A Social-network-enabled Green Transportation System

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***Abstract* - We focus on the new models of urban transportation system based on green-energy vehicles. The main goal is to design and demonstrate a prototype of social network enabled transportation system which enables communication between electrical vehicles, monitoring, information gathering, assistant driving and traffic flow control. This service-oriented system targets on significant reduction in energy consumption, pollution impact, traffic congestion, and provides solutions with affordable costs from perspective of both individual travelers and transportation agencies.**

Index Terms – transportation CPS, energy saving, social networks, vehicle sharing.

I. Introduction

In this paper, we propose a social-network approach for future transportation system. This approach combines social networks, public-owned vehicles, mechanism design and pricing incentives, optimal vehicle assignment, and hyper simulators in order to provide a ultra-green transportation system in overall. Here, social networks minimize transportation needs, and in the case transportation is necessary, minimize the energy consumption of transportation by optimal assignment and scheduling of vehicles. Public-owned vehicles can be shared by many people to minimizing Vehicle Miles Traveled (VMT) and the total number of trips. It is more energy-saving compared with private-owned vehicles, more flexible than buses, and less expensive and more efficient than taxis. Mechanism design and pricing Incentives provide the theoretical basis of energy-efficiency by introducing market mechanism to the transportation assignment and scheduling. A hyper simulation enables an accurate scheduling and routing of vehicles, so reducing the overall energy consumption.

This work aims to create a service-oriented transportation system that targets on significant reduction in energy consumption, pollution impact, traffic congestion, and provides solutions with affordable costs from perspective of both individual travelers and transportation agencies. We develop and demonstrate a prototype of social network enabled transportation system as a platform for vehicle users, municipalities, transportation authorities and industries, and internet inventors to develop products, services and monetization.

In this work, a social network-enabled cyber space is virtually built to allow people to interact, generate schedule and make reservation. Scenario-driven traffic operations are simulated to provide a prediction of arrival time with the best routing and enable optimal vehicle assignment, subject to change with dynamic traffic information. In order to optimize traffic system operation, congestion pricing incentive is performed to balance traffic assignment network-widely. Various pricing mechanisms, such as pricing for advanced reservation and real-time request, for sharing and non-sharing, for special requests such as must share with friends, fastest possible, lowest cost, etc., are designed and deployed. Global optimal pricing strategies is identified and executed. These pricing incentives facilitate prevailing traffic control and management applications, such as navigation (routing), lane scheduling, intersection control, accident response, etc. Eventually, traffic condition-based scenario-driven network-wide congestion pricing mechanism is developed to guide real-world traffic system operations.

II. Problems Definition and Related Work

Modern communities are significantly affected by their urban infrastructure systems. Certain systems dominate the landscape and have far-reaching implications for the planet. Transportation networks are an example of such infrastructure. Urban centers around the world function only because of their complex transportation networks. With increasing economic and social activities, travel demand has increased significantly over the past few decades, overloading many existing roadway systems. In the U.S., during the last three decades, annual VMTs increased by 94.2%, while roadway lane miles increased by only 8.3% [19]. Transportation consumes 27% of country's energy resources and accounted for about 11% of all the expense in economy. Vehicle emission becomes one of the major contributors to excessive air pollution. In the U.S. more than 50% of carbon monoxide has been produced by transportation systems. The relevant public health cost of traffic related pollution is huge: between $40 billion and $64 billion per year [19]. Public transportation in concentrated urban area helped reduction in energy consumptions but suffered from last mile problem and inconvenience.

Substantial technology advances have been made in area of autonomous automobiles and connected vehicles, which opens a wide landscape for future traffic system operations. We extend the current automotive ownership and operation modes (mainly private-owned vehicles plus public transportation and taxis) to a public-owned (or service-provider owned) sharing-dominated mode. In our system,

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vehicles can be autonomous or human-driven, vehicles size can vary, and so on. Different from the current dial-a-ride system, we can make configured routes integrated with cyber spaces hobby, daily needs, as well as social-connected favorite partners. Previous studies on vehicle sharing, congestion pricing and traffic simulation model development provide a solid foundation for this development.

Over the past years, vehicle sharing gains its popularity to provide enhanced mobility services. The concept of vehicle sharing is initially proposed as carpooling, which was widely used in U.S. since 1960s. Today, the vehicle sharing process is simplified in support of the various wireless communication and mobile devices. Wide-range Internet availability facilitates car sharing processes by allowing private car owners to share their cars with others. Demand-based car sharing mechanisms cannot be fully established because of unbalanced supply-demand distribution. Vehicles may possibly get stuck in low mobility demand zones but become unavailable in high demand zones. Similar problems were observed in terms bike sharing so that relocation methods were [2][22]. Car sharing mechanisms must actively address its reallocation issues in order to enhance its applicability. Our system has shared ideas with Dial-a-ride scheme [12], where both approaches have the advantages of efficiency and flexibility. The main difference is that in our system, Public Vehicle is a driverless system which significantly reduces the cost, thus will become realistic daily transportation tool. Our system also provides the information support and user-friendly platform for the PV system.

In order to reduce traffic congestion and raise revenues, congestion pricing has been proposed and studied for several decades since Pigou [21]and Knight [13] initially explored congestion pricing theory. In the 1960s, the research interest in congestion pricing was resurrected by the work of Walters [25], Beckmann [5], and Vickrey [24]. Vickrey developed a dynamic vehicle congestion model to derive socially optimal tolls featured with flexible departure and arrival time. Since then, substantial research has been conducted by transportation researchers and practitioners [17]. The well-known first-best pricing theory has attracted much research attention [5][6][28]. However, the first-best pricing theory has limited practical value. The second-best pricing principles have been proposed as a practical solution to determining tolls considering physical and economic constraints [23]. Additionally, many researchers Ferrari [8], Larsson and Patriksson [14], and Inouye [11], derived link tolls under capacity constraints based on the Wardropian traffic equilibrium [26]. Vickrey [24] and Downs [7] proposed that congestion pricing should be determined based on trial-and-error efforts to enhance its applicability. Li [16], Yang et al. [29], and Meng et al. [18] proposed the iterative toll adjustment mechanisms according to the single and network-wide link flows without demand information. Arnott et al. [3] compared the four distinct pricing strategies and concluded that considerable benefits can be achieved under congestion pricing. In practice, congestion pricing strategies have been implemented worldwide such as Singapore [20]. The cases of congestion pricing in U.S. include the HOT and express toll lane systems of SR-91 and I-15 in California, I-10 and US-290 in Texas, and I-394 in Minnesota, etc. [9].

Microscopic traffic simulation is commonly utilized in the transportation engineering fields, including transportation system design, traffic operations, and management alternative evaluation. Hence, simulation-based investigation on toll-based traffic operations is of practical importance for traffic engineers to quantify toll impacts, optimize tolling strategies, and identify potential problems prior to implementation. VISSIM is one of the most powerful microscopic simulation tools developed to model urban traffic operations. This software can simulate and analyze traffic operations under a broad range of scenarios. Many simulation studies have been conducted using VISSIM. Gomes et al. [10] developed and calibrated a VISSIM model for simulating a congested freeway operation. Lelewski et al. [15] built up a VISSIM simulation model to analyze express toll plaza operations. Zhang et al. [30] conducted simulation-based investigation on HOT lane operations for Washington State Route (SR) 167. Many studies [1][4] indicate that the output data from a simulation run are inherently correlated.

III. Approach

The current social networks focus at virtual world, even with physically connected bodies also presented as an entity in virtual world. Our system envisions that partial and selective cyber world can be mapped and further impact on the physical transportation system. We deal with this new type of social network as a social-network-enabled transportation CPS architecture, which consists of the cyber space and the physical layer, as shown in Figure 1. The cyber space is reflected from entities in social networks, where a stationary node (s-node) represents a Point of Interesting (PoI) that can be mapped onto a physical place; an edge represents connectivity between two stationary nodes (mapped to multiple transportation routes). A mobile node (m-node) represents an avatar (mapped to a person), where one or more avatars can be grouped as a mobile squad; an activity link (a-link) represents association from a PoI to one more s-nodes and a friend link (f-link) represents a binding from a friend group name onto m-nodes.

For each avatar, his/her daily life is defined by many activities associated with various PoIs and certain time windows. Execution of these activities is carried by moving avatars to corresponding s-nodes to meet the specified timing requirements. Planning of activities in daily life can be made in advance, dynamically adjusted, spontaneously created or changed. Social networks provide a natural platform to integrate s-nodes, links, avatars, and events.

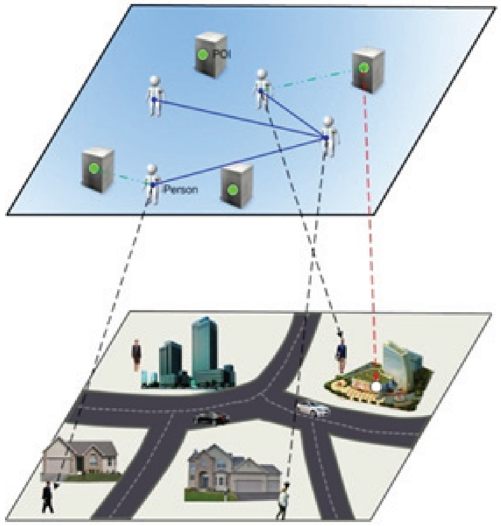

Figure 1. Cyber Space and Physical Space

In the physical plane, persons are notated as p-entity and locations as l-entity. A road system connects the l- entities. A p-entity can be located at an l-entity for a time interval, or in transit from an origination l-entity to a destination l-entity via a route and by a mover. Movers can be of various types, such as public-owned vehicles, community car pools, public transportation including subways and buses, and so on. Here, we concentrate on a particular type of mover, the Public-Vehicles (PV), a public-owned vehicle that can be shared with many people. A PV is classified as an autonomous car (driverless or self-driving). Upon a request, relying on the traffic assignment system and simulator, the most suitable PV (with some empty space, close to the location, and being able to move the person to the destination) will be scheduled to serve the need.

With introduction of cyber space and physical space, the social network-enabled component mainly lies in the cyber space to manage all m-nodes and s-nodes as well as edges, activities, a-link and f-links; while the transportation component mainly lies in the physical space to manage p-entities and l-entities as well as roads/routes and movers. Thereafter, the cyber-physical system is required to establish connection between two components.

This system creates a cyber space that runs in parallel with the physical world and assists decision making in the physical world. Tools are designed in the cyber space to easily and effectively schedule daily activities for people. The transportation component works with activity demands to achieve a service-oriented coordination. To achieve this goal, we need to address the following key issues:

- Establishing a connection between the cyber space and the physical world to enable an efficient scheduling service in terms of energy consumption and service quality.
- Providing incentives to the users and the transportation providers to enable efficient transportation service.
- Generating fast and accurate information dissemination system for providing optimal routes for every mover.

Based on the above objectives, the architecture is descripted as follows.

IV. Cyber space social network-enable architecture

The social network-enabled component mainly lies in the cyber space to manage all m-nodes and s-nodes as well as edges, activities, a-links and f-links. Every m-node (mobile node) characterizes itself by definition of its interest profile, friendship profile, and preference profile. As an initial design, an interest profile is a set of 4-tuples; which is in format of (m-node ID, a-link ID, f-link ID, time). An activity link (a-link) represents association from PoI to one or more s-nodes. In order to complete association from a m- node to s-nodes, there exists an interest binding (a-link, a-link,…, a-link, s-node, s-node,…, s-node) to indicate that activities specified by a-links can be performed at one of s-nodes in the s-node list. For example, activity coffee and activity breakfast can be associated with a same s-node satellite coffee. Such an interest binding can be manually specified or automatically generated via matching. The binding can be changed from time to time. A friend link (f-link) points to a special group of m-nodes, who are friends/avatars to stay with as activity partners or to share resources. Thus, there is a friendship profile in cyber space for every avatar, consisting of multiple triplets (m-node, f-link, m-node, m-node).

Mapping of m-nodes in the cyber plane onto a p-entity in physical plane can be a many-to-one relation which implies that a person as a p-entity can have multiple avatars in a cyber space. It can use two avatars to handle weekday and weekend activities, respectively; or a special avatar for business trip and another for family vacations since a specialized m-node should have its well defined interest profile, friend profile, and preference profile. A restriction is that at any time, no more than one m-node can be mapped onto a p-entity.

Mapping of s-node in the cyber plane onto an l-entity in physical plane is either one-to-one or one-to-zero relation. For a one-to-zero case, no physical location is required for some PoI, such as online web conferencing. Otherwise, an s-node is mapped onto an l-entity based on its location. Mapping of edge onto routes in physical plane is one-to-many relation since the route from origin l-entity to destination l-entity is not necessarily unique.

Mapping of edges in the cyber space usually comes with transportation requests to transport a mobile node or a mobile squad between s-nodes. Such requests need to be physically evaluated by PV assignment and routing. The edge transition can be assigned with different service classes based on individual preferences, such as single segment (end-to-end), multiple-segment, exclusive, shared-small, shared-large, or sharing with favorites, etc. Connection hubs are social function enabled, such as coffee shops, grocery markets, day cares, schools, gyms, etc. For example, a weekday working avatar would like to schedule a coffee stop over on the way from home to office. Meanwhile, its favorite friend has not been met for this week. A satisfactory activity schedule will be an exclusive last-mile pick up from home to coffee shop as a transportation hub while its friend will also join him for breakfast (a PoI serving both coffee and breakfast) at same hub. Thereafter, both of them will share a mover from the hub to office.

An avatar coordinates with Avatars interactively and iteratively in the cyber space to manipulate aggregation of clauses to produce activity schedule through the activity manager described below. When an edge in the schedule need to be mapped into transportation in the physical space, a request is generated and then processed by the transportation manager. It requires several system modules to accomplish the interaction between the cyber space and physical space, as proposed follows:

(1) Activity manager. The activity manager is responsible to manipulate all activity clauses submitted from the cyber space to automatically produce feasible schedules for every avatar. Transition between two consecutive activities changes binding to different s-nodes that may result in generation of transportation needs. Then, the activity manage need to communicate with the transportation manager to fulfill edge transition (from an s-node to another). The activity manager also needs to evaluate many feasible schedules, if exist, and to negotiates iteratively with m-node agents to make the optimal schedules. In general, the daily activity clause can be planned ahead of days, hours, or minutes. But changes in activity, time window, or personal preference can happen dynamically any time before the activities taking place. Therefore, the activity manager has to deal with dynamics and is able to accommodate the changes incrementally and dynamically. Overall, specifications come with edge transition requests may include but not limited to origination, destination, departure time window, arrival time window, sharing, fastest time or travel time limit, lowest price or price limit. Among these specification, origination and destination are necessary; one of departure time or arrival time must be provided; other specs are optional.

(2) Transportation manager. The transportation manager takes requests from the activity manger to fulfill edge transition (from an s-node to another) based on its interaction with both transportation system in physical space and simulator in cyber space. Every edge transition is mapped onto physical road system and proper PVs to serve the request. Two major issues need to be addressed. First, the transportation manager makes assignment of PVs for transition requests. Meanwhile, PVs themselves need to consume the road system in the physical space to fulfill transportation requirement. In this case, a simulator will run a number of scenario simulations to find out possible options to these transportation requests. The simulator must be super-fast so enough number of alternatives can be generated in a short time period. It must be accurate enough so a precise assignment and schedule can be provided. It has to be powerful enough to handle a massive amount of transportation requests simultaneously, especially in a large-scale metropolitan area. Second, a pricing system is necessary to provide the incentive to both the transportation consumers and the transportation providers. In order to do so, technology such as mechanism design, stable assignment, etc. is applied to the incentive pricing system. The transportation manager executes above tasks and negotiates with the activity manger iteratively. The negotiation between the activity manager and the transportation manager utilizes the behavior described in the preference profile to reach the goal with different priorities, such as better performance and higher price, or less price and compromised performance.

V. Incentives and Pricing Formulation

In order to maximize the system operation efficacy, considerable service requests should be planned ahead and have longer departure window. Plan ahead will enable efficient assignment of PVs and reduce pickup overhead. More people can share the PV when the departure window is longer. What will motivate people to have a non-immediate service and to wait longer for the service? Why won't they always request no-sharing, fastest time and immediate service like a taxi? Creating appropriate incentives will be critical to answer these questions and ensure the success of PV paradigm implementation. A proper incentive mechanism can minimize unnecessary requests for the best service and waste system resources. Balancing utilization disciplines and pricing strategies can satisfy the real service needs and optimize system-wide resources utilization efficiency. With such an incentives and flexibility, the PV system may provide even lower price than a bus system can do.

A price is presented from the assignment system with pickup time, travel time, number of persons in the vehicle, and so on. A number of options may also be presented so the negotiation system can make a choice of trade-off of price and performance.

Price can be determined according to the cost of transportation. Normally, people asked for no-sharing, fastest time and immediate service will be charged the highest price. On the other hand, those with sharing and no travel time limit will get the favorite price. The price presented to a person can be determined by

$$Price = \Delta C + E + P$$

where ΔC is the increased cost to pick up the person; E is the compensation to the existing passengers already in the vehicle to compensate their loss in longer travel time and uncomfortable for more people in the vehicle; and $P = p * l$ is the profit to the PV company where p is the profit per man-mile and l is the travel length.

The price is reverse proportional to the request-ahead time. Longer the request-ahead time, the lower the price. With this pricing scheme, people have incentive to plan ahead and have more flexible travel schedule to pay lower price. However, the scheme is not optimal for all partners who joint the game. Each partner will try to maximize profit or has lower price for a trip. The PV company want to make a higher price than its real cost. The existing passengers want to obtain more compensation than they really loss. They all want to make a higher price but the person ordering the service want to lower the price. Thus, the pricing scheme is modified to achieve a truthful mechanism. The approach of strategy-proof mechanism is applied for this purpose [27][31].

VI. PV Assignment and Hyper Simulator

Efficient utilization of the Public Vehicle (PV) system has two major issues, assignment and routing. First, we have to find optimal assignment of PVs to the requests. Then, we have to find the best route for the PV. These two issues interact with each other and must be deal with at the same time. Optimal PV assignment and routing are to be studied to minimize some metrics to serve a set of requests, such as the total traveling time of all PVs, minimal energy consumption and so on. First, a problem of static assignment of a set of requests is defined and a solution is obtained. For a large city, a distributed algorithm must be provided. A mechanism is to be researched to find the best match between many requests and PVs when multiple requests exist. The well-known Gale-Shapley algorithm is modified to obtain a stable solution. In the real life, the requests will arrive at runtime, so dynamic scheduling and routing algorithms are necessary for PVs. Different from previous works, we propose a routing algorithm for global assignment. This algorithm balances the load among the roads, achieving the best global performance. The problem can be defined as follows. Given a road system and a set of PVs each of them has an OD, the schedule for the minimal total travel time of all PVs is to be generated. The similar problem can be finding schedule for minimal energy consumption, minimal pollution etc.

The optimal scheduling and assignment problem is a NP-complete problem, thus we propose a heuristic algorithm. This results in a near optimal route for each PV. More difficult problem is to find optimal solutions for a system where there exist heterogonous types of vehicles. In this situation, PVs are scheduled to balance the existing road traffic, benefiting other vehicles while the PVs have the best route, resulting in a win-win solution. A key issue is to have accurate traffic information and traffic prediction on time. We propose a hyper simulator that uses the best methods to create accurate simulation and use high performance computers along with the fastest algorithm to provide a 100-fold faster simulation. With such a super faster simulator, we may have a high-quality global routing. A scenario simulation of many different situations can be simulated to find the best one or a number of alternatives of routing solutions. In the following, we will describe design issues of the hyper simulator.

In order to form up a close loop cyber transportation system, a hyper simulator is developed to emulate social network activity-driven traffic system operations. This cyber space-based traffic system control and management strategies, vehicle departure and scheduling optimization, congestion pricing mechanism, is implemented in the hyper simulator. Traffic simulation platform, VISSIM (Figure 2), is used to enable multi-agent-based individual vehicle and urban infrastructure interactions. The hyper simulator system architecture and modulated components are illustrated in Figure 3. Based on the hyper simulator, we may compute many different routing alternatives, such as end-to-end (single segment), x-segment, exclusive, shared-small, shared-large and so on.

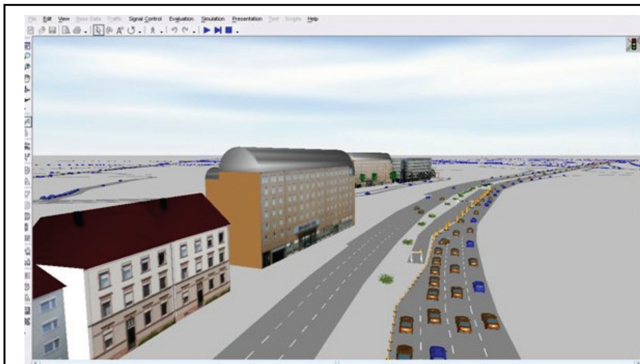

Figure 2. Illustrative VISSIM-Based Simulation Interface

We have proposed a social-network approach for future green transportation system in this paper. Vehicle sharing with public-owned vehicles can significantly reduce the number of vehicles on road. A set of new technologies including cyber space interaction, mechanism design and pricing incentives, optimal vehicle assignment, and hyper simulators enables efficient vehicle sharing.

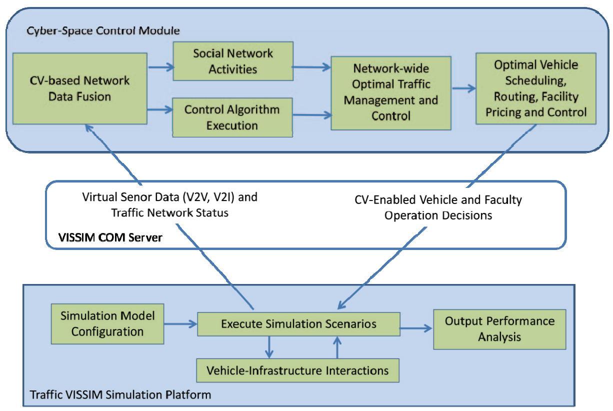

Figure 3. Hyper Simulator Platform System Architecture and Modulated Components

REFERENCES

[1] C. Alexopoulos. A comprehensive review of methods for simulation output analysis. In Proceedings of the 2006 Winter Simulation Conference, pages 168–178, 2006.

[2] P. Angeloudis, J. Hu, and M. G. H. Bell. A strategic repositioning algorithm for bicycle-sharing schemes. In TRB 2012 Annual Meeting, 2012.

[3] R. Arnott, A. de Palma, and R. Lindsey. A structural model of peak-period congestion: a traffic bottleneck with elastic demand. American Economic Review, 83:161–179, 1993.

[4] J. Banks, J. S. Carson, B. L. Nelson, and D. M. Nicol. Simulation modeling and analysis, 4th ed. Up-per Saddle River, New Jersey: Prentice-Hall, 2005.

[5] M. J. Beckmann. On optimal tolls for highways, tunnels and bridges. Edie, L., Herman, R., Rothery, R. (Eds.), Vehicular Traffic Science, page 331341, 1965.

[6] S. C. Dafermos and F. T. Sparrow. Optimal resource allocation and toll patterns in user-optimized transport network. Journal of Transport Economics and Policy, 5:198–200, 1971.

[7] A. Downs. Point of view: implementing peak-hour road pricing at full scale: finding solution to practical problems. TR News, 167:7–9, 1993.

[8] P. Ferrari. Road pricing and network equilibrium. Transportation Research (B), 29:357–372, 1995.

[9] Federal Highway Administration (FHWA). Congestion pricing: a primer. Publication number: FHWA- HOP-07-074. Federal, 2006.

[10] G. Gomes, A. May, and R. Horowitz. Congested freeway micro simulation model using vissim. Transportation Research Record: Journal of Transportation, 2004.

[11] H. Inouye. Traffic equilibria and its solution in congested road networks. In Genser, R. (Ed.), Proceedings of 5th IFAC Conference on Control in Transportation Systems, pages 267–272. Vienna, 1987

[12] J. J. Jaw, A. R. Odoni, H. N. Psaraftis, and N. H. Wilson. A heuristic algorithm for the multi-vehicle advance request dial-a-ride problem with time windows. Transportation Research (B), 20(3):243–257, 1986.

[13] F. H. Knight. The economics of welfare. Quarterly Journal of Economics, 38:582–606, 1924.

[14] T. Larsson and M. Patriksson. An augmented lagrangean dual algorithm for link capacity constrained traffic assignment problems. Transportation Research (B), 29:433–455, 1995.

[15] A. R. Lelewski, J. A. Berenis, and G. M.Pressimone. Analyzing express toll plaza operations using modern simulation models. Institute of Transportation Engineers 2003 Annual Meeting, 2003.

[16] M. Z. F. Li. The role of speedflow relationship in congestion pricing implementation with an application to Singapore. Transportation Research (B), 36:731–754, 2002.

[17] R. Lindsey. Do economists reach a conclusion on road pricing? the intellectual history of an idea. Journal Watch, 3:292–379, 2006.

[18] Q. Meng, W. Xu, and H. Yang. A trial-and-error procedure for implementing a road-pricing scheme. Transportation Research Record, 1923:103–109, 2005.

[19] Bureau of Transportation Statistics. National transportation statistics 2012. In U.S. Department of Transportation. Washington D.C, 2012.

[20] P. Olszewski and L. Xie. Modeling the effects of road pricing on traffic in Singapore. Transportation Research (A), 39:755–772, 2005.

[21] A.C. Pigou. Some fallacies in the interpretation of social cost. MacMillan, London, 1920.

[22] H. N. Psaraftis. An exact algorithm for the single vehicle many-to-many dial-a-ride problem with time windows. Transportation Science,17(3):351–357,1983.

[23] T. Vanderbilt. Heading for the cloud. ITS magazine, 2011(3):10–11, 2011.

[24] W. Vickrey. Point of view: principles and applications of congestion pricing. TR News, 167:4–5, 1993.

[25] A. A. Walters. The theory and measurement of private and social cost of highway congestion. Econometrica, 29:676699, 1961.

[26] J. G. Wardrop. Some theoretical aspects of road traffic research. In Proceedings of Institution of Civil Engineers Part II, volume 1, pages 325–378, 1952.

[27] M.Y. Wu, S.J. Ma, and W. Shu. Scheduled video delivery a scalable on-demand video delivery paradigm. IEEE Transactions on Multimedia, 8(1):179–187, 2007.

[28] H. Yang and H. J. Huang. Principle of marginal-cost pricing: How does it work in a general network? Transportation Research, 32A:45–54, 1998.

[29] H. Yang and H. J. Huang. Mathematical and Economic Theory of Road Pricing. Elsevier, Oxford, 2005.

[30] G. Zhang, S. Yan, and Y. Wang. Simulation-based investigation on high occupancy toll lane operations for Washington State route 167. ASCE Journal of Transportation Engineering, 135(10):677–686, 2009.

[31] Y. Zhang, Y. K. Ji, W. Shu, and M.Y. Wu. Capacity-aware mechanisms for service overlay design. In IEEE Globecom, 2008.