A Unified Approach for Active Safety in Automotive Cyber Physical Systems

Annalisa Scacchioli

***Abstract*— This position paper discusses limitations of the current automotive transportation active safety systems. A system approach can address all levels (the driver, the vehicle, and the traffic) of interconnection between machine, computer and human by leading to incorporating interactions and heterogeneity of different physical layers in a unified framework. The resulting analytical and computational infrastructure, with applications in crash avoidance and traffic flow management, is then discussed.**

I. Position

The problem of safety remains one of the most serious challenges in automotive transportation at a global scale. It involves the public health, the economy and the environment. Car accidents result in more than 40,000 deaths and 2,780,000 injuries each year in the US. Its cost to the US economy is estimated to be as high as $300 billion a year. Lost productivity and wasted motor fuel is estimated to be $80 billion a year. By the year 2020 road traffic accidents will be the 3rd leading cause of death due to injury, based on projections by The World Health Organization.

What can we do to solve these problems? What contributions can research and technological innovation offer to automotive safety problems? Why are these problems still so challenging, despite the recent and current technological innovations?

Constructing new roads or improving existing facilities is expensive and leads to several environmental, political and social issues. Alternatively, improving single vehicle safety technology and using telecommunication, for computing, processing and sharing on-line traffic information is a promising direction. However, this direction will not be efficient if a compartmentalized research approach is adopted. A unified system approach, that directly addresses the interaction between machine, computer, and human at all levels, is a critical enabler for the further advancement of automotive and transportation technology in terms of collision avoidance and traffic flow management.

These interactions (driver/vehicle and vehicle/traffic) are especially crucial in non-typical traffic conditions, such as close to an accident site, where driver behavior may change significantly from its normal state. Building safe vehicles that can respond quickly and robustly to unforeseen circumstances without accounting for the current driver's condition and skills, is not enough. It is similar to using traditional traffic flow models that do not account for the variability in individual driver behavior in traffic.

Contact: Annalisa Scacchioli, Visiting Assistant Professor, Department of Mechanical Engineering, New York University Polytechnic, New York City 11201, USA. E-mail: annalisa@poly.edu

A deep understanding of traffic dynamics, models describing interaction of driver intent and vehicle-to-vehicle interactions, new multi-scale mathematical approach to model traffic flow that captures the inherent heterogeneity (stemming from the diverse typology of vehicles, active safety systems, and drivers) are essential. Capturing these vehicle/traffic dynamics will allow quantifying the impact of a single vehicles/driver in unusual traffic patterns. This will lead to new methods for controlling traffic flow via vehicle-to-vehicle and vehicle-to-infrastructure technologies. A summary of our position is reported in Figure 1.

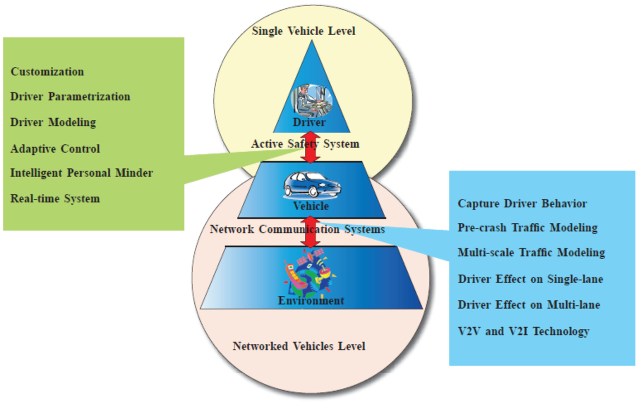

Fig. 1. *Pyramid of safe automotive cyber-physical systems:* at the base of this pyramid is the environment, including infrastructure and other vehicles. The bottom environment-level interacts with the (middle) vehicle-level through a network communication system (NCS). At the top level is the driver, who interacts with the vehicle via (semi)autonomous active safety control system (ASC) technologies.

II. Limitations of the current Automotive CPSs

A. *Driver-Vehicle Level*

The recent advances of embedded control software, of machine learning and intelligent decision making, the new MEMS sensor technology and the rapid progress in computers and digital signal processing have enhanced active safety control systems. Several automotive manufacturers are planning to completely eliminate accidents by 2020, by incorporating situational awareness and new control systems with learning and decision capabilities. However, we believe that only by accounting for the diversity of human driver behavior(s) and the condition of individual drivers in traffic, can these goals be met. In fact, current active safety systems are not customized to the individual driver. This robust approach restricts the maneuvers the vehicle is capable of achieving. Furthermore, the flow of information is unidirectional, from the driver to the vehicle. A more alert system would estimate short-term and long-term behavior of the driver and his habits and it would be proactive by assisting the driver. Once the effect of individual, diverse drivers and vehicles on the overall traffic flow is clearly understood, one can use this information to synthesize suitable modes of operation of the onboard active control system at the level of individual vehicles. An active safety control system may operate quite differently to avoid an impeding accident in traffic congestion (where lane-changing evasive maneuvers are not allowed) than in light traffic (where a lane change maneuver would be a better alternative than, for example, solely straight line braking). This vision requires a level of understanding of the interaction vehicle/traffic models that currently is not available.

B. Vehicle-Traffic Level

New technologies allow vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication enabling exchange of information and (re)action negotiation between multiple vehicles or between vehicles and the environment. However, how to best utilize the interaction/integration of this technology with active safety systems, is still not clear. Autonomous and semi-autonomous active safety systems modify the individual vehicle behavior and thus affect the traffic pattern. A malfunction of an active safety system in a single vehicle can effect the overall traffic flow. Conversely, one may want to utilize vehicle automation to disseminate information and V2V/V2I technology to impose specific, desirable global traffic patterns.

III. RESEARCH CHALLENGES

A. Capturing Driver's State and Skills

Customization of active safety systems on board passenger vehicles requires capturing the driver's short-term and long-term behavior in traffic namely, his skills as well as his current cognitive state. How can we best account for diverse driving skills, behavior and health condition when designing customized active safety systems? How can we estimate the state and skills of drivers? Which level of sophistication does one need for the driver model? How can the driver's response to external stimuli be parameterize?

B. Enhancing Active Safety Systems Performances

Current active safety control systems are designed to make them insensitive to the individual driver. However, a more accurate knowledge of the plant (driver-vehicle system) can lead to improve the vehicle's safety and performance. How can we best adjust the active safety system operation according to the long-term and the short-term driver state? Using adaptive control tools, new active safety controllers that can adapt to individual driver long-term habits (aggressive/defensive driver, expert/novice driver, etc.) and/or short-term behavior (alert/sleepy driver, etc.) can be designed. Driver models at various level of sophistication need to be developed.

C. Improving Traffic Models

Standard traffic flow models deal with homogeneous traffic. The driver is considered as an automaton: he is not influenced by the environment, health, psychology and experience. Similarly, weather conditions, road maintenance and the presence of incident sites are not considered. A first step in improving traffic models is eliminating these simplifications. How can the complexity and the heterogeneity of the traffic dynamics be described? The heterogeneity, due to several types of vehicles (with different technological characteristics), with different driver typology (old, young, expert, beginner, prudent, distracted, etc.), on various roads (small, highway, multi-lanes, etc.), is the key of an accurate representation of the traffic flow. How does driver/vehicle heterogeneity affect current traffic models? How do these models change in case of "abnormal" traffic conditions (say, in the vicinity of accidents)? New multi-scale modeling approaches to capture macroscopic (traffic) behavior starting from microscopic (vehicle) models are needed.

D. Propagation of Driver Behavior in Traffic

What is the effect of a small number of erratic/distracted drivers in traffic? Is it possible for a single vehicle to generate shock waves that propagate upstream and downstream disrupting the flow? Is it possible to control traffic with only a few dedicated vehicles? How can individual vehicle(s) control/impose desirable traffic patterns? How can new technology prevent catastrophic (eg, multiple vehicle pile-up) accidents? How can single-vehicle active safety, drive-by-wire systems interface in a safe and consistent manner with the envisioned V2V/V2I infrastructure? Simplified single-lane and multi-lane problems need to be addressed. Lane changes have been recently shown to be the cause for traffic instabilities. Unraveling disruptive driving patterns can lead to active safety systems that can be automatically disengaged by the vehicle itself. Similarly, one can envision in the future cases where these patterns can be utilized, in extreme situations, by law enforcement vehicles to control the overall traffic.

IV. PROMISING INNOVATIONS

Current automobiles are "computers on wheels" with a plethora of electronic components controlling emissions, powertrain operation and dynamic handling. Future vehicles will incorporate more sophisticated, proactive control systems able to interpret driver's intent and to warn the driver of a dangerous situation. The ultimate goal will be to have complete autonomous driving. Together with the interactions with their respective environments, driver/vehicle and vehicle/traffic interactions constitute each, prototypical cyber-physical systems, providing a grand challenge in research direction. Theory for designing adaptable active safety control systems, and suitable models to capture the multi-scale, heterogeneous vehicle/traffic interactions need to be developed.

A unified, integrated, adaptive and multi-scale approach for automotive cyber physical systems will directly impact society, economy and the environment by reducing car accidents, due to incorrect driver actions, and by reducing traffic congestion.

V. ACKNOWLEDGMENT

The author would like to thank Professors P. Tsiotras, E. Feron and J. Laval at Georgia Institute of Technology and Dr. J. Lu at Ford Motor Company for all helpful discussions on this research area during her collaboration.

VI. BIOGRAPHY

Annalisa Scacchioli received the *Laurea* degree in Electrical Engineering from the University of L'Aquila, Italy, in July 2000, and the Ph.D. in Electrical Engineering and Computer Sciences from the same university in May 2005. She was a Postdoctoral Researcher at The Ohio State University Center for Automotive Research (2005-2006), at the University of California Berkeley Civil and Environmental Engineering (2007-2008) and at the Georgia Institute of Technology *Daniel Guggenheim* School Aerospace Engineering (2008-2010). She worked as Visiting Researcher at Ford Motor Company Research and Innovation Center, Dearborn, Michigan, between 2008 and 2010. She has been a Visiting Assistant Professor at New York University Polytechnic Mechanical Engineering since October 2010. Her research interests are in the broad area of multidisciplinary physics-mathematical modeling, feedback, control and diagnostics applied to complex-engineered systems, with focus on automotive and transportation systems for improving their impact in terms of energy, safety and environment. Specific topics include vehicle active safety systems, advanced and alternative power-train. She is also interested in the analysis and control of structural dynamics, with application to earthquake engineering. Her research has been funded by, among others, General Motors Corporation, Ford Motor Company and the National Science Foundation. She is member of the Technical Committee on Automotive Control of the International Federation of Automatic Control (IFAC), of the Institute of Electrical and Electronics Engineers (IEEE) and of the Automotive and Transportation Systems of the American Society of Mechanical Engineers (ASME).