Design Principles of Post-Autonomous Vehicles

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Summary

From a technological point of view, the 20th century has been a big leap for the human society. Surface transportation system is one of new socio-technical systems, and a human's behavior is reflected through technology and in which the cooperation of both - human and technology - is desirable. Thus, introduction of fully autonomous vehicles will have very high impact on the human society. Every autonomous vehicle will always encounter interactions with not only human driven cars, but with bicyclists or at least pedestrians. Therefore, the need to focus on the human-machine cooperative vehicles, which can be seen as enhancement of autonomous vehicles, is evident. Main engineering design principles of the technology for such vehicles are presented in the paper.

1 Introduction

The need to transport humans to longer distances in shorter time has highly arisen during the twentieth century. Transporting people in the vehicles designed by human has created very tight linkage of human and technology. The vehicle can be seen as a form of human’s exoskeleton. Such a device serves as a transmission of characteristics of the exterior to the human driver. Even though the vehicle is currently not recognized in this manner, it is the technology, which directly transfers the inputs from the vehicle’s exterior and interacts with similar human receptors, as would be excited directly, when no technology will be present between human and its environment. Accordingly, the vehicle transfers the driver’s reaction to its exterior in the real time or with expectable time delay. The vehicle itself then acts as amplifier or as a filter for different quantities the vehicle or driver provides.

Historically, the vehicle was recognized as any other machine operated by human. It is a specific technology that serves human and enhances his comfort – in this case it’s about traveling from one place to another. In the beginning of automotive history, no one thought the cars would be available to almost everyone in the world and today’s congestions were not even a sci-fi imagination. The last ca. six decades are recognized as the boom of individual transportation and car itself transformed from the extravagancy of privileged to the daily need of everybody. Hence, the traffic density has become enormous and the current car interacts not only with driver and road, but also with large number of other vehicles, cyclists, pedestrians, animals and in turn the road traffic managing devices and rules.

Human and vehicle together with whole road transportation system unnoticeably passed through a change, which stood beside the mainstream of technological thinking processes. Earlier strictly technological linked vehicle and the driver became more a joint entity in complex socio-technical system[1], as related to the current road transportation system. The proud finesse of controlling the car as a machine is being left to a greater extent to the motorsport. Such situations, where driver can “play with the car” are getting more and more rare and the car transformed to an almost boring machine that allows one to individually travel over longer distances. Interestingly, another human skill developed through the last two or three decades – the ability to correctly understand the communication in the socio-technical transportation system. Current society is undergoing difficult times on the roads, in that many accidents still happen. Technologists and economists are hoping for a new technology, which will solve the suffering. Unfortunately, this has to be seen as a problem – by both, technologists and economists, they do not consider human as an integral part of socio-technical system. From the nature of those subjects, they logically treat human as a ratiō-based user. This leads to the development of sets of “new technological tools”, which are expected to solve the problems of road accidents, while on the other hand fulfilling the primary reason for development of new technology: enhancing the human’s comfort. Autonomous road transport is definitely assumed to be such technology.

In terms of technology, human is approaching new era, during which one needs to accept a different vision of technology. Until now, any technology developed was designed to be operated by human. Those hi-tech technologies, which operate autonomously at some level, were either controlled by highly trained professionals (spacecrafts, airplanes etc.) or were operating in a closed deterministic system (autonomous subway, large storage areas etc.). Also, autonomous personal road vehicles will be a sort of hi-tech, which will be operated by untrained amateur in very complex environment. Such technology has to be designed as 100% foolproof and as operating in any situation. As we are putting these robots in an open indeterministic road transportation system, we can see just from the definition of such system that the goal is not feasible at any time – one will always encounter situations, which will yet be unknown.

The new era brings another news into the scene – in some cases we approach a state-of-the-art, where no further technological progress is achievable. In other words, we cannot develop a technology, which would provide human with additional comfort while maintaining similar level of safety. In socio-technical systems this leads to situation, where we have to focus more on the human part of the system. The

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[1] Socio-technical system is to be newly understood as a system, where human directly interacts with a machine that serves as mediator, provider of actions and receiver of reactions, in interactions with other people. Other type of such system is the internet.

article is presenting rather global approaches to specific problems emerging from the ideas of personal autonomous transportation.

2 Complex Challenges in Autonomous Road Transportation

According to marketing materials of technology companies, the technology providing any function of autonomous road vehicle is already available, at least on some level. In case the company would be developing home appliances or PC software, overrated promotions and even neuromarketing techniques might be acceptable. But not in case of technology, which directly treats human’s life. The challenges of autonomous road transportation are specific in details and not fully described. Nevertheless, many parts of the technology are at a very high level. However, the autonomous vehicle cannot fulfil all the requirements for only 99,9%. It has to achieve full 100% reliability, as there will be no backup in form of highly trained pilot.

There are several challenges facing automated road transportation and needing to be addressed. These can be distributed in two groups: technological issues and soft skill issues. The technological might be quite obvious – the robots carrying people from one place to another with following abilities:

- robot has to reliably (for 100%, not 99,9%) move in a roughly known environment;
- robot and the whole system has to be hack-proof;
- robot has to interact with other robots as well as with people and animals, where people are included in the system as:
    - passengers;
    - drivers of other non-autonomous vehicles and various people movers;
    - pedestrians;
- the behavior of the robot has to be predictable by humans;
- the whole system has to have higher throughput at lower emissions, than it has today;
- robots have to obey traffic rules and they have to expect people not obeying the rules;
- any situation happening on the road must be solved with no loss of human life or serious injury;
- robot has to provide ethically acceptable solution in the situation of unavoidable accident.

From the soft skills point of view, the problems are currently seen only on the legal side. This seems very unfortunate, as the law is only formally specifying the living space of every individual in the society. For example, the often discussed responsibility for the accident happening is not sufficient. In such case, the legal consequences are the least of interest – the psychological and social impacts of the serious accident are much higher and not easy to overcome. In addition, possible accidents of autonomous vehicles are not the only subject of concern. Primarily, one has to focus on the non-critical situations. The following problems from the psychological and social perspective can be specified:

- human's degradation of the skill to drive and control the vehicle;
- cognitive dissonance, finally leading to frustration and depression caused by several factors, mainly by:
  - the loss of independence;
  - stress from unknown level of trust in the autonomous driving system;
- psychic problems of multiple people will degrade the social comfort in the whole society;
- unemployment – for example, 3% of people are employed as drivers in Czech Republic [5]; it's irresponsible to pretend that all of them can be trained for new work requiring higher qualification.

One can see that the problems emerging on the human's side raise important questions, for instance: do people need such technology? What are the real positives of such technology for an individual and for the society? Are we able to develop better technology?

2.1 Human Dilemmas and Self-Driving Vehicles

The current movement toward self-driving cars is seen in the automotive industry as well as political systems. For some, it is like a tsunami wave that is flooding the consumer and threatening their independence and freedom. The wave is huge and felt by many that they will be drowned within it.

The ambivalent and at times negative reaction of the consumer to this groundswell of autonomous or self-driving vehicles is puzzling to many in the auto industry. The industry uses factual information to try and convince the driver that self-driving vehicles will be an overall improvement over legacy vehicles. These positives can be summarized as being environmental benefits such as improvement of fuel economy, optimization of highways, reduction of required cars to only 50% of the current amount needed, platoon driving that would save on fuel consumption, decline on death tolls, stress reduction, and decline on parking space [6]. There are several theories proposed dealing with the consumers' reaction to the process of moving from legacy to self-driving cars. The role of cognitive dissonance, as it applies to dependency versus independence, can possibly assist in understanding many of the consumer's reactions.

Referring to Festinger's work on cognitive dissonance [7], that is, when an individual feels anxiety when dealing with opposite wishes or drives, the reaction of many drivers to self-driving vehicles becomes clearer. In the instance of self-driving vehicles, the concept of dependency vis-à-vis independence and the cognitive dissonance it creates in many drivers is apparent and can be analyzed.

Multiple child developmental theorists have studied and posed various theories about how children develop. Different theoretical approaches to how a child develops into an adult are presented in [8], [9], [10] and [11]. However, they all directly state or infer that a child should move from a dependency position to an independent one as they progress into maturity. Concepts of trust versus mistrust, capacity to self-organize and self-regulate, and cognitive development that serves the child well as it moves from dependency to independence are seen in these theories. Thus, when placed in a position of total dependence in a self-driving car and depending on algorithms to make all the decisions, many drivers, in turn, are going against basic cognitive and emotional decision making positions based on independent thinking and feeling learned throughout their early and later life.

Other aspects relating to cognitive dissonance as it applies to dependency vis-à-vis independence and self-driving vehicles are seen in cultural differences, generational differences, and aging issues. The cultural issues on the individualistic/collectivistic dimensions are addressed in [12]: "An individualistic culture, such as the predominant culture of the United States, values individual goals more than collective goals. In a collectivistic culture, the needs of the group take precedence over the needs of the individual". In terms of generation differences, they explore four dominant generations from 1901 until present, differentiating them into Builders, Boomers, Gen-Xers, and N-Geners. The earlier generations had characteristics of dependency while the middle generations moved toward independence, and the most recent generation appearing to be a paradox in that they need reinforcement and caretaking while not conforming to bureaucracy (this generation being a combination of dependency and independence) [12]. Heather Sundell, a current Los Angeles writer, addresses her emotional dissonance to the self-driving car: “The thing is, I've always been independent to a fault, not always asking for help when I needed it. My license, the cars I've had and the freedom I have had for almost half of my life have been my greatest gift, my deepest solace, and my darkest vice” [13].

The aging population is another example of cognitive dissonance as it relates to self-driving vehicles. Lisa Yagoda writing in a Senior Newsletter emphasizes how important driving is for the elderly: "Driving a car is more than just a mode of transportation or a way to get from one place to another. Driving is an important daily activity that represents independence, competence as an adult and the ability to have control over one's life" [14]. Thus, the move to self-driving cars does not solve the internal problem of independence of elderly people.

Miller and Parasuraman approach the dissonance that a driver might feel from another perspective when dealing with an autonomous self-driving vehicle. Their study deals with the concept of trust and is very applicable to the aging population as well as younger drivers. The idea "who's in charge?" is the thesis of their study. They propose: "Trust is an indicator of how accurately the operator understands the system (and have their input seriously considered by the vehicle)” [15]. The important psychological ramification around trust deals with the drivers feeling that they have an impact on the self-driving vehicle (algorithms) if and when it is indicated.

Interestingly, a recent study by the Michigan AAA shows that 84% of the consumers who do not want autonomous features on their next car stated: "they trust their own driving skills more than technology" [16]. The ongoing problem that drivers experience concerning losing their independence and freedom and resulting in cognitive dissonance can possibly be solved through the concept of synergy and the combining of the driver and vehicle into a third, more productive entity.

2.2 Solving Technological Challenges

If we omit the human oriented issues in autonomous transport and focus only on the technological challenges, then we can look for a solution into a similar transportation system in the IT – the internet. The internet applies two global types of transportation protocols – collision protocols and non-collision protocols. In road transportation, the collision protocols are inacceptable, as we cannot afford the repeatability of tasks. Therefore, the approach of non-collision protocols looks feasible at the first sight. Such protocols have a rule based approach, similar to road transportation system. These rules then have to be complete and orthogonal. The completeness of rules fully eliminates the existence of unknown system state or situation. Rule of orthogonality specify the boundaries and connections of the rules and removes the contradictory rules.

Idea of rule based autonomous transport is something that pushes the current research and development activities toward fully autonomous transportation. Unfortunately, this idea, or often nearly an ideology, neglects the main entities in the transportation system – human and its natural environment. These two are defining the system openness and inability to create a complete set of rules, which would be always obeyed at every time and without any exception.

The implications based on the preceding evidence give us the only solution for an autonomous transportation system, which can be effective and safe to human and environment. It is to create specific areas, where the complete set of orthogonal rules can be created and will be obeyed. These areas can be i.e. subways, trains or some special types of local transportation systems in closed environments like airports, naval ports or industrial areas.

2.3 Automated Driving as an Option

The current “marketing based” automated driving solutions are showing the self-driving vehicle abilities. These solutions are presented either in almost closed environments, like expressways, or at very low speeds, where detection of critical situation is feasible and possible system’s non-reaction does not generate much damage. Unfortunately, such demonstration can provide an incorrect image of current technological state. There are too many insoluble challenges on the way to fully autonomous road transportation that have not been presented yet in any scientific feasibility study of autonomous transportation.

Based on the knowledge, that some situations in road transport can be very boring for the driver and the time spent in vehicle can be used more wisely, we definitely need make the traveling more comfortable. Human can become bored especially in very algorithmic and highly deterministic situations. Hence, in such a situation the driver makes errors. These situations have been already defined and manufacturers are trying to cope quite well with them. Good example can be queue assistance or highway autopilot[2].

Nevertheless, engineers have to deal with the nature of human learning process. The learning process is based on creation of new neuronal paths in the human brain. When training the newly learned ability, these paths are being strengthened. They can also strengthen until they become very fast conditioned reflex [2]. However, if we stop training the new ability, we start to lose it. While driving the vehicle, we are always under the continuous training process, where we optimize our abilities of prediction and of dynamic control of the vehicle. If we allow the driver to use highway autopilot or queue assistant at any time or always, we will only generate drivers, that will not be able to safely control the car during more complex situations. Thus, driving automation has to be given only as option in specific situations, emerging from further stated design principles of post-autonomous vehicles.

3 Bertalanffy’s System Theory and Synergy

General systems theory studied by Ludwig von Bertalanffy contains the seeds for a theory of synergy that is helpful in resolving the dependence vis-à-vis independence dissonance that self-driving vehicles can create. Recognizing the theory is somewhat abstract, Bertalanffy clearly addresses it when he writes: "The meaning of the somewhat mystical expression ‘the whole is more than the sum of its parts’ is simply that constitutive characteristics are not explainable from the characteristics of isolated parts. The characteristics of the complex compared to those of the elements appear as ‘new’ and ‘emergent’." [4]. Also, Bertalanffy proposes the idea that a system is not limited by two material entities, and can be applied to any ‘whole’. Thus, the notion that two parts can combine into a third part is the foundation for a concept of synergy.

Synergy is seen operating at many levels. An example from chemistry involves two common elements chlorine and sodium that are toxic to humans, but when combined into a new substance they become positive and helpful, i.e. ordinary table salt. Interestingly, Corning in [18] refers to the automotive revolution beginning in 1906 as an example of a synergistic convergence when he writes: "A sense of adventure, and freedom and independence that automobiles provided for their owners were psychological factors that helped the automotive revolution occur when it did”. The idea that two parts can form into a third entity is a key concept when resolving the driver vis-à-vis the vehicle dilemma.

The driver and the vehicle (algorithms) can thus form a new third entity. Its forming can give the autonomous vehicle a new perspective. Miller and Parasuraman in [15], though, dealing with robots, speak to a similar concept: "The human and automation systems can adapt to various contexts; in adaptive systems automation determines

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[2] This does not refer to current state of faulty design version of Tesla Autopilot feature, but to the global idea of autonomous driving in deterministic situations.

and executes the necessary adaptations, while in adaptable systems, the operator performs the desired adaptation". How this third entity comes into being also can be addressed.

4 Six Design Principles of Post-Autonomous Vehicles

Current approach to autonomous (self-driving) vehicles is realized on the basis of design of fully autonomous robot transporting human from A to B. The obvious challenges of opened semi-self-organized road transportation system identified earlier are shifting the idea of 100% safe autonomous road transport of humans from complicated to impossible. On the other hand, the unique entity of human-machine unit fulfills the idea of safer, more efficient and comfortable road transportation, while maintaining the human independence and responsibility for the majority of activities realized during the driving. In fact, the proposed emergence of third entity also copes quite well with ethical and moral issues, raised i.e. in the MIT Technology Review [21]: how should self-driving cars be programed to act in the event of an unavoidable accident? The article reads: “Should it minimize the loss of life, even if it means sacrificing the occupants, or should it protect the occupants at all cost? Should it choose between these extremes at random?" The place of the human in these difficult decision making situations cannot be and should not be ignored. Bertalanffy does well in writing to this issue: ”Man (human) is not a passive receiver of stimuli coming from an external world, but in a very concrete sense creates his (its) universe" [4]. Thus, the input of the driver (human) within an algorithmic world will be of utmost importance in trying to answer unanswerable questions.

4.1 Principle no. 1: Do Not Let the Driver Loose His Skills

As mentioned earlier, any human skill degrades when it is not used. Based on the current knowledge, it is necessary for a human to actively drive on a regular basis at least 100 - 200 km per week in numerous environments, where driver encounters not negligible amount of various interactions. Vehicle systems have to obey such rule and cannot allow the driver to use autonomous features when the minimum threshold is not achieved.

4.2 Principle no. 2: Every Human is an Individual Entity

Every human has his own specific individuality, which is projected also in his driving habits and behavior. The driver can be defined and identified by a specific pattern of his driving skills and habits. These patterns have to be analyzed by the vehicle and implemented as parameters in vehicle’s behavioral dynamic model. If the driver’s skills are below the minimum threshold of optimal vehicle control, the vehicle shall act as a teacher, not as the final corrector of the situation – current ADAS and active safety systems behave as a very bad driver, as they act too late, too early or in irrelevant situations [17]. Therefore, every autonomous system has to adapt itself to an individual driver.

4.3 Principle no. 3: Keep Human Independent

Human's development from child to adult represents similar road to individual's independence, as is present in the whole history of mankind. The independence can be understood as a control over one's own life. Road vehicles represent a technology to enlarge the space of our independence – they allow us to travel to longer distances by the routes we independently choose, at speeds we choose, at level of safety we choose with possibility to modify or cancel the route at any time without any time consuming communication with human or computer based driver. Many people, especially the young and healthy ones, cannot imagine what kind of independence they might loose with self-driving vehicles. Therefore, it is irrelevant to ask them and apply the modern "wisdom of crowd" data acquisition method, which is fancy, but inappropriate.

Thus, the human needs at least to feel the virtue of independence. Therefore, a third entity approach can provide at least the feeling of independence, while raising the level of safety.

4.4 Principle no. 4: Keep Driver in the Loop

Driving is highly multi-tasking activity and brain cannot focus only one or on none – there's no "zero" state of the brain. Certain level of distraction is needed to keep driver active in a safe driving loop. Current ADAS systems are minimizing the level of distraction inputs emerging from the driving process, therefore the driver searches for different kinds of entertainment. It's evident, that in case of emergency the driver is not able to react in time and correctly. Therefore, if we remove one driver's activity by some ADAS system, we have to replace it with another activity, which will be associated with the driving process [22]. Driver adapted vehicle can provide specific distractive actions that can keep driver's situation awareness at acceptable level and minimize his tendency to search for other distractive activities.

4.5 Principle no. 5: Trust is Evolved Bi-Directionally

Still, the human-technology unit will encounter situations, where human would like to transfer the responsibility for driving to the vehicle. Similarly, as vehicle learns behavioral patterns of his driver, the driver acquires behavioral patterns of vehicle. This is highly positive process in terms of gaining trust of technology. While vehicle has to be adapted to the driver skills, the driver shall adopt the knowledge of vehicle skills. Hence, a human-technology interface has to provide clear and easily acceptable information to human about the vehicle's capabilities at any time – we cannot make a test driver from any driver, like i.e. Tesla currently does. Furthermore, such interface cannot be distractive and shall engage more human senses, than only sight or hearing.

4.6 Principle no. 6: Gain Feedback from Driver

Sensors, which are detecting the state of vehicle's environment – open road transportation system – have to deal with a specific problem: they can never know for sure, if the signal they are receiving corresponds to the reality. They can encounter similar experience as human – hallucinations. Unlike sensors detecting the state of the closed system of vehicle (like ABS or ESC sensors), one cannot define any algorithmic state in which one would know exact information (or at least an assumption) the sensing systems should return. Thus, the external detection systems rely only on stochastic expectations of the system behavior. They don't get any real feedback, except that they did not crash into anything. However, there is always quite a reliable sensor in the vehicle, which is relatively selfish on sharing the information he acquires – the human driver or passenger. Therefore, we fuse the information from the sensors of exterior with the sensors of human to obtain a valuable feedback for the reliability of all the sensors.

5 Conclusion

Today's society can be called "technology driven" – we almost worship technology like something spiritual that can solve all the problems of the human race. This happens also with the road accidents and automated transportation. Hence, we, technologists, have to always rectify this blind adoration and educate others about the real limitations of technology, even though it might limit the money income. But it is undeniably a better approach to the evolution of human-technology cooperative units.

We can also apply the mentioned third entity approach on our route to safer and more efficient road transportation. This in global does not have to mean "automated", even though some sci-fi literature is tempting with such ideas. On the other hand, we are being educated with unfortunately more realistic vision of centrally controlled future human existence in i.e. Aldous Huxley's Brave New World or George Orwell's 1984. A key contribution of a new approach to safer transportation presented in the article develops several global principles, which should be implemented in human-vehicle symbiotic units to create a more efficient third entity. Finally, application of the principles in new technology designs aids in retaining one of humans' most important values – independence.

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