Cognitive Mobility - CogMob

Máté Zöldy
Dept. of Vehicle Technology
BME
Budapest, Hungary
zoldy.mate@kjk.bme.hu

Péter Baranyi
Dep. of Computer Science
Szechenyi Istvan University,
Győr, Hungary
baranyi.peter@sze.hu

***Abstract*—Mobility is a crucial part of our everyday lives as we continuously move and change. The rapid digital development of the 21st century allows us to expand our experiential cognition with ever smaller, cheaper, and more sensitive sensors, data fusion, and artificial intelligence, with more and more data available to us. The advancement of cognitive functionalities is the enablers to connect to analyze, understand and optimize mobility. Human and artificial intelligence and a deeper combination of these provide a new viewpoint of mobility. This paper aims to define the domain of cognitive mobility.**

Keywords—Cognitive Mobility, Motivation, Value, Tool, Infrastructure

I. Introduction

Mobility is an elementary part of our lives, as we are constantly changing and moving. For many, the word mobility is primarily related to transport, i.e. a change of location that is visible to the naked eye, for which we often use the help of some means. However, mobility can be much more diverse: for example, social mobility, which describes a change in the social situation of an individual or a family, or labor mobility, which creates a link between a job and a choice of residence.

During the research and cognition of cognitive mobility, our interest is on the movement, especially the cognition of transport, the mapping of the cognition methodology. Relocation is a long process preceded by the appearance of a need/need, decisions on how to fulfill it, and how to route it. Important elements are vehicle use; infrastructure; their environmental effects; time and energy; and resource requirements even in historical time horizon. The result of relocation is the satisfaction of the triggering need or demand, thus creating individual and social value. Analyzing historical mobilities is a tool for a better understanding of the present and the future.

Cognition and its mapping have long been a part and foundation of our lives. The rapid digital development of the 21st century allows us to expand our experiential cognition with ever smaller, cheaper and more sensitive sensors, data fusion and artificial intelligence, with more and more data available to us [1]. Among other tools, they help get to know and map the world, thus mobility in more detail. This also opens up new dimensions in understanding and development. Many of these focus on existing system components, but it is becoming more and more common to have detailed experiential knowledge of the triggering needs or the value created. This can lead to new solutions. Getting to know our world, our decisions, our opportunities can, in extreme cases, mean minimizing or even abandoning mobility, as we have seen during the Covid waves of the past year and a half, or in the case of new compact urban planning objectives.

Earlier use of cognitive mobility was limited to measure the transition from one place to another in idea space [2, 3]. According to my approach, this unique mobility example is part of cognitive mobility, can be analyzed and understand better with this approach, but it is a partial segment only.

The cognitive capabilities for humans and the developing artificial cognition of machines are merging in the mobility deeper and deeper. This paper is aiming to provide a viewpoint of a framework where human and machines capabilities are part of one mobility system.

II. Definition

Cognitive Mobility (CogMob) investigates the entangled combination of the research areas such as mobility, transportation, vehicle engineering, social sciences, artificial intelligence, cognitive infocommunications. The key aim of CogMob is to provide a holistic view of how mobility in a broader aspect can be understood, described (modeled), and optimized as the blended combination of artificial and natural/human cognitive systems. It considers the whole combination as one unseparable CogMob system and investigates what kind of new cognitive capabilities of this CogMob system are emerging. One of the CogMob focus areas, based on its nature, is the engineering applications in the mobility domain.

Two critical dimensions of cognitive mobility should be defined: ranking of mobility and elements of mobility.

Ranking of mobility is a scale with two pure theoretical endpoints that refers to the cognitive level of participants of the mobility.

- **intra cognitive mobility** – the participants of the mobility have neraly similar cognitive capabilities (i.e human drivers driving cars or robot forklifts at a logistical yard)
- **inter cognitive mobility –** mobility participants have different cognitive capacities (self-driving subway with human passengers or tourists with google maps and hard copy maps)

Elements of mobility refer to the essentials of the mobility:

- **triggering necessity**: is the root cause behind the mobility action
- **decision:** it has more levels. It influences how mobility happens, even happens or not. It reoccurs several times during the activity as well.
- **tool/vehicle/quality:** are different quality parameters that influences the decision and the resource need and the output of the mobility

- **infrastructure/resources: o**n top of the infrastructure, mobility uses many resources as money, time, energy, etc.
- **human-machine interface:** covers a wide range of options up to a smartphone, smart map, web tracking interface, simulation software etc.

III. Related discussion areas

In the discussion section, the CogMob related research areas are examined from a historical point of view. This chapter highlightes the increasing role and influence of natural and artificial cognitivity in mobility. It demonstrates that human and its environment merges more and more closely in the mobility and provides us a "one system" modeling space that makes mobility more understandable.

Historically the research areas connected to mobility are fragmented into silos and work parallelly with a low number of interdependencies. Most of the researches were focusing on their domain. The development speed of mobility in the 20th century was increased. The main areas were *vehicle engineering, infrastructure, road planning& decision making, transportation science, human-machine communication and social sciences*. Parallel technological development of these sciences reached the level where more and more synergies could be achieved with deeper cooperation (figure 1).

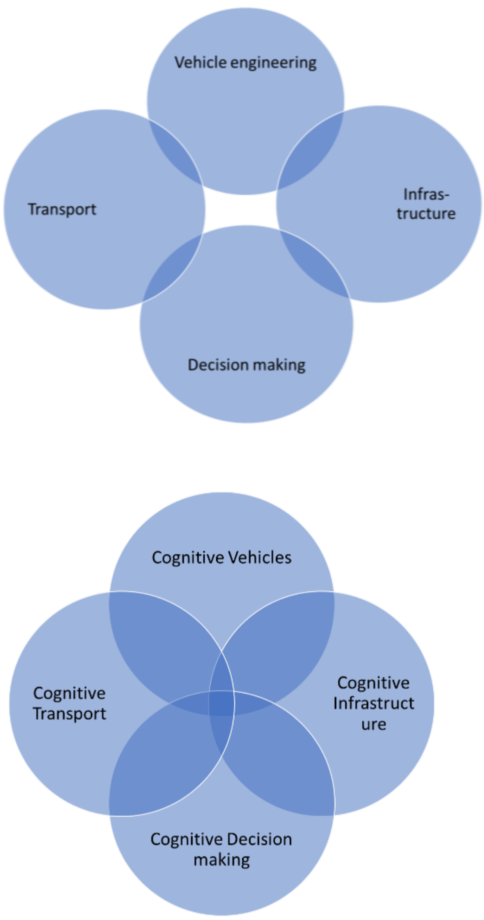

Fig. 1. Basic fields of mobility have higher synergy level and the domians are merging to create more efficient cooperation

The cooperation level of these sciences is increasing as, for example, the vehicles were simply users of the infrastructure in the past, but nowadays, the infrastructure and the vehicles cooperate and provide inputs for decision-making and route planning.

A. *Cognitive vehicles*

The vehicle's cognitive level started to increase with the growing importance of safety aspects. The first tools provided mainly mechanical aid for the driver. During the last decades of the 20th century and the beginning of the 21st century, the informatically enchanted driver assistant tools role is increased in the vehicles. A cognitive vehicle engineering workshop was held in 2019. The workshop aimed to explore and critically review what biological inspiration in perception, learning, and decision-making could bring in the future for increasing the intelligence of vehicles and other robotic systems [4]. The papers and the workshop's discussion sessions focused on the potential benefits and pitfalls in applying bio-inspired approaches when developing intelligent real-world systems that perceive, interact, learn, and make decisions. It is clear that a vehicle engineering focusing discussion involves infrastructure through perception and clearly goes hand in hand with decision-making.

B. *Cognitive Infrastructure*

Previously, new transport infrastructure was usually built on commercial grounds: think of the Panama Canal or the first railways or the electricity grid's construction at the beginning of the 20th century. Although there were complex systems among them, they are stand-alone devices that facilitate the movement of goods. Cognitive transport infrastructure, in contrast, is a meta-infrastructure; it contains many factors. It aims to accelerate capacity using several new technologies such as 5G communications networks, artificial intelligence and big data analytics programs, social media, internet-connected devices or cloud-based storage. The range of users and developers is also complex, as elements of cognitive infrastructure are developed and used by individuals through companies to public institutions [5]. The complexity of infrastructure and communication between users is increasingly similar to communication between people. The knowledge accumulated in one domain can be adopted in another area [6].

C. *Cognitive decision making*

Research is also intensive in the field of cognitive decision-making. Cognitive memory is also important for mobility decisions; for example, continuous re-planning of the route is accomplished by adding cognitive factors. Furthermore, when the error was reduced, the results were significantly improved, indicating that the vehicle could learn cognitive variables and improve decision-making related to choosing the right route. This opens up the possibility of unsupervised learning in the area of reasonable path decisions. The decision of vehicles is cognitively similar to the human mind, which also assigns the classification of events to processed samples.

Examining other features of human cognition, such as emotions and memory structure, offers an exciting way forward in the future. Unsupervised learning is one of the exciting cornerstones of self-driving vehicle development. Data mining can also facilitate routing; however, they need an optimized mining strategy to make selective data choices [7].

D. *Cognitive Transport*

Building intelligent transport systems is one of the great challenges of transport planning in the 21st century. The development of cooperation between conventional and autonomous vehicles at different levels in the global transport system is the task of the present and the near future. Already in this decade, the proportion of self-driving vehicles and the heterogeneity of traffic flows will increase, accompanied by the subdivision of vehicles and transport infrastructures to ensure their effective control and improve the quality of transport services provided. Creating a cognitive multimodal transport system is a complex example of the intellectualization of vehicles, transport infrastructure and the systems and networks that connect them. The primary driver of this process is the factor of AI in transportation systems. A successful system will significantly improve the safety of people and freight; reduces the average time for passenger and freight transport; improve the efficiency of the use of the capacity resources of the national transport system to ensure a higher level of environmental safety, and has a significant impact on the national economy. Along with the latter finding, it can be stated that the development of a cognitive multimodal transport system will be a strong impetus for the development of the national economy in general [8].

E. Human-machine communication

The history of human-machine interface (HMI) was started with the first cars. The first international conventions related to vehicle HMI were formed in the 1949 Geneva Convention on Road Traffic [9]. Among other areas, it contains several rules concerning the internal HMI of a vehicle; for example, there must be a speedometer and a steering wheel installed in the vehicle.

The emergence of route selection assistance systems in the 1970s, followed by the increasing complexity of first-generation driver support systems, triggered increasing communication between driver and vehicle. Systems to support early driving, such as ABS, ASR, ESP - were already in use at the end of the 20th century, but a “Tempomat” capable of automatically adjusting the following distance appeared as early as the turn of the millennium. However, the real breakthrough in complex Driver Support Systems was at the beginning of the 2010s, when the more complex functions appeared [10]. The vehicle and its driver and the passengers (eg aircraft on-board displays) and the communication between the infrastructure and the driver and between the vehicle and the vehicle and the vehicle infrastructure have appeared. At present, in most transport sub-sectors, the driver cannot be left out of mobility, but the functions that partially enable self-driving require increasingly complex communication, thus stimulating the development of communication interfaces.

F. Social Sciences

CogMob is primarily a holistic new approach that, in addition to putting artificial and natural cognitive abilities into a new understanding of mobility, also supports the outlook for the social sciences, thus helping the process of understanding mobility. The interplay between mobility and economic processes is a well-known relationship. Interpretation of mobility from the social science aspect helps to understand the processes that trigger mobility and the social processes that develop due to mobility and can provide an input parameter for further mobility development.

The aim of CogMob is primarily a holistic approach to mobility, connecting its areas with the tools used by info-communication. It connects some aspects of the system, such as decision, infrastructure, tool, and offers a shared space for optimization with the help of IT tools, which they consider to be part of a cognitive system.

IV. EXAMPLES

In this chapter, some examples are provided which clearly show the combination of cognitive levels, mobility modes, and mobility elements.

A. On-board energy management

On-board energy management or refueling management of vehicles is a good example of cognitive vehicle technology. Especially important for self-driving vehicles. The propulsion system of vehicles is currently undergoing many changes, the most complex being plug-in hybrid technology: it combines an electric powertrain and a conventional internal combustion engine, in the latter case with renewable or even synthetic fuels. In conventional systems, the communication between filling points (charging points or filling stations) and vehicles is one-way, using a narrow channel - the so-called totem pole - and with reduced content, only providing information on fuel price. From the point of view of vehicle energy management, research shows [11, 12] that the amount of available fuel/energy, charging limits, and waiting time are also important parameters. An intermediate state of decision-making is databases on the Internet that allow prices to be compared. The much longer time, and thus the waiting time due to the charging needs of others, as a decision criterion can only be achieved by exchanging better quality and quantity of information between the systems.

Inland and maritime navigation and off-road use, mainly in agricultural land use, will open up additional areas for improving the optimal energy management of vehicles with a cognitive toolbox. For example, in many cases, there are only estimates of the current consumption of a vehicle compared to the usual consumption of up to g / kWh in passenger transport [13].

B. Environment perception

Autonomous vehicles pose several challenging problems, one of which is perceiving and understanding the environment. The traditional leader senses the characteristic statistical environmental signals in his senses, characteristic of his eyes, and makes decisions based on them, like these systems, high-level, more dynamic relay systems, such as controllable signage, traffic light adaptive traffic control, incoming traffic updates from the navigation system, or even information from traffic news. The proliferation of driver support systems and newer multi-functional vehicles and their interconnection with intelligent infrastructure adds a new dimension to decisions. The key area of this connection is perception. Because self-driving is critical to safety, and many of the operations performed. At the same time, driving are based on the results of various sensing algorithms (e.g., road users and infrastructure objects in the vehicle environment must be reliably identified and localized), perception one of the most critical subsystem. However, the perception can be subdivided into sub-problems, such as object detection, lane detection, traffic signal detection, environment modeling, etc. In these, artificial intelligence-based solutions already play a prominent role today and are expected to do so in the future [14, 15, 16].

C. Vehicle drivetrain solutions

The use of complex devices based on artificial intelligence has also begun in the vehicle driveline. Diesel engines must meet increasingly stringent standards while continuously increasing performance. With the development of electronics, more and more components, such as injectors, exhaust gas recirculation, pressure limiters, become controllable and thus special engine conditions are available. An intelligent engine control system is being developed [17] to ensure optimum performance under changing operating conditions. The concept aims to achieve the optimal operating parameters of the motor to ensure the desired efficiency. In addition, a supporting vector machine-based forecasting model has been developed to predict engine performance under changing operating conditions. It was observed that the model of the supporting vector machines could accurately predict the engine's performance.

The application of statistical regression models has also begun in vehicle development. Research demonstrates the applicability of a three-step statistical analysis algorithm when vibration and sound pressure data are used as covariates to predict exhaust gas composition [18].

The results of machine learning can also be used well in vehicle control. A robust autonomous road tracking function is necessary to guarantee the safe speed and movement profile of a vehicle with variable tire-road contact. A solution for this case is a combination of Linear Parameter-Varying (LPV) control integration and machine learning-based analysis. The integration takes place in two steps. The result of the estimation method is generated through decision trees for the coefficient of adhesion. The result of the estimation is integrated into the robust LPV controller via a scheduling variable. An error in the machine learning algorithm is incorporated during control design. In a second step, it is proposed to optimize the longitudinal velocity over a predicted horizon, aided by a set approximation of the machine learning-based accessibility to the steering intervention [19].

D. Infrastructure and environment

The design and development of mobility-related infrastructure is also an excellent example of the advancement of cognitive elements. At the beginning of the 20th century, the concept of linking energy flow and urban development emerged. An important part of the urban ecosystem model is the design, optimization, and management of its mobilities. The close link between energy flow, urban structure and urban development is straightforward and can be traced and facilitated by cognitive means [20]. In addition to the design of cities and road networks, the simulation of mobility infrastructure has a prominent role for self-driving vehicles.

On the one hand, the development of traffic simulations is an essential tool for increasing the safety level of mobility. Reprocessing and constantly updating existing maps requires enormous amounts of energy and money for traditional structures and opens the door to computer-based technologies, especially simulations [21]. Simulations also play a huge role in development. Self-driving vehicles are difficult to integrate into homologation procedures of conventional vehicles [22,23], and their very lengthy testing time can be reduced by using simulation spaces such as digital-twin solutions [24]. In these, the simulation and reality run parallelly, in synchronism, so the simulation can be validated at any time with real measurements.

E. Decision making

In addition to designing mobility systems, cognitive methods provide support to support and make momentary decisions. Roundabouts have been a practice for decades because their throughput is easily adapted automatically to emerging traffic needs and is much safer than traditional roundabouts. However, they are a big challenge for self-driving vehicles. Although one of the focuses of the developments in their case is the highway scenario, the work done in the roundabout requires more time and effort. The research demonstrates the application of an MPC controller in circular conditions. In doing so, it can be seen that the application of cognitive techniques in this case also increases the efficiency of the system [25]. During the control of vehicles, the primary optimization, the solution of the placed one, and multi-aspect optimization are possible. In addition to avoiding vehicle collisions, coordination is motivated by minimizing energy loss, thus optimizing consumption and minimizing environmental impact by stopping and driving at the intersection. A reinforcement-learning-based optimization task can be built with an offline solution that can improve the economic performance of autonomous vehicles. Optimization tasks are interconnected, i.e., quadratic optimization with the vehicle model is used as the environment during training [26]. The use of new technologies of consciousness is unavoidable not only in the ground but also in air mobility. Unmanned aerial vehicles are a technology that is making significant progress and the new applications that are emerging every day make research in this area extremely attractive [27].

Conclusions

Mobility is one of the elementary building blocks of our 21st century life, and the cognitive approach consciously makes it possible to understand and extend it more deeply. The dimensions presented in the paper (ranking of mobility and elements of mobility) help interpret the extensive topic of mobility. The snatched and presented examples illustrate the similarity of the scientific work started in each subject area of CogMob in many cases, thus creating a holistic framework to handle natural and artificial cognition within the mobility in one system.

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