Industry 4.0 as a Part of Smart Cities

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Abstract — **In this paper, we propose the conjunction of the Smart City Initiative and the concept of Industry 4.0. The term smart city has been a phenomenon of the last years, which is very inflected especially since 2008 when the world was hit by the financial crisis. The main reasons for the emergence of the Smart City Initiative are to create a sustainable model for cities and preserve quality of life of their citizens. The topic of the smart city cannot be seen only as a technical discipline, but different economic, humanitarian or legal aspects must be involved as well.**

In the concept of Industry 4.0, the Internet of Things (IoT) shall be used for the development of so–called smart products. Sub-components of the product are equipped with their own intelligence. Added intelligence is used both during the manufacturing of a product as well as during subsequent handling, up to continuous monitoring of the product lifecycle (smart processes). Other important aspects of the Industry 4.0 are Internet of Services (IoS), which includes especially intelligent transport and logistics (smart mobility, smart logistics), as well as Internet of Energy (IoE), which determines how the natural resources are used in proper way (electricity, water, oil, etc.). IoT, IoS, IoP and IoE can be considered as an element that can create a connection of the Smart City Initiative and Industry 4.0 – Industry 4.0 can be seen as a part of smart cities.

Interconnection of these systems can be expected to change - transport processes from design logistic processes through to their online optimization with respect to the chosen objective function and the latest information from the transport infrastructure. Linking information from process-based Industry 4.0 with intelligent transport systems of the smart city could create very effective, demand-oriented and higher productivity of manufacturing enterprises as well as sustainable development of society.

***Index Terms* - Smart City, Industry 4.0, Internet of Things, Internet of Services, Internet of People, FOG, Cyber-Physical System**

1. Introduction

The first industrial revolution influenced manufacturing processes by mechanical equipment powered by steam. The second industrial revolution is characterized by mass production; the most well-known representative is Ford Company and their Ford Model T. The third industrial revolution was changed our lives by using of the electronics and proliferation of information technology (IT) into manufacturing [1, 2, 3]. Currently we are standing on the threshold of the fourth industrial revolution, which is marked by linking sub-components of the production process via Internet of Things.

The term Industry 4.0 was first used in 2011 at the Hannover Fair and can be defined as a collective term for technologies and concepts of a value chain organization which creates together Cyber-Physical Systems (CPS), Internet of Things Internet of Services, Internet of People (IoP), and Internet of Energy [4].

The whole concept of Industry 4.0 is based on six design principles. These principles support companies in identifying and implementing Industry 4.0 scenarios [5]:

1) *Interoperability*: the ability of CPS, humans and Industry 4.0 factories to connect and communicate with each other via Internet of Things and Internet of Services.
2) *Virtualization*: virtualization means that CPSs are able to monitor physical processes. A virtual copy of the Industry 4.0 factory which is created by linking sensor data (monitoring physical processes) with virtual plant models and simulation models.
3) *Decentralization*: the rising demand for individual products makes it increasingly difficult to control systems centrally. Decentralization means the ability of CPSs within Industry 4.0 factories to make decisions on their own
4) *Real-Time Capability*: the capability to collect and analyze data and provide the derived insights immediately. Thus, the plant can react to the failure of a machine and reroute products to another machine.
5) *Service Orientation*: the services of companies, CPS, and humans are available over the IoS and can be utilized by other participants. They can be offered both internally and across company borders.
6) *Modularity*: flexible adaptation of Industry 4.0 factories to changing requirements by replacing or expanding individual modules as well as changing requirements by replacing or expanding individual modules. Modular systems can be easily adjusted in case of seasonal fluctuations or changed product characteristics.

A. The Properties of Industry 4.0

The main characteristics of Industry 4.0 include *horizontal integration* through networks in order to facilitate an internal cooperation, *vertical integration* of subsystems within the factory in order to create a flexible and adaptable manufacturing systems and *through-engineering integration* across the entire value chain to enable customization of the product [6]. The Figure 1 illustrates the relationship of three kinds of integration. The horizontal integration across companies and the vertical integration of a production inside the plant are two basic building blocks for engineering integration across processes. This is because the product life cycle involves several stages that should be performed by different companies. Connection of technologies

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and services in the concept of Industry 4.0 factory is shown in the Figure 2 - The concept of Industry 4.0.

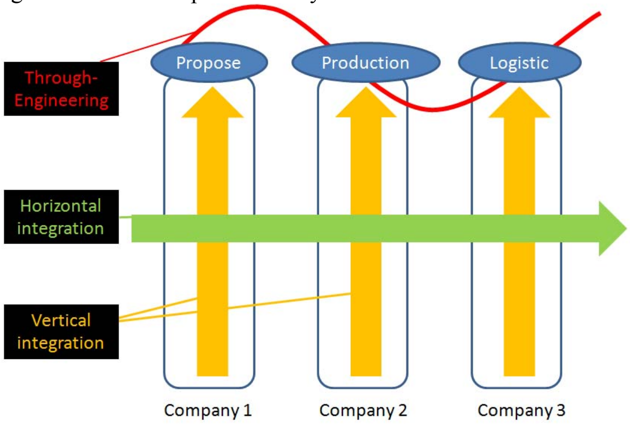

Figure 1 - Integration through Industry 4.0 [33]

Each component of the manufacturing process, e.g. part of a product, material, transport, staff, business unit, etc., has its own intelligence and negotiating priority. Every component knows where it is located in a workflow and can communicate with the facility through, for example RFID technology. After approaching the particular destination station, it tells it which part and variant it is, and requests to be processed with the appropriate method [7].

The benefit of Industry 4.0 factory is that a component of a production system calls a smart service only when it is really needed. All production processes are demand-oriented and the manufacturing resources are used only in the case of necessity [8].

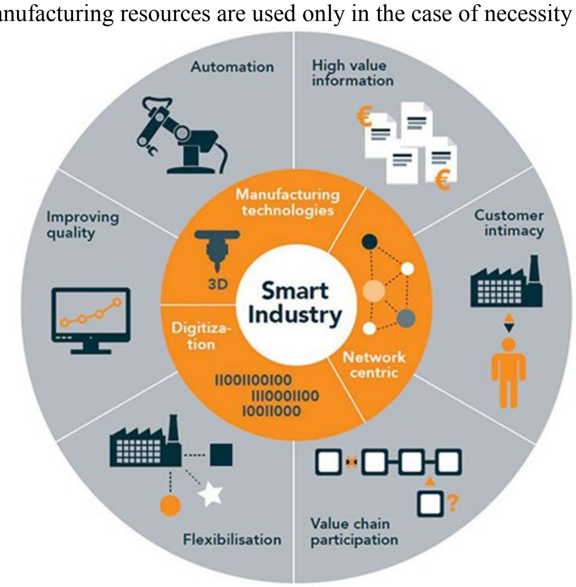

Figure 2 - The concept of Industry 4.0 [35]

The Industry 4.0 provides smart services in the real-time to minimize resources and to maximize the use of existing infrastructures (effectively to meet all the requirements).

Another basic element of the Industry 4.0 factory is a Cyber-Physical System (CPS) as a system of collaborating computational elements controlling physical entities. CPS can provide autonomous information exchange; invoking the necessary action in response to the current conditions and mutual independent checks; sensors, machines, components and IT systems will be interconnected within the value chain not only inside individual companies but also outside [9]. Inter-connected CPS can interact with each other using communication protocols based on the Internet (addressing most often via IP addresses). The data will be analyzed to anticipate errors or faults, and to adapt to the changed conditions of the production in a real-time [10].

This topic is really needed and very topical. This can be demonstrated for example by the fact that Germany plans to invest 40 billion Euros each year in the development of the concept of Industry 4.0. The investment across the EU are expected to be 140 billion Euros every year [11].

B. The Properties of Smart City

According to IEEE [12], „a Smart City brings together technology, government and society to enable the following characteristics: a smart economy, smart mobility, a smart environment, smart people, smart living, and smart governance". The main purpose of the Smart City Initiative is thus ensuring the sustainability of cities, improving quality of life and safety of their citizens, and providing maximum energy efficiency, all of those in the six key areas: economy, environment, mobility, people, living, and governance, with the contribution of the latest technologies [13].

The European Union (EU) has devoted constant efforts to devising a strategy for achieving Smart Urban Growth for its metropolitan city-regions [14]. So it means that the transformation of cities into smart city must be understood as a series of processes.

Due to the population expansion over the past 35 years, and moving of people into cities, which is expected to grow in the future even more rapidly (especially in developing countries), it is certainly a very important topic [15].

However, many changes are needed for cities to become more efficient, attractive, inclusive and competitive. This change will not only require a new paradigm in the way how cities look, but will also require a breakthrough in how cities, businesses, citizens and academia think and work together [13] – the overall feeling. The transition towards smarter cities is about reinventing cities, such that citizens are no longer considered only as *users*, but also as *key stakeholders*. Technology should be no longer looked as a static asset, but as a *dynamic enabler*. Business is no longer viewed as a provider, but as a *partner*. The notion of urban evolution is replaced by *transformation* [16]. The Figure 3 is the basic concept of the smart city that was published by IBM in 2008.

In this paper, we propose a view on the Industry 4.0 as a necessary part of the Smart City Initiative. Industry 4.0 changes the point of view as the industrial factories are perceived. Factories based on the principle of Industry 4.0 will respond directly to the online user demand (demand-oriented production).

So it means that the production will be organized based on current demand and it will be sourced via electronic commerce (e-commerce) services. Thanks to the collected data, it will be possible to predict the user behavior and to transform this information to the production environment, including planning of human resources [17].

A smart product allows monitoring of the entire product life cycle - from the award of demand, production, and delivery to destination, up to continuous monitoring of product parameters or to its friendly disposal.

One of the most common aspects of the Industry 4.0 and the Smart City Initiative is transportation. Transportation must be understood as a service. In order to achieve that, it has to be coordinated in a proper way in order to deliver the material or people to factory, the product to a customer and all of these things in the right time. This topic is discussed in the next chapter.

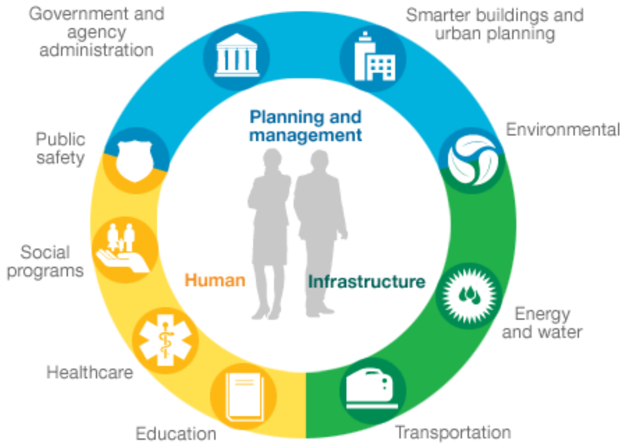

Figure 3 - Smart City Initiative (IBM, 2008) [36]

2. Cyber-Physical Systems (CPS)

The important part of the Industry 4.0 is the Cyber-Physical System (CPS), networking machines and components with the additional intelligent and highly flexible software. CPSs are connected with embedded systems, these being parts of complete devices with real-time computing constraints. CPSs link such embedded systems to digital networks facilitating independent data processing. The assignment of an IP address allows such systems to be controlled and monitored online (the Figure 4 shows the basic principles of CPS). Owing to such embedded computer systems, sensors and actuators, cyber-physical systems organize production automatically and autonomously [18]. Central process control can be eliminated as it can be taken over by CPS-based components. This concept of a value chain organization is also referred not to the Industry 4.0, but also smart city, where each component should behave in the same way. *CPS can be considered as the first common area that connects the smart city and Industry 4.0 factory to the whole forming a mutual symbiosis.*

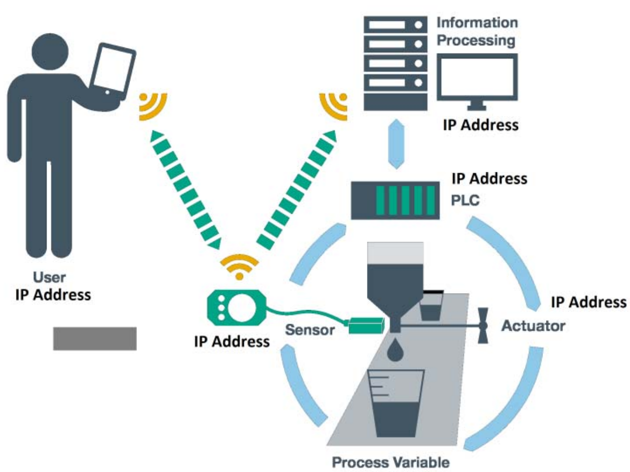

Figure 4 - Paradigms of CPS [37]

A. *Internet of Things (IoT)*

The IoT is a network of physical products embedded with electronics, software, sensors, and network connectivity, which enables these objects to collect and exchange data.

The IoT allows objects to be sensed and controlled remotely across existing network infrastructure. Each IoT object is uniquely identifiable through its embedded computing system, but is able to interoperate within the existing Internet infrastructure [19].

It means that in terms of the Industry 4.0 (e.g. components of manufacturing line – sensors, actuators, autonomous transport vehicles within the Industry 4.0 factory, etc.), and smart city (e.g. mobile phones, smart TV, control system in building, CCTV, etc.), needed devices will contain embedded system ensuring connection with the internet and interconnection of devices.

When a customer makes order via e-commerce then, he/she is able to follow not only process of delivery, but the entire value chain or manufacturing process. On the other hand, the Industry 4.0 factory can follow life cycle of product. *IoT can be considered as the second common area connecting the concept of the Industry 4.0 and the Smart City Initiative.*

B. *Internet of Service (IoS)*

The IoT concept is expected to offer advanced connectivity of devices and products via machine-to-machine (M2M) or human-to-machine (H2M) communications and covers a variety of protocols, domains and applications [20]. Each device connecting to internet is being expecting having a set of smart services called Internet of Services (IoS). The IoS has to be standardized in order being independent throughout providers or manufacturers. The interconnection of these embedded devices is expected to usher in automation in nearly all fields, while also enabling advanced applications like a smart grid [21].

IoT products with IoS can refer to a wide variety of devices such as automobiles with built-in sensors, DNA analysis as well as devices for environmental/food/pathogen monitoring. These devices collect useful data with the help of various existing technologies and then autonomously flow the data between other devices [22]. Current market examples include smart thermostat systems and washer/dryers that use Wi-Fi for remote monitoring [23]. It can be expected that IoS will become common not only in terms of the Smart City Initiative but also in terms of the Industry 4.0. Smart services provided by Industry 4.0 factory should be only those that will be public oriented (e-commerce, following manufacturing chain). *IoS can be considered as the next common area that connects the smart city and Industry 4.0 factory in one cooperating segment.*

C. *Internet of People (IoP)*

IoT technologies with embedded IoS can be used to create the Internet of People (IoP). It could be seen as Cyber-Physical System with enhanced, people-centric applications, as opposed to things-centric ones. The combination of the real world with the virtual world for the benefit of people, and enabling the development of sensing applications in contexts such as health monitoring, social networks enhancement, or fulfilling people's special needs [24].

IoP is the key element because of creating and optimization of services, processes and environmental conditions based on people feedback. IoP creates the connection between environment and people, between real world and cybernetic world, between reality and between virtual realities.

Interconnection of Industry 4.0 factories and smart cities can be very efficient for both sides. Industry 4.0 factory may receive and get very important feedback from a customer side (e.g. how often the product is used, what is the most often reason of issue, etc.). Smart city citizens can directly communicate with people in factories and in very efficient way make changes e.g. during manufacturing process. *The fourth common area interconnection of the smart city and Industry 4.0 is IoP. It can be seen as a step when people connect on the both sides.*

D. Internet of Energy (IoE)

Internet of Energy (IoE) is probably the most developed area as compared with previous Internet of Everything. IoE is integrated dynamic network infrastructure based on standard and interoperable communication protocols that interconnect the energy network with the Internet, which includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy resources, and energy efficiency resources. Electronic power conditioning and control of the production and distribution of electricity are important aspects of the smart grid [25].

Energy efficiency is a very often discussed topic. IoE can help to achieve big energy savings via remote monitoring, and the most important – the energy production can be controlled based on actual demand [26]. The actual demand can be calculated using information collected from IoT using IoS or IoP. Energy sources are common for factories and cities. The data received from Industry 4.0 and the smart city energy loads will be collected together and actual energy production will influence based on current demand. *IoE can be considered as the fifth common area where it intersects concepts of the Smart City Initiative and Industry 4.0 factory.*

E. FOG Computing

FOG computing is architecture and a distributed computing infrastructure that uses one or a collaborative multitude of end-user clients or edge devices to accomplish a substantial amount of storage. Some application services are handled at the network edge in a smart device and some application services are handled in a remote data center – Cloud [27]. FOG`s goal is to improve efficiency and reduce the amount of data that needs to be transported to the cloud for data processing, analysis and storage. This is often done for efficiency reasons, but it may also be carried out for security and compliance reasons [28].

The basic concept of FOG computing is shown in the Figure 5. Many of processes are taken place on a smart device or on the edge of the network in a smart router or other gateway device. This distributed approach is growing in popularity especially because of the IoT. It is very inefficient to transmit all data to the cloud for processing and analysis.

FOG Computing can be used in almost every part of the Smart City Initiative – important data will be sent up to the top level of controlling, while the rest of data will be used only in local edges. FOG Computing can be also used in Industry 4.0 factories where can effectively separate manufacture data and only useful data will be provided to control, analysis and management level. IoT generate much information and is important to separate them in the nearest level in order to save the speed of calculation, bandwidth, efficiency and decentralization. FOG Computing architecture is the next common area that is also suitable both for smart city and for Industry 4.0 factory.

3. Industry 4.0, Smart City and Smart Transportation

Also the transportation field changes rapidly with the introduction of Industry 4.0 and the challenges of the Smart Cities Initiatives. The first change that must be mentioned is the service oriented focus. Transportation can be no longer viewed as simple „moving people and goods from one place to another" [29]. Transportation must be understood as a service. A citizen as well as industrial process does typically not care about the actual process of traveling (even though in some cases people want to drive the strong car just for fun and enjoy the surroundings). It is important to participate at chosen activities at given location at certain time or to have goods/components delivered at certain time to target destination. In smart cities, we must build a city in a way, that it might be possible to minimize traveling. If the activity location is close to my home, I am able to get there without the need for mobility. The high speed Internet also allows us to work from home without the need for travel (Teleworking, etc.). In this way, with smart urban planning and additional aspects of smart cities, the focus shall not be on mobility but rather accessibility.

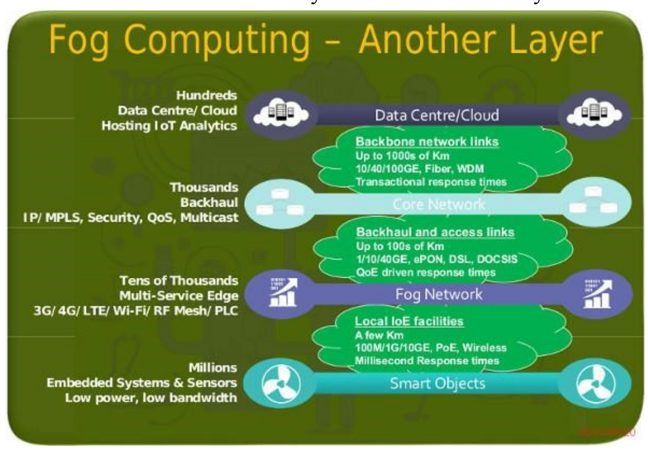

Figure 5 - The basic concept of FOG Computing [38]

The concepts described above introduce additional topics in transportation field, such as Transport Service Level Agreement (T-SLA). If we understand transportation as a service, it must be assured, that certain quality criteria are met. We must learn how to measure and enforce such T-SLAs.

Only such smart transportation service with predefined T-SLAs can ensure that a company will be Industry 4.0 conform. It will be possible to provide all components on demand and just in time. This further minimizes news of storage rooms and optimization of the entire manufacturing process. At the same time, proper management process and ensuring meeting of the T-SLAs can further support other concepts such as sharing of vehicles. For example, the same vehicle can be used in the morning to collect employees of a given company and get them to work and in the evening back home. During the day, such vehicle can be used as a support for city public transport system. In this way, the Industry 4.0 and smart cities are further closely connected [30].

Another important topic is an introduction of autonomous vehicles. Technical solutions for this field are already available and especially in a closed environment of a company fully in use [31]. After introducing a proper legislative, it is going to become a common appearance even in a city road network. However, autonomous vehicles introduce new challenges. Not only is the technology of the particular vehicles an important topic. We must incorporate such vehicles into city/company traffic management. This includes new topics such as intersection and area control taking into consideration platoon of vehicles and priorities for such platoons, or for example modifications to vehicle routing problem. In a city environment with a mixture of autonomous and human-driven vehicles this topic is even more complex and safety becomes a critical issue.

Variable production of Industry 4.0 factory generates various kinds of residual materials, which can be considered as the input component to the next manufacturing process. Transportation of waste (no further use) is not a high priority and may be postponed to another time period (off peak). The existence of a number of sites is assumed for waste collection. Each of this site can itself determine the amount of waste and at what time it is able to take that. Due to on-line information generated waste arises targeted demand for transportation service similar to smart bins, which reports its fulfillment and ask for removal [32]. *Smart transportation throughout Industry 4.0 factories and smart cities are the next common area where these two concepts are intersected and where should be taken into account that they can be seen separately but as a whole.*

4. Conclusion

In this paper, we propose to unite the view of the concept of Industry 4.0 and the Smart City Initiative. Even though the terminology differs, the principles are, or at least should be the same. We propose to see the Industry 4.0 factory as a building block of smart cities, among other objects such as smart building, smart street, smart campus or others.

We suggest several common areas fulfilling requirements both the Smart City Initiative and Industry 4.0 – Industry 4.0 as a part of the Smart City Initiative. These two concepts are based especially on Internet of Things, Internet of Energy, and Internet of People. Industry has always been an essential part of the overall concept of cities and cannot be seen separately. Linking individual components can be expected through the IoS. Another important element is also FOG Computing that effectively transmits only the necessary data, and the greatest part of the job is trying to do locally either in smart devices or the parent network elements.

The smart city is based on the six key areas: Smart People, Smart Economy, Smart Living, Smart Governance, Smart Mobility and Smart Environment.

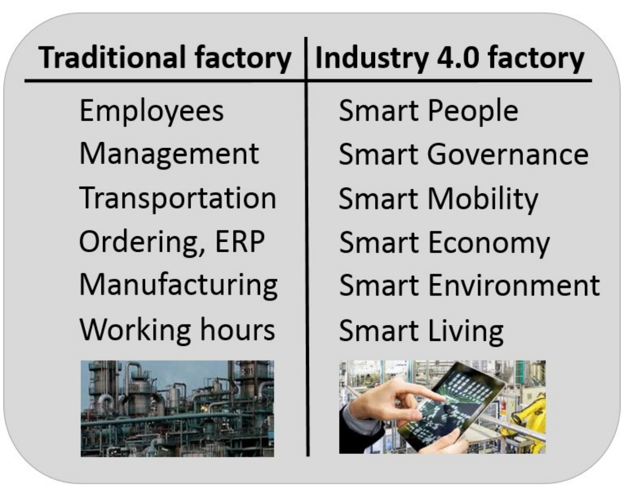

Figure 6 - Traditional vs. Industry 4.0 factory (own source)

As we can see from the Figure 6, when we compare a traditional factory and Industry 4.0 factory, the same six key areas can be seen in the Industry 4.0 factory as in the smart city. The key information needs to be shared between Industry 4.0 factories and smart cities are for example traffic, energy needs, energy consumption or waste-handling.

The first city in the Czech Republic aiming on becoming smart city is Písek. Apart from a general strategy expressed in the form of a Green-Blue Book [33], different smart city projects are addressed here. At the same time, several factories are located in Písek. For this reason, the approach of conjunction the Industry 4.0 and smart city will be conducted here as one of the particular projects.

When looking at transportation, new challenges and concepts were briefly discussed. If we really want to have a smart city or a fully automated company process according to Industry 4.0, most attention must be paid to sharing (not only vehicles but even infrastructure), minimization of resources or storage, orientation on services and accessibility rather than mobility. Integration into a city or company management is a necessary tool. If we want to be ensure transportation services on demand and just in time, transportation service level agreements must be defined and efficiently ensured and enforced. In this way we can really achieve an integrated environment which improves quality of life and ensures sustainability through minimization of the resources utilized.

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