

Review

# Disruptive Innovation for Automotive Industry and the Solutions for Enterprise Innovation System Reengineering

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**Abstract:** Focus on the current disruptive innovation trends, automotive industry needs to have solutions for enterprise innovation system reengineering. The innovations include the energy and power technology bringing vehicle powertrain electrification, intelligent control technology bringing autonomous drive/intelligent vehicle, and communication technology bringing vehicle connectivity and sharing. Facing the impact of these, enterprise innovation system reengineering needs to be considering the effects to strategic planning, product development process, and new business models, etc.

**Keywords:** automotive industry; disruptive innovation; enterprise innovation system reengineering

## 1. Introduction

Automotive industry played important role as transportation tool in modern society after automobile was invented near the end of 19th century. After 100 years' development, automobile became a completed product with systematic development process, which was mostly a mechanical system, with some electronic, hydraulic and control systems inside. By the end of 20th century, the automobile market became almost saturated and automotive industry seemed like a sunset industry. But from the end of 20th century, automotive industry renovated itself with technological innovations, which got new opportunities and new challenges.

Innovation for products (including services) is driven by requirements from legislation, market and customers, as well as pushed by technology developments. Innovation theory was well developed during the whole 20th century with the development of modern industry and management theories. Professor Clayton M. Christensen from Harvard University initialized the concept of disruptive innovation, which differentiated it from sustaining innovation in 1997 [1]. His theory was well developed and it was systematically elaborated in his following book in 2003 [2]. Disruptive innovation brings new substitutes or alternative solutions for current products/processes in existing market, which can also turn 0-customer market into a new market. The disruptive innovations are widely existed in computer, internet, mobile communication, Artificial Intelligent (AI), etc., and also bring new products and new business models for automotive industry.

Actually, disruptive innovations played important roles from the beginning of automotive industry. Henry Ford was using flow lines with the division of labors based on specialization, which significantly reduced the manufacturing cost and turned the normal workers into new customers for passenger cars after 1908 [3]. After that until 1920's, new requirements of diverse and better transportation tools from the US customers drove the new business models of yearly new models, leasing new cars and buying used cars, etc., which made GM develop fastest [4]. The over one hundred years' history saw many innovations like these in automotive industry, both in technology and in business models. In new century, new technologies developed much faster and disruptive innovations brought more effective changes for modern automobiles, including



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electrification, intelligence and connectivity, etc. Enterprises need to have some solutions for their innovation system reengineering, to face the challenges from disruptive innovations.

## 2. Energy and Power Technology and Vehicle Powertrain Electrification

After the first industrial revolution, steam engine was used as the power system for trains and boats, etc., which changed the transportation tools and brought changes for the society of 19th century. After the second industrial revolution, inner combustion engine (ICE) was widely used as the power system for automobile during the whole 20th century, and the energy system was mostly relying on fossil fuel from then on. The third industrial revolution brought automation and control for automobile in mid-20th century, which improved the performance for ICE and automobile. But the fossil fuel based power system faced the depletion of fossil fuels, and also produced CO<sub>2</sub> and pollutant. These drive automotive industry to seek new energy and power technologies. On the other hand, the lithium ion battery technology was developed and became more and more mature, which can be used in electric powered vehicles. In 2019 three experts for lithium ion battery got The Nobel Prize in Chemistry, which is a milestone for the industrialization of lithium ion battery. Comparing to the sustaining improvement of ICE, electrification is a disruptive innovation for automobile power system, which brings deeply changes for the industry.

Vehicle electrification includes three basic categories, as battery electric vehicle (BEV), hybrid electric vehicle (HEV) and fuel cell vehicle (FCV) [5]. BEV is driven by electric motor(s) instead of ICE, and all energy comes from the electric energy stored in lithium ion battery or some other kind of batteries. HEV uses both ICE and electric motor(s) in different ways due to different architectures, and battery helps to provide assistant energy for ICE to optimize ICE running condition and reduce CO<sub>2</sub> and pollutant emission. It also includes Plug-in Hybrid Electric Vehicle (PHEV), which can be using outside electric power from plug-in charging. FCV uses Fuel Cell System (FCS) to transfer the chemical energy from H<sub>2</sub> and O<sub>2</sub> into electric energy, and the vehicle is directly driven by electric motor(s) using electric power from FCS and/or batteries [6]. All three types are using control system, electric motor(s) and batteries as shown in Figure 1, which can be using the extra recovery energies from brake when deceleration and/or downhill.

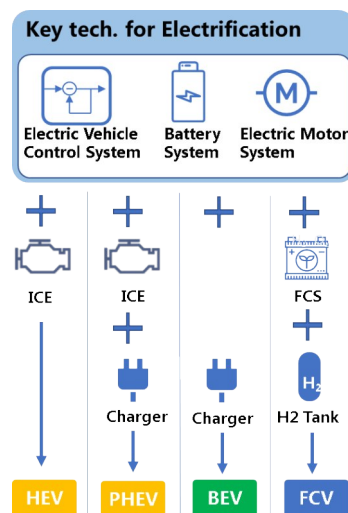


Figure 1. Vehicle Powertrain Electrification.

Vehicle electrification brings different new sub-systems and parts for power system. The most important systems are vehicle control system, electric motor system and battery system. Vehicle control system includes hardware and software, and it's different from control system for conventional vehicles, due to more considerations for energy management. Electric motor system includes physical motor and its control system together with the high voltage driven unit - Power Electronic Unit (PEU). Battery system includes physical system step by step from battery cells to modules to pack(s), and the control system – Battery Management System (BMS). Vehicle electrification also brings new solutions for conventional steering, brake and air

conditioning systems, which can be electric driven directly instead of conventional ICE Front End Accessory Drive (FEAD).

Electrification brought completely new and different ways for vehicle power system, and it's a disruptive innovation replaced or will be replacing conventional ICE using fossil fuel. Electrification technology itself, develops fast and has some inner innovations also. Electric motor is integrated into other systems of powertrain system, and it becomes electric automated transmission, electric axle, or electric wheel. In electric motor PEU, normal Si-based IGBT (Insulate-Gate Bipolar Transistor) is replaced by SiC-based MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor), to improve the efficiency. Battery system is integrated more with vehicle body or chassis, and it becomes Cell to Chassis (C2C) or Cell to Body (C2B) or named structural battery, which uses vehicle body or chassis as the pack frame for battery system to reduce the whole volume and mass. Such kind of innovations, both sustaining and disruptive, will make the electrified vehicle more efficient and advanced.

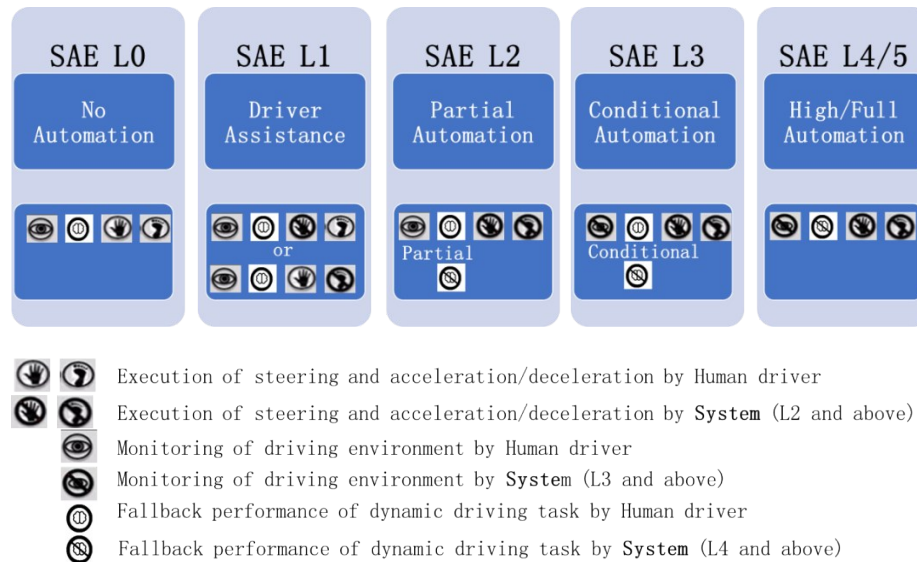
### **3. Intelligent Control Technology and Autonomous Drive/Intelligent Vehicle**

As mentioned above, the third industrial revolution brought automation and control for automobile in mid-20th century. The whole second half of 20th century saw great progress of Classical Control Theory and Modern Control Theory which also enabled electric control and automation in automotive industry. The devices were also developing fast to support the implementation of the theories, such as transistor, IC (Integrated Circuit)/LSI (Large Scale Integrated Circuit)/VLSI (Very Large Scale Integrated Circuit), microchips, microprocessors, computers, etc., which resulted quite a few Nobel Prizes, e.g. 1956 The Nobel Prize in Physics for transistor and 2000 The Nobel Prize in Physics for IC. The development of control system technology also brought significant changes to automotive industry, and changed the vehicle from mostly a mechanical system to a mechatronics system. The current forth industrial revolution furthermore brings Intelligent Control Theory, especially Artificial Intelligent (AI), to automotive controls.

Control systems were introduced to all conventional mechanical systems in vehicle and improved vehicle performance significantly, including systems for powertrain, chassis, and body. For powertrain control, EECU (Engine Electronic Control Unit) makes conventional ICE to be controlled effectively, and TCU (Transmission Control Unit) realizes transmission automatic control, including AT (Automatic Transmission), AMT (Automatic Manual Transmission), DCT (Dual Clutch Transmission), etc. For steering, EPS (Electric Power Steering) assists driver and improves steering performance and stability. For suspension, Active Suspension helps to improve ride comfort, including Active Stiffness Control, Active Damping Control, and Active Anti-Roll Bar. For braking, some systems improve vehicle stability and safety, including ABS (Anti-lock Braking System) or EBS (Electronic Brake System), TCS (Traction Control System), EBD (Electrical Brake Distribution), VDC (Vehicle Dynamic Control) and final summarized as ESP (Electric Stability Program)/ESC (Electric Stability Control). For body control, there are also some controllers for body parts such as doors, windows, lights, etc. Electronic control systems above with only control wiring connected, are also named x-by-wire, including steering-by-wire, braking-by-wire, etc., and finally chassis-by-wire and drive-by wire. As more and more controllers are used in vehicle, it's necessary to have a Vehicle Electronic Control Unit (VECU) to balance all functions and conflicts. Multi controllers' implementation makes the EEA (Electric and Electronica Architecture) technology necessary, together with the Functional Safety (FS) technology to reduce the risk of failure.

If the full vehicle system is considered as a close-loop control system, human driver acts as a sensor/observer, meanwhile a decision making unit, and also a feedback control and actuation unit. Driver uses eyes to observe outside environment and makes decisions using his/her brain, following with hands/feet actions to give demand to the controllers to realize steering, braking or acceleration. As computer technology and AI develops fast until relatively mature, human driver can be replaced partially or fully by a controller, for Intelligent Vehicle or Autonomous Drive. The intelligent vehicle can be classified from Level 0 to Level 5, as shown in Figure 2, from all human action to partially automated until fully automated without any human interruption [7]. Partially automated control is also names ADAS (Advanced driver assistance systems) including AEBS (Automated Emergency Braking System), FCW (Forward Collision Warning System)/CAS (Collision Avoidance System), LDWS (Lane Departure Warning System)/LKA (Lane Keep Assistance), ACC

(Adaptive Cruise Control), etc., which can effectively reduce the risk of accidents from miss operations of human drivers and improve the vehicle safety substantially. Fully automated control can release the human burdens of driving tasks and improve the transportation efficiency, which needs highest level reliability and functional safety through extensive testing and validations.



**Figure 2.** Levels for Automated Driving.

Intelligent vehicle, especially high level, is mostly a disruptive innovation as it replaces human driver partially or entirely. Inside it there are three types of technologies, as environmental perception, intelligent decision making, and control implementation. Environmental perception would be implemented by all sensors instead of human eyes and/or ears, which includes Lidar (laser), Millimeter Wave Radar, Camera, etc. and the data fusion for multiple sensors. Intelligent decision making is performed by a controller or computer to be replacing the functions of human brain. Control implementation makes all actuators performed automated following controller demand without human actions of hands/feet. All these technologies are complicated, especially the decision making philosophy and methodology according to human brain. Here AI can give helps, and there are some algorithms to make the intelligent decision making more efficient, such as machine learning especially deep learning and reinforced learning, etc.

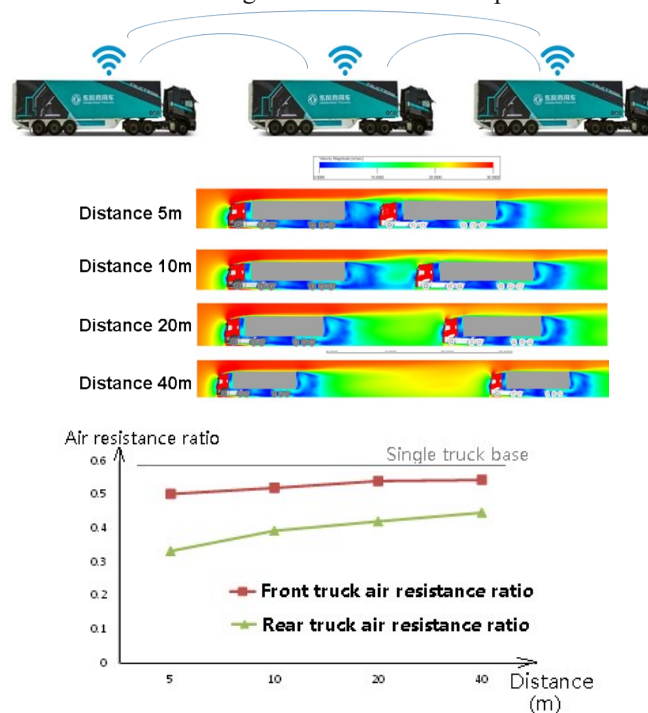
#### 4. Communication Technology and Vehicle Connectivity and Sharing

At the time of the second industrial revolution, wired communication such as telephone and telegram appeared. As the third industrial revolution brought automation and control, it also brought the development of connection and communication technologies. The development of computer science led to connections among computers, from local area network (LAN) to wide area network (WAN) until internet which is capable to connect all the computers worldwide. On the other hand, the wired communication also developed to wireless communication, and telephone developed to mobile phone. The current forth industrial revolution furthermore brought blooming and crossover of communication technologies. Mobile phone communication technology evolution is from 1G until 5G and future 6G. Smart cell phone combined some functions of computer into cell phone, and cell phone developed from a tool for just voice communication to a tool for combining voice, figures, characters, files, audios/videos, etc. More and more mechanical systems become mechatronics systems, and their control systems are connected through Internet of Things (IOT).

Communication and connectivity technologies also brought substantive changes to automobile. Inside the vehicle, CAN (Controller Area Network) was widely used instead of hard line to connect multi-controllers, and it developed to Automotive Ethernet, which will support future fiber-optical communication bus system. Outside the vehicle, wireless communication technologies are used and make the vehicle

connected. Vehicle connectivity is divided into 3 levels [8]. The first level is current telematics, or named infotainment system, which gives information to human driver. In this level, the map and navigation system is used, but it just gives information to human drivers through their eyes and/or ears. The second level is using the data of connectivity to help the on-vehicle sensors for environment perception, and release the burden of sensors to some extent. This includes data from vehicle to vehicle (V2V), vehicle to infrastructure (V2I), etc., and it's summarized to vehicle to everything (V2X). In this level, the map and positioning/navigation system is used, and it provides data to vehicle controllers, currently with the format of ADASIS –Advanced Driver Assistant Systems Interface Specifications. All data from on-vehicle sensors, V2X, and map and navigation system, will be processed by data fusion technology, to get the whole completed environment perception result. And the big data produced by connectivity, is also used in controllers to improve the vehicle performances, or to predict the future failures. The third level is cooperative controls of vehicles and the entities connected to vehicles, and all these become a completed system—ITS (Intelligent Transportation System) [9]. All above real world data of transportation system, connected with a virtual model, and this produced the Digital Twin supported ITS, which enables future Smart City and Smart World.

Connectivity technology improves vehicle and transportation not only safety and efficiency, but also energy conservation. Here is a typical application of Truck Platooning based on V2V [10]. Normally if a truck is controlled by a human driver, it will be decelerated after the driver foot presses the brake pedal and then the controller activates the braking. The following truck driver identifies the deceleration using his/her eyes, and this makes quite a long safety distance necessary between two running trucks with high speed. If the function of human driver eyes is finished by sensors, the long safety distance still cannot be reduced due to a time delay between pressing brake pedal and vehicle deceleration. If these two vehicles are connected through V2V, which means two vehicle controllers are connected and one action can be identified by the other immediately, with slight delay due to data transferring through networks. This can significantly reduce the distance between two running trucks with high speed, which can substantially reduce the air resistance due to the changes of airflow field outside the two trucks, as shown in Figure 3. Lower resistance means lower fuel consumption and lower CO<sub>2</sub> emission, e.g. the rear truck fuel consumption can reduce 15% when it's 5m distance behind from truck, comparing the single truck base. This affection can be huge whenever it's in the scale of the whole transportation system, including all possible trucks. But there are still some research works necessary before Truck Platooning comes into mature implementation.



**Figure 3.** Truck Platooning and the Effect of Airflow Field and Air Resistance Ratio.

Based on communication and connectivity technology, the models of transportation are changed.

Formerly individual owned vehicles can be shared and the vehicle uptime and transportation efficiency can be improved prominently. Former different transportation tools can also be connected, and this makes the transportation by different tools more efficient and smoother. All this is named Mobility-as-a-Service (MAAS) [11]. Essentially transportation is to move persons or freight from one position to another position, and normally it's finished by not only one tool. If the routine commute is mostly by subway, the two sets of shared bus ride on both end can make it more efficient and comfort. Freight transportation for long distance is usually finished mainly by air or ship, and the two sets of truck transport on both end is necessary. The shift of different tools can be planned and scheduled efficiently and seamlessly, supported by connectivity and sharing technologies.

## **5. Innovation System Reengineering of Automotive Industry**

Normal companies usually have an innovation system including all business processes, but mostly more suitable to sustaining innovation which is the evolution and improvement for current products. Currently more and more disruptive innovation and revolution brings impacts to automotive industry, and the current existing innovation system cannot respond effectively and efficiently. The innovation system reengineering is necessary, which includes identifying/creating new requirements and solutions in strategic planning process, quick respond and iterations in product development process, and new business models to make profits and maintain the sustainable development.

Firstly, it's very necessary to keenly identify the new requirements brought from the disruptive innovation in strategic planning process, and then respond to it timely following with suitable product solutions. Disruptive innovation can bring new products/solutions together with new customers, or to say turning 0-customer market into a new market. For example, worldwide climate change brings powerful respond to reduce CO<sub>2</sub> emission, and there are more and more policies/regulations/legislations for it. Sustaining improving the current existing ICE and vehicle to reduce the full vehicle CO<sub>2</sub> emission is necessary. On the other hand, the revolutionary solution of electrification brings 0 CO<sub>2</sub> emission solutions such as BEV, FCV, etc. and also brings a new market which is formerly not exist. Chinese government declared a new policy to promote BEV firstly in public service area, such as shuttle bus, post office trucks, sanitation trucks, taxis, etc. Resultantly the new market developed quickly. BEV sanitation truck started from 0-custom and quickly arrived 1976 units in 2015 due to the strong incentives from the government. As the incentives ramped down, BEV sanitation truck sales arrived 1522 units in 2018. After that new policies made it continuously increase, from 4445 in 2019 until 4867 in 2022 and 6567 in 2023. Autonomous drive is another example. Due to the insufficient of skilled labor for heavy duty truck driving, partially or fully automated drive would be helpful to release the driver burden. This would be producing a new requirements and then new market for it, which is not formerly existing.

Secondly, it's necessary to have quick respond and quick iterations in product development process. As disruptive innovation of technology is not mature enough, it needs a mass of testing and validations. On the other hand, the quick emerging market cannot wait fully conventional validation process with long time. The only solution is quick respond and quick iterations in development process. For example, Waymo, a company for Autonomous Drive from the US, made mane testing from 2019, and until April 2021 they drove more than 20 million miles (32 million kilometers) in public road, and 20 billion miles (32 billion kilometers) in monitoring drive, which includes different scenarios in different environments.

Thirdly, disruptive innovation also brings new business models, which changes the conventional sales process significantly. For example, at the very beginning although there were some incentives from the government, the BEV was still expensive for normal taxi owners. BYD, the BEV manufacturer from China, tried another solution. Instead of selling BEV to taxi owners, BYD established its own taxi company and ran the BEV taxi by itself. As electric power was much cheaper than fossil fuel and taxis normal run long distances, the BEV taxi company can benefit from it and maintain its normal operation. Another example is Volvo Truck from Sweden. Volvo Truck produced Autonomous drive mining trucks but at the beginning the trucks were expensive for normal mining companies to buy them. Instead of selling the trucks to mining companies, Volvo Truck established its own mining company, and ran the autonomous driving trucks in Kalk Mine of Norway. The trucks can be running without rest as no human driver necessary to run it, the company

can benefit from it and maintain its normal operation.

Finally, and the most important is the organization and the culture for innovation. Usually the innovations are initiated by start-ups, which are small companies with more efficient structures. If a current existing company with traditional business would like to compete, it's better for it to have a separate business unit for the business produced by innovations. The business unit needs to identify the special requirements, respond with quick development and quick iterations, and sometimes design new business models to make the new business succeed. If it's mixed with traditional business, usually the new business with small profit would get less resources to support, although it will bring some high potential profit. The innovation culture is also very necessary for the unit, which encourage the innovative ideas together with the effective actions to turn the ideas into reality. It also includes the evaluation system for business, development, investment, human resources, etc. In this case, Google had some good ideas and made a good exploration [12].

## 6. Conclusions

Current disruptive innovation brings new solutions for automotive industry, including vehicle powertrain electrification, autonomous drive/intelligent vehicle, and vehicle connectivity and sharing. However, challenges for automotive industry comes together with opportunities, and enterprise innovation system reengineering is necessary facing these. It's necessary to keenly identify the new requirements in strategic planning process, to have quick respond and quick iterations in product development process, to be considering new business models for new markets, and to reengineering the organization with more innovative culture.

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