Including the social component in smart transportation systems

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***Abstract*—Designing the next generation of transportation systems to support the societal need for human accessibility is a grand challenge problem. Despite important work within the *intelligent transportation systems* (ITS) and *cyber physical systems* (CPS) communities, new ideas are needed to address the critical issues facing our transportation systems today and in the future. In this position paper, we argue that insufficient progress has been made to fully embrace the inherently social components of transportation systems. We claim that by explicitly incorporating people, transportation *cyber social physical systems* (CSPS) will offer new opportunities for efficient sensing and control of transportation systems, while also introducing challenges from a modeling perspective.**

I. Need for smart transportation systems

A. Context

Transportation networks are the lifelines of modern society. Advances in transportation have facilitated the growth of cities and cultures while dramatically improving standards of living all around the world. They have evolved over time as new mobility and accessibility needs have arisen and new technologies have become available.

Today, the demands for freight movement and human mobility have never been greater. Projections suggest that over the next 40 years, the world will become home to over nine billion people, and that global mobility demands will triple worldwide [1]. In emerging economies, global mobility is projected to increase by a factor of five [1]. As a result, petroleum consumption by the transportation sector is set to double and CO_2 emissions are projected to almost triple [1].

With this in mind, the *Transportation Research Board of the National Academies* [4] has identified a set of grand challenge problems in transportation in the United States. Today's transportation systems are congested, unreliable, and lack resilience to natural and manmade disasters. Safe movement of goods and people remains a top priority of every transportation agency, however, insufficient progress has been made. Moreover, the environmental performance of our transportation systems has significant room for improvement, and our dependency on nonrenewable energy sources is unsustainable. To meet the rising demands placed on our transportation systems in the face of its ever increasing complexity, cyber physical systems represent one of the most promising technological innovations primed to transform the transportation landscape.

Indeed, it has never been more important to meet these grand challenges both for the present, and also in the future. One of the hardest problems when designing any civil infrastructure system, including transportation systems, is the enormous expense of physical infrastructure investments, and also the long expected lifespans of the projects. While cyber investments can be rapidly prototyped, updated, and replaced, civil infrastructure investments are designed to last for generations. While we are building 2060's infrastructure today, we have very limited capabilities to predict the future needs on this infrastructure. In the face of highly uncertain futures, transportation cyber physical systems offer opportunities to make our infrastructure modular, flexible, and resilient.

In the last few years, noteworthy progress has been made in transportation CPS. Automobiles are increasingly autonomous [9], [5], [2], and GPS data streams from crowd sourced phones and navigation devices are now mainstream [7]. On–demand ride sharing services such as Lyft and Uber are disrupting taxi markets, and bike sharing systems are optimized to support recorded travel demands. Overall, CPS thinking is providing us tools to transform transportation systems from passive and rigid, to active, intelligent and adaptable. These developments are ultimately leading to systems that can be used to sense, collaborate and control the transportation systems in real–time with the end goal of making the system safer, more reliable, more robust, more cost–efficient, and more environmentally friendly.

B. Position

While cyber physical systems technologies and innovations are important to the future of transportation systems, insufficient progress has been made to integrate a fundamental aspect – people – into the system. Because people are an essential component of any transportation system (either demanding transportation directly, or by demanding goods resulting in freight traffic), it is appropriate to expand the scope of our CPS tools to explicitly account for their interaction with the system. Unlike many CPS systems where it is possible to abstract away the behavior of people, in transportation systems, directly incorporating people into the system offers an opportunity for new sensing and control paradigms which are not possible when only considering cyber and physical aspects of the system. On the other hand, integrating people into the system brings a new set of research challenges that must be addressed in order to design principled transportation *cyber social physical systems* (CSPS) because people are active agents that directly affect its performance. While most work focuses on controlling the physical components of CPS, the social component is equally important in ensuring that the grand challenges of transportation are met holistically.

II. Research opportunities

We focus our research challenges for CSPS on problems in actuating, sensing, and modeling transportation CSPS, discussed next.

A. Closing the loop with people

Many conventional *intelligent transportation systems* (ITS) and CPS applications have focused attention on directly controlling the physical infrastructure to improve efficiency and safety. For example, traffic signal control has been an active area of research for more than 50 years. Ramp metering and variable speed limit control offer additional mechanisms to reduce traffic congestion on urban highways. Within the vehicle, a concerted effort has been made to completely automate driving, with potential for incredible improvements in safety and efficiency.

Improved cyber physical systems will undoubtedly improve transportation systems with relatively low cost compared to pure physical infrastructure investments. However, many of these technologies have not yet reached the market. In the case of traffic control technologies, this is partly due to the fact these systems are still relatively expensive to install and maintain. Despite large volumes of GPS data available from consumer devices, there is still insufficient data to optimize traffic signals based on this information alone. Dedicated sensors in the road remain costly to deploy network wide, and as a result, only about half of the signalized intersections in the US are under centralized or closed loop control [12].

On the other hand, in the last few years, a new control device has become ubiquitous with commuters. With more than 150 million smartphones in the US, most with routing applications included on the device, companies such as Google, Here, TomTom, etc. now have the opportunity to control traffic with information. If the number of drivers using navigation services continues to increase, there is a vast opportunity to manage traffic through load balancing, which might provide significant improvements at relatively low cost for physical control infrastructure.

The possibility to "control" traffic by influencing driver behavior has been recognized by transportation economists for a number of years, mostly through work in mechanism design and pricing. Unlike traditional ITS strategies or autonomous vehicle research that increase the capacity of our existing systems, controlling transportation systems through the behavior of people offers an opportunity to also influence the demand for transportation. For example, the Instant [8] project explored providing incentives to drivers who change their commute time to avoid the peak instead of charging users during congestion.

Combining both types of control (physical infrastructure and people's behavior) offers several challenges. First, the objectives of all commercial navigation companies are not necessarily aligned with the traffic management authorities. In the best scenario, the lack of coordination between the controllers will be inefficient, and in the worst case, they may destabilize each other. Another challenge is that unlike a dedicated actuator, people may either misinterpret information, or they may exercise their free will and completely ignore it. Inspired by the recent work [13], we have recently started exploring the possibility of nudging users to drive systems to a desirable equilibrium [11].

B. Social sensing

Smartphone growth has also transformed how information is collected on our transportation infrastructure. Companies like AirSage use network cell tower data to track cell phone users at city scales, offering agencies the opportunity to purchase cheap, aggregated origin–destination information, which is a critical input for transportation demand models. GPS data from the devices is used by most traffic information providers such as Google, Here, and Inrix, while [10] has explored the ability of social media to improve demand models during events.

Social sensing data can be partitioned into two types – participatory and passive. Participatory sensing requires active participation on behalf of a person to contribute data. Examples include commuters reporting an incident, posting information on Twitter, etc. Passive social sensing uses information without the user being actively engaged in its collection or transmission.

In participatory sensing [3] systems, two main challenges are incentivizing participation, and validating the accuracy of the information. Unlike physical sensors, in these systems, it can be difficult to control when and where the information is collected. Moreover, it can also be extremely hard to recruit participants to regularly contribute information. When participatory information is collected through a smartphone application, it can be especially quite difficult to even make users aware of the application, let alone download and use it. One promising research direction is to manage and influence participation through gaming, mechanism design, and social networking. This was effectively used by Waze to encourage drivers to regularly contribute GPS data needed to build navigable maps.

The second challenge for participatory sensing systems is managing the quality and authenticity of the contributed information. In some cases, sharing accurate information may actually be against the contributor's benefit. For example, allowing a traffic monitoring company to observe a secret shortcut may enable other commuters to reroute, congesting the shortcut. It is not unreasonable to believe users will game participatory systems for their own benefit.

Compared to dedicated sensing systems which may be designed, deployed, and maintained by the same agency using the data, it may be difficult to track the data provenance in participatory systems. Because the data is occasionally resold to data aggregators (i.e. GPS data from small collectors is sold to traffic monitoring firms), there are incentives for the seller to generate fraudulent data if the data is priced by volume. Because the GPS signal is prone to jamming and spoofing, reliance on unauthenticated participatory data to control the transportation system allows for the possibility of attacks through the shared data.

For passive sensing, maintaining the privacy of users is an ongoing issue. Because users do not actively participate in the collection of their data, it is easier for the user to be ignorant of the data being collected. For both passive and participatory social sensing data, it is especially hard for users to fully understand what can be inferred from the data they are sharing. While privacy in transportation data has been a topic of research with significant progress over the last few years, many approaches to location based privacy are application specific. As models of human mobility improve, even less data will be needed to perform potentially privacy invasive inference. Techniques to inform and protect users are needed.

C. Models of cyber social physical systems

Modeling CSPS systems accurately can prove to be challenging due to the uncertainty in exogenous factors. It is well known that demand patterns on transportation networks change over time due to a number of political, economic, and cultural reasons, and predicting these changes is not always possible with a high degree of certainty. Therefore, understanding human behavior and building complete models for human mobility is difficult, but nonetheless, it is very important for the development of future CSPS.

While data from social sensing is transforming how we monitor infrastructure, it is also allowing us to see how users move throughout transportation systems over increasingly long temporal and spatial scales. Historically, it has been very expensive to build and calibrate detailed models of human–infrastructure interactions because the data has been cost prohibitive to collect at large scales, and transportation agencies are still structured around the various vehicular modes.

More recently however, it has become possible to track users across modes and across cities using social sensing techniques and thus, new models can be developed to better predict human mobility. However, since these datasets are only beginning to become available, our ability to use this information to influence the development of improved mobility models is also just beginning [6].

Models for how humans respond to information to actuate transportation systems, or how humans may game incentives for social sensing systems are also needed.

III. Conclusions

Transportation systems are arguably one of the largest and most complex CSPS that exist in the world today, with local and global impact. Thus far, most work to develop smart transportation systems has focused on the relationship between the cyber and physical components. However, the social component influences the performance of the system at all levels and provides new opportunities for efficient monitoring and management. Using people to sense and influence the system has a number of advantages. It also has several associated issues that must be addressed in order to meet the grand challenges for transportation. Therefore, in order to create safe, resilient, and reliable transportation systems of the future, we must also comprehensively study and understand the social component. Linking research efforts of social scientists, transportation domain experts, and the CSPS community should be actively pursued.

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