Cyber-Physical Transportation Systems: From Stalled to Suddenly Lurching Forward

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As a fully connected world emerges around us mobile and mobility-centered applications offer rich opportunities for research, development and entrepreneurship that will transform the world through seamless connectivity, massively distributed participatory sensing and feedback mechanisms, and automated and semi-automated controls that fully incorporate complex social behavior. These CPS-based mobility systems will exist in a data-rich environment in a large societal system involving millions of moving passengers, vehicles, goods, and applications that interact among themselves, communicate with or without human involvement, and possibly even negotiate transactions cooperatively or competitively to consume transportation "supply"[1].

Cyber-Physical Transportation Systems (CPTS) involve automotive and communications technologies as well as technology enabled applications aimed at improving safety and increasing efficiency. In this short position paper, the focus is mainly on the communications technologies and the applications they enable, rather on the automotive technologies. That said, it is important to point out that a pressing issue indeed is the training and development of computer scientists who are understand automotive engineering and in developing automotive engineers with formal training in computer science and large scale data analysis. As researchers and educators, we should keep this pressing need in mind as we develop curriculum and research teams.

Advances in CPTS in the past few years have to a large extent been focused on ad-hoc vehicular networks (VANETs) and that work has primarily been concerned with the communications issues and not the applications themselves. According to googlescholar, more than eight thousand papers have been published on VANETs in the last 15 years (most of these in the last 10) -- the vast majority concerned with routing protocols and data dissemination architectures. Some, in the last decade, have focused on security and privacy issues, but not nearly as many as are needed to ensure that those challenges are adequately addressed so that large scale implementations can be launched.

Missing, is a body of work detailing exactly how transportation systems will be made more efficient, as well as precisely which communications protocols and communications system designs should be applied under specific conditions and in specified networks.

This lack of a solid foundation leading to implementation is not for lack of interest. In the Europe, Asia and the US, government agencies and technology companies alike have been investing in programs

[1] Many of these "supply trading" ideas and related mechanisms were originally proposed in 2011 and 2012 by Professor Jay Jayakrishnan at UC Irvine.

similar to the US DOT Research and Innovative Technology Program (RITA)'s Connected Vehicles Program. However, like many earlier ITS efforts, the promise connected vehicles has been very slow to materialize.

Interestingly, while in early ITS efforts it was often the case that technologies developed more slowly than clear visions of applications (This was largely the case with dynamic traffic assignment in which the framework was clearly articulated in the 1990s but the mathematical models, computing capabilities and data for O-D estimation and even accurate traffic monitoring has been slow to reach fruition.) with respect to VANETs and connected vehicles the communications capabilities appear to be fairly well developed but the applications are less well defined. And, liability and security issues are sure to delay large scale implementations even if these applications are better articulated in the coming years. However, the fairly sudden emergence of the ***possibility*** of autonomous vehicles should push implementations forward. While it seems unlikely that autonomous vehicles will be commonplace in the near future, preparing for a time when they will be will requires that technology providers, public agencies and engineers of every stripe work together.

One of the primary reasons that CPTS (ITS) systems have failed to match the expectations of researchers, planners and the public has been a reliance by public agencies on old technologies such as inductance loop detectors and a reluctance to adopt newer, less expensive and possibly more robust technologies such as wireless sensors that do not require lengthy and dangerous road closures for installation. Further, methods of travel time estimates using probe vehicles that were first introduced twenty years ago have never proved as successful as predicted, and even now researchers and public agencies are developing newer ways to collect and analyze probe data using Bluetooth, in-vehicle navigation systems and mobile phone technologies or simply extending traditional dedicated GPS probe studies with larger scale on-going studies using, for example, both taxi's and commercial vehicles in congested urban centers.

Transportation engineers have developed increasingly more sophisticated and more complex models of transportation systems management over the last thirty years. These models have been enabled by advances in mathematical modeling techniques, availability of data, and of course ever increasing computing capabilities. Despite these vast improvements in computing power, in many application areas the complexity of the models has so far out-paced those improvements – delaying the development of implementable models which would lead to improved environmental sustainability, economic competitiveness and resilience, and in many cases, safety and security of transportation systems. The mathematical modeling tools required to calculate, for example, real-time tolls on even moderately sized transportation networks, are notoriously slow, even with today's computing platforms. Methods to employ very large scale distributed and parallel computing may in fact finally lead to breakthroughs in implementation of these models, but even then barriers with respect to public and public agency acceptance of such systems could prove impenetrable.

The brightest immediate impacts of CPTS systems will be improved safety of newer vehicles which will come directly from automobile manufacturers (many of whom are partnering to study technologies with academic researchers). And, improved safety for these early adopters will improve safety for all drivers. Eventually traffic monitoring based on a number of different technologies will provide accurate real-time traffic information. And, parallel and distributed computing in cluster and cloud configurations, possibly even using the computing capabilities of "vehicles as a cloud" will likely lead to advances in the solution of large scale network optimization problems of various kinds (real-time or robust tolling, ramp metering, intersection control etc.).

And while the large scale adoption of technologies and technology centered transportation systems management has developed at a much slower pace than would have been predicted twenty years ago, new, futuristic ideas are being proposed that would allow users to negotiate in real time for spots in transit queues or even places in traffic queues. An influx of entrepreneurial ideas and applications into the transportation industries, coupled with ubiquitous mobile computing devices, may prove a more reliable path to adoption than public agencies could possibly provide. If security concerns and liability issues can be addressed head on by engineers and planner simultaneously with the development of the emerging technology systems, then there are reasons to be very optimistic about the long term impact of these systems.