

## **Nash-Stackelberg Games in Transportation Networks: Leveraging the Power of Smartphones for Traffic Monitoring and Management**

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Transportation is one of the first sectors to directly benefit from the information, knowledge and management opportunities created by the convergence of communication, computation and sensing, the emergence of web 2.0 and of the mobile internet. Numerous companies have been created that provide traffic information services both to traffic managers, to companies and to individuals, although not yet stable, the traffic information market is alive, well and growing. However, more change is coming, with the development of the 'social' internet and its potential exploitation to enhance transportation system performance. The talk will summarize the traffic information 'revolution' and will discuss the implications of this revolution for traffic management.

The first part of the talk will describe how the problem of real-time estimation of mobility for traffic information purposes has been addressed. The recent explosion of smartphones with internet connectivity, GPS and accelerometers onto the consumer market has led to the development of many products by companies including Google, Apple, Waze, INRIX and Nokia. These services are routinely used by travelers to navigate 'their' transportation system better. These services are underpinned by a software architecture that needs to enable the generation of live traffic information while not threatening an individual's expectations of privacy. The talk will describe the different aspects of traffic information generation, in the context of the *Mobile Millennium* system, which was one of the first demonstrations that traffic data could be crowdsourced from user's smartphones, launched by UC Berkeley. In addition, the talk will describe how, from 2008, when the project was launched as *Mobile Century*, the integration of mobile measurements obtained from smartphones into distributed parameter models of traffic (including Hamilton-Jacobi equations, first order conservation laws and systems of conservation laws) was achieved. Techniques discussed will include variational data assimilation. Other techniques developed will be briefly presented as well, relying on sequential data assimilation, in particular ensemble Kalman filtering. An important result of this work was the migration of this technology to industry, including the launch of a commercial product by Nokia and NAVTEQ in 2009.

The acquisition of information is only the first part of the solution to the traffic management challenge. In the second part of the talk, the problem of understanding how this information can be used *effectively to improve* transport system performance will be discussed. Providing information to all travelers about congestion and suggesting, for example, alternative routes to improve their travel times, might, for example, simply create more congestion on the alternative routes without improving the performance of the system as a whole. One solution to this is to use incentives to 'nudge' the behavior of a specific portion of the users of the network (so called "compliant" users), so that traffic can be managed more efficiently and effectively. The problem thus becomes one of identifying the 'compliant' portion of the traveling population and the incentives that can be used reliably to elicit the required changes in behavior to improve system performance as close as possible to social optimum, given that the rest of the users (so called 'no compliant') will continue to act selfishly. This problem can be posed using the theoretical framework of Nash-Stackelberg games. In this framework, Stackelberg 'leaders' are individuals who are willing to be 'nudged' (for example, given a financial reward, some motorists will decide to take a longer route). Nash 'followers' do not respond to incentives, resulting in a less efficient flow allocation (sometimes called user equilibrium in the transportation literature).

The talk will present the application of Nash-Stackelberg thinking to traffic management. The talk will address the question of whether an optimal route assignment (optimal Stackelberg strategy) that minimizes the total cost can be computed and will describe a simple, optimal and robust (in the sense that some perturbations are still optimal) strategy, the Non-Compliant First (NCF) strategy, that can be computed in polynomial time. A new project conducted under the California Department of Transportation, called *Connected Corridors*, to be officially launched

in 2015 in Los Angeles, for which UC Berkeley will serve as the prime academic institution will also be used to illustrate these new paradigms in traffic management.