Preface

I first started thinking systematically about the evolution of transportation networks in the early 1990s when I was a transportation planner at the Montgomery County (Maryland) Planning Department working with the group developing a regional travel demand forecasting model. My job involved developing a new generation of travel demand forecasting models, predicting the number of trips coming into and out of each area, matching trip origins and destinations, determining the mode (car, transit, walking) they would use, and assigning the route on the network they would follow. These models originated in the 1950s in Chicago, and by the early 1990s had been deployed in all large US metropolitan areas. The model I worked on, Travel/2 was distinct in several ways, mainly ensuring an equilibrium between supply and demand (the travel times used to generate travel demand, and the travel times resulting from that demand). However, these models all took as a given the underlying transportation network. If we could forecast traffic growth, and others could forecast land use, why couldn't we forecast the growth of networks? This idea was one of the drivers for me to return to graduate school for a Ph.D.

As I was preparing to return to graduate school in 1994, I remember a conversation I had with my former college roommate Robert Forsythe, who was living and working in nearby Virginia. I proposed that the network itself (not merely the travel times on the network due to the demand, but the physical capacity of the network) responds in some fashion to demand. Like firms, links (segments of the network) with more demand will grow. In the current political arrangement, the decision about which links to expand appears to be made by a central authority. However, it does not have to be that way, and maybe the authority is just responding to local conditions.

I also was thinking about road pricing. It is well understood by transportation economists, but almost no one else, that the only real solution to congestion is pricing: electronically (and wirelessly) collecting tolls from cars, thereby giving travelers the proper signal about the impact of their trip on other travelers. Suppose that instead of a state monopoly on roads, they were privately owned and raised revenue through tolls. What would happen? Would society be better or worse off?

I took those ideas with me to graduate school in Civil Engineering at the University of California at Berkeley, and when I was putting together my dissertation prospectus, I proposed to study *A Model of Road Pricing with Autonomous Links*. Networks would be comprised of independent links, each deciding on a pricing strategy and an investment strategy, given all the others were doing so as well. Each link would charge tolls, and collect revenue proportional to the tolls. Each link would choose a pricing strategy to maximize its profits, conditioned on other links doing the same. I prepared some analytical models, and proposed constructing a simulation framework to look at more complicated cases that could not be analyzed by hand. This proposal did not consider capacity or investment, which it still took as given, though the intent was to relax that assumption.

I proposed this to my committee at my Preliminary Oral Examination in 1996, and in short, though I passed, the prospectus was given a major haircut. The oral examination committee, in its infinite wisdom, thought the topic was too ambitious. One of the members of my dissertation committee said "A monkey can do simulations", which may be true, but a monkey cannot formulate simulations, and I believe simulation is an important tool for understanding how complex networks work.

With the guidance of my advisor Mark Hansen, my dissertation was reshaped into what it became *On Whom the Toll Falls*, which examined historically and analytically the question of whether jurisdictions choose taxes or tolls (which depends on the trade-off between raising revenue from non-residents (favoring tolls) and transaction costs (favoring taxes). The title indicates its consideration of equity and incidence, and the comparison between tax and toll financing regimes. Taxes are cheaper to collect than tolls, but tolls, particularly boundary tolls, can raise money from non-residents much more effectively. This was ultimately published as several papers and a revised version was rolled into the book *Financing Transportation Networks* (Levinson, 2002). Chapter 13 of this extends that dissertation's research by examining which level of government manages particular roads depending on the transportation technology (the speed of travel) and thus the amount of cross-border flows.

I landed at the University of Minnesota in 1999, and picking up the idea that had been set aside, started writing proposals to examine the question of network evolution. In my second year there, I was able to obtain funding to examine the "network growth problem" from the Humphrey Institute's *Sustainable Transportation Applied Research (STAR) Initiative*. The STAR program funded a student, Bhanu Yerra, to develop the models in his Master's Thesis, which became several papers: Yerra and Levinson (2005); Levinson and Yerra (2006). The core essence of that research is replicated in Chapter 8, which lays the groundwork for further simulations.

Another project, funded by the Minnesota Department of Transportation, examining the Twin Cities networks, *If You Build It, Will They Come*, supported the Master's Theses of two other students: Ramachandra Karamalaputi and Pavithra Parthasarathi, and resulted in several more papers: Levinson and Karamalaputi (2003*a*,*b*); Parthasarathi et al. (2003).

The results from these papers were rolled into a proposal to the National Science Foundation: *CAREER: The Evolution of Transportation Networks: Empirical Re-*

search and Agent-Based Models, which was funded (on its third submission) starting in 2003, and supported Feng Xie's dissertation and much of the research presented in this volume.

While suffering a fever at the Regional Science conference in San Juan Puerto Rico in November 2002, I detailed the ideas for the set of papers that became my research agenda for the remainder of the decade. The models outlined then (SOUND, SONIC, SIGNAL) extended the SONG framework described in Bhanu Yerra's thesis, which was being completed at the time.

Other follow-up research included the MnDOT grant *Beyond Business As Usual: Ensuring the Network We Want is the Network We Get*, which funded the research in Chapter 15 (conducted with Norah Montes de Oca).

Finally, I received support from the UK's Economic and Social Research Council to study *The Co-Evolution of Transport Networks and Land Use*, which resulted in Chapters 7, 10, and 12 (the last with Shanjiang Zhu), as well as other related papers (Levinson, 2008*a*,*b*).

My co-author, Feng Xie, engaged in the network growth research upon arriving in the United States in 2003. This research was his Master's Thesis, Ph.D. Dissertation, and other related research conducted at the University of Minnesota, for which I was the advisor. Except for Chapter 8, this volume is basically a synthesis of his thesis and dissertation chapters and other pieces of network growth studies we have published in peer-reviewed journals and conference proceedings. Without his excellence and commitment to scholarship, this research would not have been nearly as successful.

Feng Xie's original work added an important empirical dimension to the network growth research. He put a significant amount of efforts in extracting historical data and conducting retrospective examination of network growth in empirical cases (Chapters 4-7, Chapter 4 with Michael Corbett). Findings from these empirical analyses not only provide the critical evidence that network growth follows a logical and predictable path, but also shed important light on the subsequent analysis of governance, accessibility, topology, sequence, and land use / transportation interactions.

While SONG (Chapter 8) can be thought of as proof of concept, demonstrating some techniques for modeling the evolution of the hierarchy of road networks, SOUND and SONIC (Chapters 9 and 10) reproduce the observed topological features or sequence of link deployment. Using SONIC/PF and SIGNAL (Chapters 11 and 12) we explored the co-development of transportation networks and land use in simulation, while closely watching the sensitivity of the resulting collective features of networks / land use gradients on model parameters.

Another important contribution of his work, and the main theme of his dissertation, is to explain how ownership affects network growth. Based on the empirical findings (Chapters 4-6) that ownership is a critical factor of network growth and that different ownership structures (and thus different objective functions) may result in different courses of network growth, Xie constructed game-theoretic models in Chapter 13 that associate governance choice with spatial spillovers and network growth. His dissertation work also evaluated the difference in evolution between networks developed under different ownership structures in a controlled environment (Chapter 14).

Engaging in the application of empirically calibrated network growth models to policy and planning studies, Feng Xie also developed a more realistic and sophisticated representation of network growth. On the demand side, he implemented more realistic traffic assignment procedures (stochastic user equilibrium) in travel demand forecasting (Chapter 12); on the supply side, he modeled the investment and pricing policies of suppliers at different levels, considering the benefit, cost, budget, prioritization, variable tolls, inter-jurisdictional collaboration, stated vs. revealed investment rules (Chapters 14 and 15, the latter with Norah Montes de Oca), etc. In addition, it is his original work that used accessibility as an organizing concept to model supply-demand interaction in a holistic model framework of network growth. This economic framework for network growth centered on accessibility distinguishes this line of research from the physics-models that describe how networks might grow without explaining why.

Other students in our Networks, Economics, and Urban Systems (Nexus) research group working on related network growth projects not presented above include Lei Zhang, Wei Chen, and Wenling Chen. The alumni and affiliate researchers of the Nexus group contributed in many ways, and all deserve acknowledgment. Research is in the end a collaborative effort.

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