconnected digitization.

X. THE STATUS OF TELECOMMUNICATION STANDARDS

There is a huge advancement of new telecom standards, and an excellent recent survey in IEEE has drawn a detailed map of standards and SW modules, interfaces worth to mention [14]. Copyright had been requested from the authors to refer this mapping of standard from 1970 onwards,

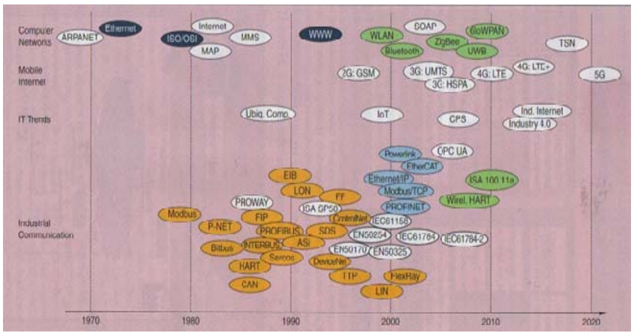

Fig. 4. Milestones in telecom standards [14], (Requested courtesy diagram from the authors)

Regarding the INDUSTRY4.0 domain, the very basic applicability question is still open: Industrial processes are time-sensitive, real-time and the available telecom standards are all limited in certain resources. The Ethernet-based developments to address Real-Time needs offer presently 3 classes. Class A manages RT services at 100 msec cycles times, Class B allows 10 msec, (both with extensions to IEEE802) while Class C runs with a 802.1 TSN method, where Ethernet operates with priorities and in addition with scheduling at the lowest layers (with 1 msec range).

Time Sensitive Networks (TSN) are under development, but significant results cannot yet be predicted for the next year.

As the future tasks to be solved are more complex, the networks to support the solutions get more heterogeneous, more mobile and multivendor. The 5G networks will need to manage very hard limits of compromise.

For the present applicability, the EtherCAT and the OPC-UA [11], [12] are verified as possible bases for the Industrial Interoperability of IIoT elements and controls. It appeared at around 2005, at the time, when Service Oriented Architecture concepts got world-wide industrial acceptance, and the G3 started to be securely operational. Regarding the INDUSTRY4.0 standardization process, the global-level, international work is referencing RAMI4.0 based on the OPC-UA communication technology. [13]

For IIoT and CPS areas, the trend shows a shift from the ISA95, ISO factory control "Pyramid" model, towards the distributed, service oriented concept as shown in the following Figure 5. [1], [25]

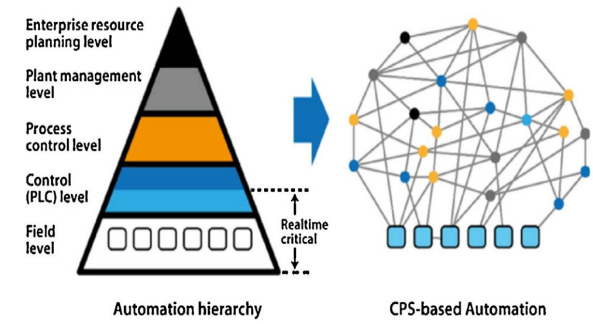

Fig.5. The trend from the pyramid to the SOA model

The IIoT communication with devices will rarely happen directly. Sensors and device information will rather be published and consumers can subscribe to this information.

Typically they will communicate via IP-networks among each other and with cloud based BigData and Cloud-Services applications. [12]

Requirements are: - independence from the communication-technology from manufacturers, OS or programming language; - Scalability, -Vertical and horizontal across all layers; -Secure transfer and authentication at user and application layers; - SOA transport via established standards for live and historic data, command and events; - Mapping of information content with any degree of complexity for modelling of virtual and physical objects; - Unplanned and adhoc communication for plug-and-produce functions; - Integration into engineering and semantic extensions;- Verification of conformity with the defines standard; as mapped in [12].

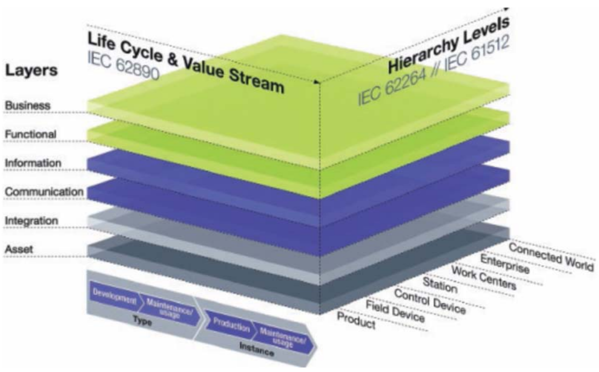

Fig.6. RAMI4.1, Reference Architecture Model for INDUSTRY 4.0

The industrial automation environment is just a subdomain within the field of IoT, as already shown in Figure 4. There are several other, mayor fields, where services can be built up at similar vertical stacks of standards. Figure 7 gives examples for application areas handled by Mobile Broadband Services and also for application area of the Automotive sector.

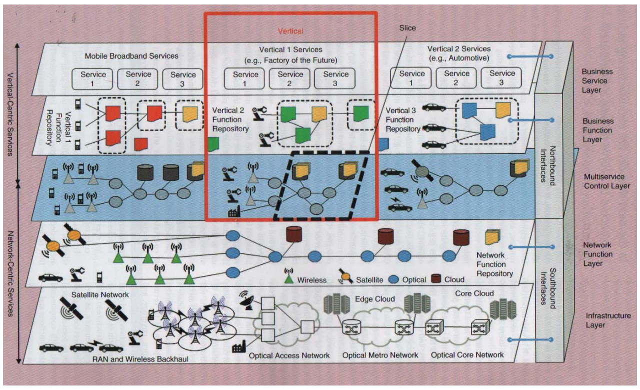

Fig. 7. Vertical and Horizontal integration: Service architectures for mobile, FoF and automotive sectors. (Requested courtecy diagram from the authors of [14])

XI. COMMUNICATION CASES FOR THE AUTOMOTIVE INDUSTRY

The state-of-the-art of vehicle communications is usually abbreviated as V2V, V2X (or as "car": C2X). There are significant global and local challenges to manage and tasks to solve, since transportation is a major contributor to GDP, but also the cause for losses and negative consequences of emission, death tolls, congestions, resource underutilization, etc.

What are the main issues for communication along the transport and automotive sectors? Some are listed here: -The presently available automotive products, with their lifespan of more than 15 years, need to be part of an active environment; - Newly manufactured vehicles must be ready for a new intelligent transportation environment; - Personal- and community transport vehicles, or heavy-duty vehicles, lorries, trucks need services with overlapping services; - Security and safety is a most demanding requirement; - Real-time services are needed with fast and very fast mobility speeds (TGV, airplanes, drones; - Addressing needs geographical, and relative extensions to present addressing methods; - A large variety of mobile platforms, operating systems are involved; - Intelligent infrastructure is essential to take active role in the operation of services; - Responsibility for data validity, availability, accessibility needs a harmonized agreement; - Vehicle manufacturers keep responsibility for the data management and communication within the transport vehicle; - Interactive multimedia needs higher bandwidth; - Real-time data must be verified for out-datedness, - Time-sensitive standards are needed to be available, - Autonomous driving of vehicles are about to be available at any site, while the infrastructure and targeted services are not yet available.

V2V and V2X scenarios use G3 and G4, later on planned G5 technologies, IP and non-IP (for safety messaging). It needs access to global resources and also to local sensor networks. GeoNetworking introduces addressing features to open connections with mobile nodes located in a given geographical vicinity, e.g. with vehicles in front, behind the back, on its side, or at a defined global area nearby of far away. Important feature is the time-sensitivity, and the speed in respect to the environment. To name just the most common commercial services of V2X: - Accident, incident warning; - Weather condition warning; - Roadwork Information; - Lane utilization information; - In-vehicle speed limit information; - Traffic congestion warning; - Road Tolling; - Route navigation.

A different series of services are reflecting traffic efficiency and road safety services: - Lane departure prevention and lane change assistance; - Road quality warning; - Obstruction detection; - Collision avoidance; - Radar view and neighbor supervision; - Safety margins; - Local danger alerts; - Road side safety information display; - Enhanced driver awareness. [15] These are supporting services to assist the drivers or modules to advance autonomous driving and are under development at MTA SZTAKI, Budapest, Hungary.

XII. DEMONSTRATORS, TESTING THE USE-CASE SCENARIOS FOR INDUSTRY (CPS) AND FOR THE AUTOMITIVE SECTORS

As it can be seen many countries and also within the EU's Horizon 2020 projects pilots and joint demonstrator sites are financed to spread the best practice examples, and to promote harmonized solutions, e.g. for software and hardware solutions, service oriented architecture based implementations, etc. For the Cyber-physical Manufacturing Systems most national platforms plan demonstrators. An example of CPMS is detailed in the simplified architecture of the Smart Factory demonstrator at MTA SZTAKI, Budapest, Hungary.[16]

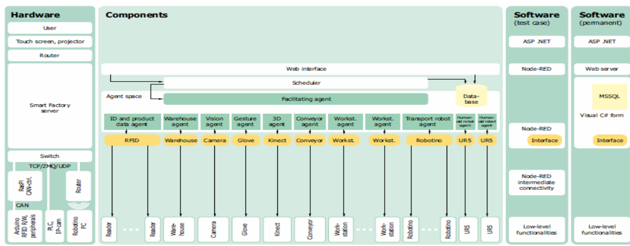

Fig. 8. SMART FACTORY pilot at MTA SZTAKI [16]

Regarding test environment for autonomous driven cars, the Hungarian Government recently decided to develop and implement a test base in Western Hungary. [17], [18] and [19] Further details for standards SOA and intelligent transport services are referenced by [20], [21], [22], [23] and [24].

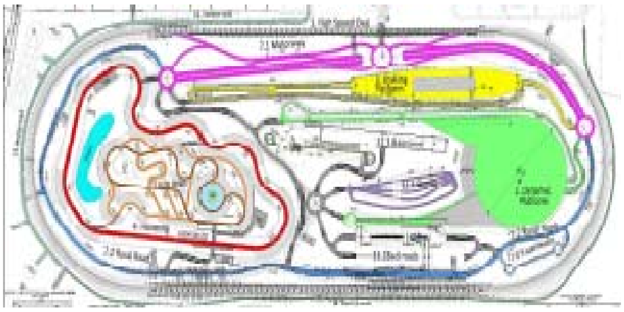

Fig. 9. Hungarian test environment plan for autonomously driven vehicles [18], [19]

Though vehicle test environments are already available in Europe [22], this new one will be unique to handle many new features, functionalities, services for assisted driving, and fir autonomously driven vehicles.

XIII. CONCLUSION

The need for industrial communication standards has been the initiating push (and pull) by GM 5 decades ago. Communication-standards had been developed by dozens in number, but the constantly broadening and widening of the application areas, the unsolved tasks are not at all lessening. Networking among groups of key players is more essential than before, global end-user requirements cannot allow individual solutions. Testing, verifying sites, training environments are trying to foster the development of best practices, good and sound solutions. A prime test environment for testing autonomous vehicles and advanced driving services is being developed in Western Hungary, while pilot sites for INDSUTRY 4.0 are under implementation at several sites throughout Hungary,

Networking at international level is also important. EU Commissioner had pointed out the need for national-level projects with national government commitments in each and every EU member-state. The Commission intends to generate EU-wide joint harmonized actions in this specific area of interconnected digitization.

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