



Integration of autonomous vehicles and Industry 4.0

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Abstract. The current trend of automation and manufacturing is digitalization called Industry 4.0. The digitalization is not only the manufacturing process upgrade but also logistics and intelligent transport solutions. Rapid development of intelligent control techniques has also brought changes in automotive industry and led to developments of autonomous vehicles. This paper presents a concept for an integration of self-driving vehicle ISEAUTO into Industry 4.0. ISEAUTO is a last mile automated shuttle bus designed and built in Estonia for short range transportation.

Key words: self-driving car, Industry 4.0, autonomous shuttle.

1. INTRODUCTION

Autonomous vehicles (AVs) and Mobility-as-a-Service (MaaS) can provide more efficient logistics and passenger transfer methods. Furthermore, smart sensors along with implementation of cognitive computing and the Internet of Things (IoT) represent an AV as a cyber-physical system (CPS), within which information from all related perspectives is closely monitored and synchronized between the physical devices and the cyber computational space. By utilizing advanced information analytics, AVs will be able to perform more efficiently, collaboratively and resiliently. Thus, it is possible to integrate AVs into Industry 4.0 systems. Competence and know-how about AVs as well as self-driving algorithms gained during ISEAUTO project presents a base for urban mobility studies. The paper presents ISEAUTO as a CPS that can be abstracted into sensing, computing, and actuation modules.

According to the report from McKinsey & Company, fully automated vehicles are unlikely to be commercially available before 2020 [1]. The implementation of AVs combining the application of MaaS or Transport-as-a-Service (TaaS) have become more realistic and meaningful. The readiness of these technologies empowers researchers to help industries to increase their productivity and create more benefits.

Since the term Industry 4.0 was first pushed by German government [2], it has been applied to a larger scope of technical elements and brought more connections between the virtual world and the physical one. Industry 4.0 describes a set of concepts that can drive the next industrial revolution. The potential of adopting the AVs into industrial area is promising for accommodating most technical concerns in the following areas:

- *Cost-efficient:* instead of traditional fuels, energy like electricity can reduce the cost and increase the effectiveness of manufacturing. Unmanned methods can also help to cut down expenses of employers' payments;

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- *Digitalization*: using cloud computing to deal with big data captured by sensors from AVs help factories to keep control of all information and stay on track of the current status;
- *Safety/Liability*: real-time tracking and monitoring system ensure the safety during the vehicle operation. The avoidance of human intervention ensures better technology acceptance and a sustainable customer relationship;
- *Flexibility/Scalability*: involving more partners in this ecosystem brings more robustness and lowers the risk of dependency on a certain component, reaching continuously to different levels of investments and making the market more competitive;
- *Environment-friendly*: the reduction of the emissions of waste/pollution protects the living environment and adds satisfaction to surrounding residences. Clean energy also contributes to the whole production life circle thus completes the supply chain.

2. INDUSTRY 4.0 IN TERMS OF SELF-DRIVING VEHICLES

Self-driving vehicles are also foreseen to become a part of Industry 4.0. European technology platform ManuFuture¹ is developing a vision for 2030, where production logistics is integrated through self-driving mobile platforms both indoors and outdoors by artificial intelligence (AI), see Fig. 1.

Several initiatives are started in the world to integrate automated shuttles into industrial environment. However, most of the trials are still in early stages. Following use cases are reviewed in more details, a summary is presented in Table 1.

*Foxconn*². In 2017, Taiwanese firm Foxconn planned to build a \$10 billion plant to the south of Milwaukee. They proposed that some lanes should be reserved only for AVs and the driverless-vehicle lanes could connect the Foxconn factory with Milwaukee's Mitchell

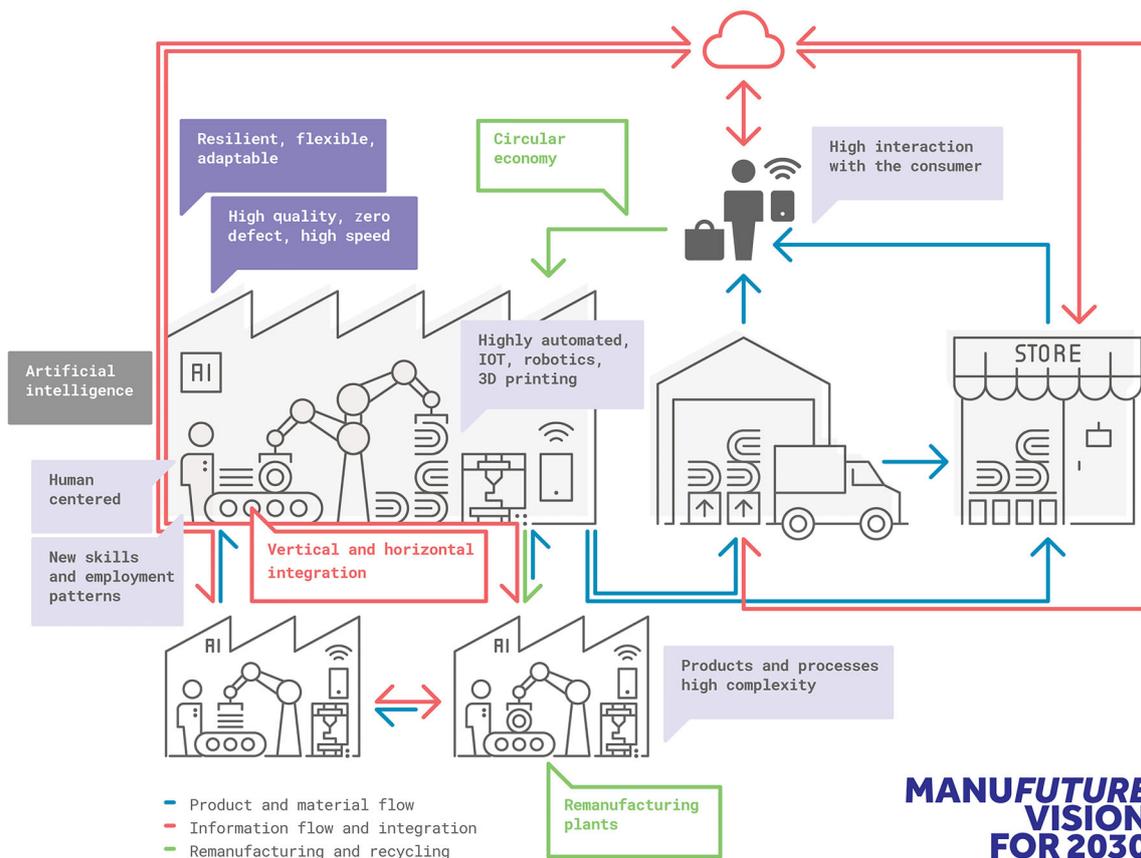


Fig. 1. ManuFuture technology platform vision for 2030.

¹ <http://www.manufuture.org/>

² <http://www.foxconn.com/>

Table 1. Comparison of shuttle buses developed worldwide

Case study	Location	State-of-art features	Status
Foxconn Factory	Milwaukee, US	Reserved lanes on normal highways only for autonomous vehicles.	Plan
Baidu	Fukushima, Japan	Transport workers within the nuclear power plant facility.	Plan
Tsintel Technology	Tianjin, China	Provide commuting services at a low speed in semi-open environments.	Pilot
Magride	Guangdong, China	Serve as a short-range transportation transferring employees.	Operate

International Airport. This plan would help Foxconn to automate its shipping of both goods and people. While accidents in US involving AVs have attracted attention in headlines, the advantage of such vehicles is safety, especially on dedicated routes with a constant ebb and flow of users.

*Baidu*³. Under the agreement with SB Drive, ten Baidu Apolong mini buses will be exported to Japan from China in early 2019. Apolong buses are set to enter Japan's self-driving market as shuttle buses in practical use at the crippled Fukushima No. 1 nuclear power plant to transport workers within the facility. There is also a plan of using self-driving bus service for maintenance workers and tourists at Tokyo Haneda Airport.

*Magride*⁴. Magride is a leading solution provider for short-range intelligent campus transportation in closed areas like airports, industrial plants, residential quarters and amusement parks. Its L4 shuttle bus G100 has already been used in Vanke Architecture Research Centerinstitute (Guangdong, China) for more than 1 year as a short-range transportation transferring employees. Its latest product G200 started pilot tests on open roads since August 2018.

*Tsintel Technology*⁵. Their pilot tests started from August 2017 in Tianjin Huaming High-Tech Industrial Park (CHINA) with an L4 autonomous shuttle bus, operating in semi-open environments. The shuttle bus can provide commuting services at a low speed on fixed and controllable routes. It can also be managed as a fleet for campus commuting, logistics, road cleaning or even excursion tours.

3. ISEAUTO AS A LAST MILE PLATFORM FOR INDUSTRY 4.0

Nowadays the most effective autonomous approach relies on data fusion of information, coming from plenty of

different sensors, some of these sensors are already available on commercial cars [3], others will be introduced step-by-step. The research and development activities have to enable high/full autonomous driving; and Industry 4.0 has to deal with a lot of new requirements (e.g., fail-operational systems, cyber security), technologies (connectivity over 5G, neural networks, future computing platforms), and topics (data analytics, AI) [4].

ISEAUTO [5] last mile bus is operating in the campus of Tallinn University of Technology (TalTech) close to parking lots and some pedestrian areas. That means that an obstacle should be detected in both short and long distances at the same time. It is difficult to have an accurate and fast prediction of the pedestrian behaviour in case of the car in order to react properly. In case of a stop or a recalibration of sensors, situations can occur when a pedestrian is not detected properly due to overlapping with another pedestrian. In case of a jaywalker the system must be able to react and remain in a safe state. This holds also for people lying on the ground or small animals. In all possible situations the system has to be able to stop before any injury occurs. Sensors shown in Table 2 are used in ISEAUTO last mile bus to observe the environment and for mapping, localization and navigation processes.

Similar sensors are often used in industrial systems. For example, machine vision is widely implemented in adaptive industrial robots [6] and LiDARs for safety curtains.

With many national/regional schemes implemented, the autonomous vehicle market is getting more and more crowded these years. Year 2017 and 2018 have witnessed many players increasing their involvement in this global competition; and huge investments from all over the world chasing the same goal and trying to get a share from the market. A successful application of using AV as a service in industry needs to take certain criteria into consideration (see Fig. 2).

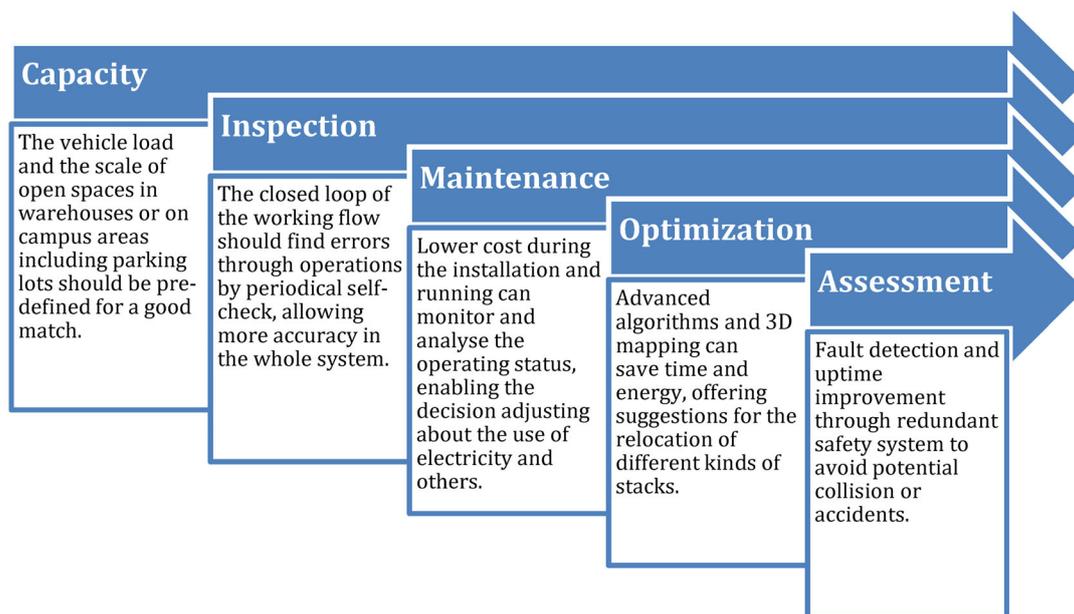
³ <http://ir.baidu.com/>

⁴ <http://www.magride.cn/>

⁵ <http://www.tsintel.net/>

Table 2. Sensors used in ISEAUTO last mile shuttle bus

Sensor	Type	Quantity	Placement
LiDAR	Velodyne VLP-16	2	Roof
LiDAR	15° VFoD	1	Front
Ultrasonic	PGA450-Q1	8	4 x front, 4 x back
Radar	IWR1443	1	Front
Camera	Basler	5	2 x front, 2 x sides, back
Satellite navigation	RTK-GNSS+IMU	1	Roof

**Fig. 2.** Criteria for using autonomous vehicles as a service for industry.

The ISEAUTO navigation technology doesn't require much fixed installation of infrastructure. It can be tailored to specific requirements in a cost-effective method, even for industry applications, from individual steps in a process to complex material flows. The advanced technology of the self-driving platform creates significant competitive advantages, while guaranteeing a high flexibility in operational procedures at the same time. Safety systems and an integrated system are a prerequisite for a safe and efficient human-machine interaction (HMI).

The unmanned operation is feasible in many industrial fields, for either individual or defined fleet operations. The automated vehicles are not tied to shift patterns, thus substantially increasing cost-effectiveness, while bringing reductions in daily operational damage. Despite of highly autonomous functions, the whole range of models can also be easily operated using conventional

manual controlling mode and can well cope with potential technical issues like power cut-off, network failure etc.

Autonomous multi-agent systems, which optimize the planning and scheduling of industrial processes using the example of courier and express services is presented in [7], where the multi-agent-based approach is used for the optimization and synchronization of logistic and production processes in Industry 4.0 applications. Another research approach that nowadays receives attention in the industry is cellular transport systems. The idea of cellular transport systems [8] is embodied by dedicated (cellular) material handling entities. Cellular transport systems can be represented by autonomous conveying modules or transport vehicles. They are built upon a controlling architecture consisting of several small, self-organizing, intelligent units, which act and decide autonomously [8].

4. AUTOMATED VEHICLES IN INDUSTRY 4.0

The proposed concept is integrating autonomous shuttle vehicles with multi-agent based workflow. The AI supported smart planning and scheduling of production involves self-driving vehicles into the process to serve intelligent resource transportation. In industry, performance indicators and energy efficiency are the most important factors to automate production [9]. These factors can be improved by smart production planning and scheduling service, which has all information from the production. It is important that all the equipment is connected to the cloud and provides real-time information about energy consumption, productivity and capacity. In case of the lack of this functionality, a monitoring system can be added also for older equipment as discussed in detail in [10]. By extending the production planning and scheduling with self-driving vehicle, much higher flexibility and efficiency can be achieved. Figure 3 is presenting the integration concept where production cells are physical units located all over the industrial area of the factory. One or more autonomous vehicles (AV 1, AV n) are serving the production units based on resource requests and guided commands from a cloud-based planning and scheduling system.

In the concept, several types of AVs can be applied for different purposes. Last mile shuttle buses like ISEAUTO are for transporting humans; universal mobile robot like [11] is for transporting goods and

materials. The latter is also applied for different purposes in addition to transportation. For example, road cleaning or snow blowing during the idle time or securing the factory area in the night time.

5. DISCUSSION/CONCLUSIONS

In the near future, self-driving vehicles will take its place in everyday life and industry. Requirements from the Industry 4.0 are specified and the very first attempts of integration self-driving vehicles are reviewed in the paper.

ISEAUTO is the first research and educational project in Estonia targeted on the design and development of a self-driving vehicle. The potential of adopting ISEAUTO self-driving platform into Industry 4.0 is proposed in the paper. The long-term objective of the ISEAUTO project is to establish a smart city testbed where different types of researches regarding future urban mobility can be studied. The smart city testbed is a real-life environment where self-driving cars, delivery robots and smart infrastructure objects are placed. ISEAUTO last mile bus can be a base for Vehicle-to-everything (V2X) platform, a vehicular communication system that incorporates other more specific types of communication as Vehicle-to-infrastructure (V2I), Vehicle-to-vehicle (V2V) and Vehicle-to-pedestrian (V2P); V2D (Vehicle-to-device), V2G (Vehicle-to-grid), or any other entity that may affect the vehicle.

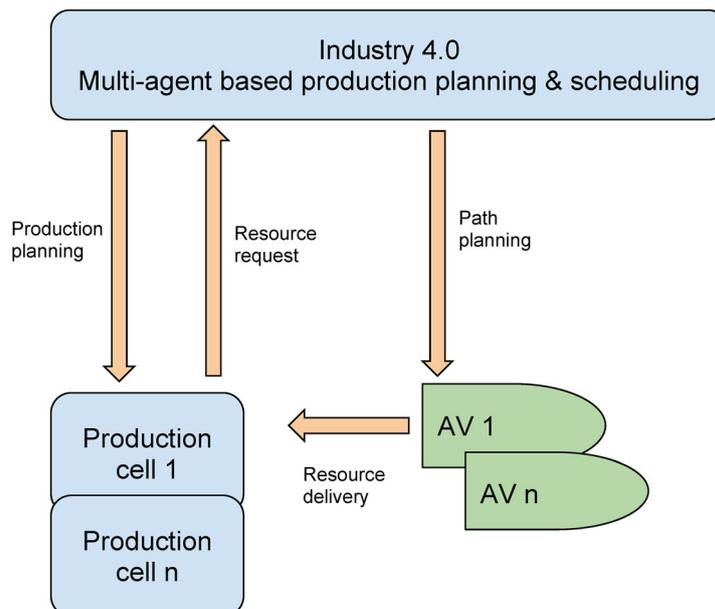


Fig. 3. Integration and production planning and scheduling with autonomous vehicles.

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Isejuhtivate sõidukite ja Tööstus 4.0 integratsioon

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Tööstuse automatiseerimise ja digitaliseerimise järgmist sammu nimetatakse tööstusrevolutsiooniks Tööstus 4.0. Digitaliseerimine ei tähenda selles kontekstis mitte ainult tootmisprotsesside täiustamist, vaid ka tootmislogistika ja transpordi uusi integreeritud lahendusi. Autotööstuse ja eriti isejuhtivate sõidukite ning autonoomsete süsteemide kiire areng võimaldab luua täiesti uusi Tööstus 4.0 lahendusi. Artiklis on uuritud erinevaid lahendusi, mida maailmas on püütud rakendada, ja välja pakutud TalTechi ning SilberAuto koostöös valminud isejuhtiva platformi ISEAUTO kontseptsioon Tööstus 4.0 integreerimiseks, samuti analüüsitud selle tootmislogistikasse rakendamise võimalusi.