Roads of the future

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Abstract:
Roads are a core issue in society, especially owing to CO_2 emissions. Launched in 2010, IFSSTAR's R5G program for a "5th Generation Road" has become the *de facto* roadmap for adapting highways to mobility in the 21st century. This approach, in line with the EU's program "Forever Open Road", seeks to build an effective system of national innovation for responding to climate change by making highways part of an evolving, automatic and resilient, system of mobility. The strategies of the automobile and construction industries now take "Roads of the future" into account.

Whereas greenhouse gas emissions decreased between 1990 and 2014 in France, they have increased since then. According to the Ministry of Transportation, they amounted to 463.1 million (metric) tonnes of CO_2 equivalent in 2016. The transportation sector ranks first with 136.3 tonnes, *i.e.*, 30% of all greenhouse gas emissions; and in this sector, road traffic ranks first, representing 95% of emissions. Private vehicles account for 50%; large goods vehicles (trucks with a gross combination mass of more than 3,500 kg), for 21%; and utility vehicles (vans, pickups, etc.), for 20%. Our roads, on which 85% of trips are made, are in the eye of the environmental and energy transitions.[1]

In this context, digital technology is controversial. On the one hand, it is a solution that facilitates access to shared modes of mobility for sure, inclusive and clean transportation. On the other hand, digital technology is a problem, since it is likely to stimulate more trips, congestion and urban sprawl. The environmental, energy and digital transitions — a three-pronged challenge — will affect highways, which have to be adapted, and road builders, who do not want to be "uberized". To take up this challenge, stakeholders in the French highway system (world leaders in this sector) have formed alliances with transportation and telecommunication firms for conducting experiments on the "highway of the future" and designing an "integrated offer" (DE PRÉMARE 2019).

What has been called fifth generation roads (R5G) are being developed under the EU's Forever Open Road program (LAMB *et al*. 2012). These programs are based on automation, adaptability and the resilience to climate change (JACQUOT-GUIMBAL & HAUTIÈRE 2012, HAUTIÈRE *et al*. 2015).

[1] This article has been translated from French by Noal Mellott (Omaha Beach, France). The translation into English has, with the editor's approval, completed a few bibliographical references. All websites were consulted in September 2019.

Fifth generation roads

● AN AUTOMATED HIGHWAY SYSTEM: The intent is to make the most of technology for managing road traffic and developing new forms of mobility.

A first objective is to adopt new traffic management strategies based on the increasing connectivity and automation of vehicles so as to improve the highway system's performance and its return on investments, and to make trips safer and more reliable. These strategies will optimize uses of the infrastructure by taking advantage of a cooperative smart transportation system (platooning, pricing, personalized traffic information). The current tasks are to design optima that combine the measurement of traffic flows with individual nomadic services, to develop reliable data chains and to foster the coexistence of automated and conventional vehicles on roadways.

Another objective is to install road systems that can retrieve data from sensors, whether part of the infrastructure or on board vehicles. Existing systems of sensors should be used while integrating new generations of devices for acquiring increasingly accurate traffic data at a lower cost. This implies open, standardized interfaces for the sake of competition between suppliers and cooperation between other stakeholders, independently of suppliers. The intent is to avoid rapidly obsolescent investments.

Hidden behind these objectives are legal hurdles that must be cleared by drafting a regulatory framework adapted to the rollout of a cooperative, smart transportation system and the automation of traffic. Finally, the players active in this process will have to be assisted by harmonized plans for rolling out this system; managers will have to be involved in the process; and people will have to be trained and learn new skills.

● ADAPTABLE ROADWAYS: Since not all new offers of mobility are likely to be adopted, the question of adaptable highways means proposing a road system that is flexible, profitable and capable of adapting to future demands for mobility. Various sorts of solutions can make highways adaptable.

First of all, new methods of road construction are to be designed. Factories will prefabricate roads in modules, so that damaged sections on a highway can be replaced fast. These methods will incorporate processes of quality control based on low-carbon materials that can be recycled, demand less energy and repair themselves, thus prolonging the infrastructure's life-cycle.

As a consequence, roadways will be built in layers that strike the right balance between the noise from the vehicles running over them and the interaction with water, between adhesion and resistence. 3D-printing will make this possible. Robotic or automatic methods will allow for higher maintenance and upkeep requirements, even in traffic. I might also mention incorporating in roads a layer of sensors for monitoring the state of the road.

Finally, a highway must be capable of integrating, if need be, systems for up- or downloading renewable forms of energy for electric vehicles and roadway equipment, such as signs and lighting.

● RESILIENCE TO CLIMATE CHANGE: Highways must be resilient to cope with the effects of climate change.

Among these actions are: identify the needs of climate managers; harmonize climate data Europewide; assess the socioeconomic impact of disruptions; detect eventual points of vulnerability in networks; set future service levels for the trans-European network; determine the key technology for attenuating climate change; and investigate worthwhile processes of adaptation. To meet this overloaded agenda, some solutions are already on the shelf, such as drainage systems that adapt to the increasing frequency and severity of precipitations, heat-regulated roadways for reducing freezing on the surface and curbing the effect of extreme heat (including in urban areas), and materials that absorb pollution or store CO_2.

Digital technology to the rescue

● HIGHWAYS FOR A SEAMLESS MOBILITY: Via the generalized use of smartphones, transportation users, whether or not professionals, will optimize their trips. Notwithstanding the potential rebound effects, which the previously described solutions will absorb, these new offers will gradually turn the highway system into a reliable infrastructure "*between massified modes of transportation*", a trend facilitated through carpooling stations or (possibly automated) intermodal hubs (AMAR 2016).

Highways are thus trying to be at the service of other modes of mobility. This will, for example, help air transportation reach its strategic goals by 2050. A seamless service between transit modes already exists for chaining trips via various modes, but it is also valid for designing the transportation infrastructure and key forms of technology. Furthermore, the optimization to be expected of logistic chains will lower costs, or even the duration of trips (ZOFKA *et al*. 2016).

● NEW KNOWLEDGE AND OPTIMIZED COSTS: Digital technology can help us better design and operate future highways (HAUTIÈRE & BOURQUIN 2017a).

The concept of an "electronic twin" that feeds on real-time data from vehicles and sensors in the infrastructure and is coupled with artificial intelligence will help optimize maintenance costs and improve safety as well as traffic or energy management. It will potentially allow for handling problems not yet solved and deploying driverless vehicles safely on our highways (EHRLICH *et al*. 2016).

● A SUSTAINABLE BUSINESS MODEL FOR NEW SERVICES: The economy is the field where digital technology can render the most services to for our highway system.

Thanks to data from sensor networks, we can imagine global performance contracts. Given the absence of intermediaries and the traceability of transactions (thanks to blockchains), new services can be developed. Once automatic vehicles rely, for example, on light detection by camera or Lidar (for road signs, signals, marks, etc.) in order to accurately report their location, their owners — unlike the drivers of conventional vehicles — might be billed for this service (HAUTIÈRE *et al*. 2019a). We could then imagine setting indicators of minimal performance for the infrastructure with a sustainable business model, something hard to do nowadays.

R5G, France's adaptation of the Forever Open Road program: Goals by 2020

IFSSTAR's R5G for a "5th Generation Road" seeks to stimulate actions in line with the EU's Forever Open Road program and involve stakeholders in this trend. In other words, R5G was intended to be a "frontier object" with which stakeholders could identify. It sought to build a national ecosystem of innovation while waiting for energy to be fully liberated at the financial, regulatory and fiscal levels. This laboratory undertook four actions (HAUTIÈRE 2018):

● ALIGN THE NATIONAL AGENDA FOR R&D WITH THE FOREVER OPEN ROAD PROJECT.

The intent was to foster strategic programs nationally (similar to the national strategy for the environmental transition: SNTEDD) or even co-finance calls for projects (similar to Eranet+Infravation). In turn, the Forever Open Road program would profit from these national actions (such as Mobilité 3.0). For this purpose, a strategy was adopted to make challenges like the ones proposed during COP21 for an "energy-positive road" (capable of producing, storing and delivering energy from renewable sources) or under the French program for developing autonomous vehicles (PFVA).

● INFORM PUBLIC POLICIES RELATED TO HIGHWAY INNOVATIONS.

The starting point was to set up the Institute of Infrastructures for Mobility (IDRRIM), in particular, its committee on education, research and innovation, which brought together public and private stakeholders. Besides making an inventory of existing arrangements related to innovation, this committee support lent to new initiatives. A convention on innovative road networks for the energy transition, signed in April 2015, led ADEME to issue calls for projects on the "Route du Futur" that same year. Backing was also given to forward-looking actions, such as the study on the impact of changes in mobility on road infrastructures (ATEC *et al*. 2019).

● CATALYZE INNOVATIVE SOLUTIONS FOR HIGHWAYS.

Among the many tasks: present (or support the presentation of) R&D programs via ADEME's calls for projects, such as I-Street (GEISLER *et al*. 2018); build adapted testing equipment (*e.g.*, Plateforme Mutualisée d'Innovation Transpolis in Ain department or Equipex Sense-City in Marne-la-Vallée); bring the issue of highways into the research programs of organizations active in innovation (like ITE Vedecom et Efficacity, IRT SystemX and Railenium, or the "poles of competitiveness" devoted to urbanism and transportation, such as Mov'eo, Cara, ID4Car, iTrans and Cap Digital); work with trade groups to help firms have a handle on changes in their business processes; encourage the creation of startups (SATT, incubators such as Green Tech Verte); and support the drawing up of training programs that explicitly take account of infrastructures (such as the master's program on smart mobility at the École des Ponts and Télécom ParisTech).

● ACCELERATE PROJECTS OF TERRITORIAL DEVELOPMENT by working with local authorities on their highway projects.

This usually involved metropolitan areas (such as Paris, Lille, Nantes, Bordeaux and Montpellier) negatively affected by problems stemming from controlled access highways. They placed experiments with R5G on the agenda and offered stakeholders the possibility to propose experiments. Another focus was on corridors such as A4 in the European program SCOOP@F (HAUTIÈRE *et al*. 2017b) and A13 under the CPIER Seine Valley program (PIZZAFERRI 2019).

Conclusion and prospects

To cope with societal issues by 2030, highways must be automated and be made adaptable and resilient to climate change. Their designers and builders have understood this. Thanks to R&D conducted over the previous ten years, these stakeholders have been, in 2019, taking part in the strategic committee on the automobile industry, where issues of automation and of the energy and mobility transitions are addressed. They have also been participating in the strategic committee on the construction industry, which has focused on the question of roadways.

The intent now is to deploy the solutions from R5G demonstrations, draft a "doctrine" for highways in the 21st. century, and take up the challenge of resilience to climate change, which, till now, has tended to be overlooked. It is thus necessary to move beyond solutions for attenuating climate change or adapting to it. The highway infrastructure and system must be turned into a toolbox for geo-engineering the climate. After all, if 2% of the surface area of France — the country's highway system — causes (directly or indirectly) thousands of deaths per year, these same 2% could save us by producing energy and removing pollution from the air, and by capturing and storing massive amounts of CO_2 (HAUTIÈRE 2019b).

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