The new face of road pricing: designing for public acceptance

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Transportation authorities are increasingly looking to distance-based road-use fees to offset funding shortfalls, manage congestion and reduce automotive emissions. The endgame for "road user charging" is to replace fuel taxes with a more equitable usage-based payment, to reduce traffic jams and greenhouse gas emissions, and better fund road and transit infrastructure.

The project that our team at Skymeter has developed over the last five years touches on many facets of system design, societal and environmental matters. The hardware and software engineering activities we engage in, however, are merely enablers in a much larger context: universal road pricing–i.e. designing a technology that governments can immediately apply to transportation demand management and later enables a transformation of the transportation tax base from gas taxes to paying for use in proportion to the congestion in which we are driving.

So we find ourselves designing systems in the context of transportation policy, taxation policy, even the relationships between municipal and federal governments, and–in larger countries such as ours–the relationship between those two levels of government and intermediate state or provincial governments.

In addition to matters of funding, our work has impacts on congestion that force us to consider matters of urban planning, urban health and even fairness and social entitlement.

We also impact emissions in a couple of ways. The first is the obvious connection between congestion and the additional emissions that idling in traffic causes. The second is that many governments, when using road pricing, prefer to charge different rates for cleaner vehicles.

But if we are merely designing telematics systems that use hardware and filters to rectify global positioning system (GPS) signals, and geographic information system technologies to optimize communications and pricing costs, why the concern with all of these other matters?

Changing the way we pay for roads is fundamental to our access to the most common form of mobility–our automobiles. Making this shift is world changing. At the core of the entire issue is a social, political and economic framework that challenges this critically necessary shift: *acceptability*. This includes acceptance by motorists of GPS technology for metering road use, acceptance of payment based on when and where they drive rather than by fuel volume, acceptance of a metering device in their vehicles instead of at the pump or toll booth, and acceptance of prices that vary by location or time of day. We also must consider acceptance by our customer–government tolling authorities–which means thinking about things like minimization of infrastructure both for its cost and its unsightliness in our cities and landscapes and, most importantly, privacy management, minimization of operating costs and operating complexity, and enforcement. And, in many ways, enforcement costs depend on motorist acceptance. These factors are all interdependent. And there are a lot of constraints.

The larger picture

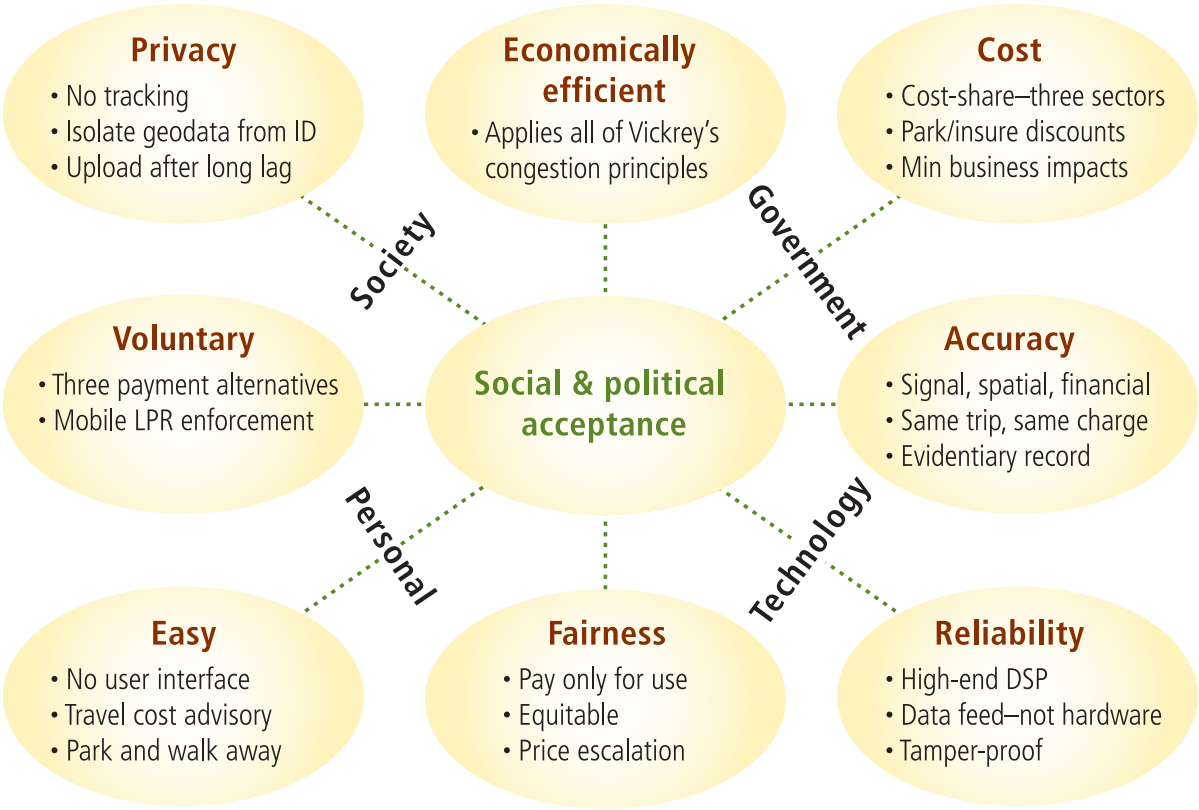
We have had nearly a century of car-centric urban design and suburban development. This built environment is as much designed for cars, whether moving or parked, as it is for humans to walk and sit. In fact, more horizontal space in our cities is dedicated to cars than to humans.

Unfortunately, it's one thing to have academic hand-wringing over how we have designed urban environments or our mobility preferences into an unsustainable corner. It's quite another to start designing our way out. There is no indication that we are going to abandon the automobile or our suburban houses in a decade or two. If the change we desire–market economics applied to road use–is to be achieved in a politically heterogeneous society, then many parties will have to be satisfied.

- *Governments* will demand economic efficiency, low cost (or, conversely, sufficient revenues) and measurement accuracy and reliability to be useful in generating records to enforce charges;
- *Motorists* will demand basic fairness and reliability. They'll also want assurance they are not overpaying and, if they are going to pay, that others are unable to avoid payment. They will demand something easy to use with a high degree of privacy. Few motorists will readily tolerate being mandated to use a meter that records their position, hence the system must be elective; and
- *Society* as a whole will likely demand that the system function effectively, protect privacy and have alternate payment methods.

Government

Governments already have an exact, reliable, near-free and easy-to-enforce mechanism to collect a proxy tax for road use–the gas tax. To address government acceptability of a new way to collect road-



This figure shows the range of acceptability issues that have been identified and addressed with Skymeter's proprietary road pricing technology.

use tax, we addressed four issues: economic efficiency, cost, accuracy and reliability.

Economic efficiency

Economic efficiency, for our purposes, measures the degree to which we can maximize the economic productivity of a resource. For roads, we would like to maximize their carrying capacity–i.e. minimize congestion. Since pricing signals affect human choice, we know that higher road-use prices during peak-demand hours will reduce congestion. This is simple supply and demand thinking, where the "good" is road space. (This is no different than congestion pricing for electricity.) We also observe that the motorists who do not use the roads during peak hours following the application of a congestion tax find another time or way to travel. Hence, a pricing scheme that varies according to time, distance and place (TDP) is required. Technically, this is best done with GPS.

Good governments generally prefer economically efficient taxes provided they can be managed without political consequences. Therefore, we recognized that while GPS is the technical winner, compared to the fuel tax, it has some drawbacks that must be addressed to make it acceptable to governments.

Cost

Governments collect fuel taxes through an existing network of fuel distributors. Because these networks absorb almost all of the costs of that collection, it is unlikely that a tax-collection system could be less expensive.

We approached cost reduction by developing a telematics-based application platform that moves extremely little data, while handling a large number of applications that share a common set of requirements, thereby distributing costs over several sectors: road tolling, parking, pay-as-you-drive (PAYD) insurance, leasing and maintenance, as well as courier zoning, taxi plating and others. These applications are liability-critical; in other words, there is money at stake, because they are all payment service-related. All require accuracy of charges, measurement integrity, repeatability of charges, privacy and data security. Fundamentally, we defined a new category of GPS application and designed a platform meant to exhaust the applications in that category rather than being dedicated only to road tolling. As this market matures, the ability to generate revenue from a wide variety of applications will become the single greatest determinant for cost management.

Accuracy

Positioning accuracy in an urban GPS environment is difficult and never without errors. We pursued a course of greater, but still imperfect, signal filtering inno-

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vations including sensor fusion and took advantage of a near real-time (instead of real-time) requirement, allowing us to do some additional processing not possible in a navigation application. This led to the development of a new class of GPS positioning generator unlike any used in the navigation-class receivers that have been stock in trade for road-tolling system developers until now.

That was still not enough, but we had made a couple of other observations. First, tolling operators and motorists will be *somewhat* focused on positioning accuracy, but will be *absolutely* focused on the accuracy of the charges. Second, there are methods to geocode street and roadway "price maps" that could ensure small trip variations could resolve to an identical charge. These had not been attempted before because all other researchers, to our knowledge, had focused on resolving error-prone GPS estimates to street maps through a process called map matching, a heuristic that can fail in certain circumstances[1]. We shifted the emphasis from "accurate positioning to a street" to "accurate positioning on a price grid," thereby guaranteeing "same trip = same charge" for TDP tolling, with equivalent guarantees for parking and insurance.

Reliability

Reliability means two things for a system that incorporates in-vehicle telematics: it works all the time and everywhere, and it is very hard to tamper with.

Having it work all the time and everywhere is a matter of always receiving signals and always being able to derive a correct and consistent price from those signals. Recent advances in high-sensitivity GPS receivers ensures that we can almost always receive signals, and the use of two other motion-related sensors ensures that we now have no data gaps and our proprietary process provides consistent pricing.

At a minimum, providing for tamper proofing means the device cannot be moved, opened, shielded or jammed without detection. When any of these events occur, we are able to take remedial or permanent action and signal the device state with a lamp colour change visible to both motorists and enforcement. We deploy an additional step to ensure the device cannot be faked. We send a short-range data burst on demand to the mobile licence vehicles or handhelds that confirm health. This prevents the construction of a ruse device with only working signal lamps.

Lastly, because we have a complete history of the device movement–i.e. park, drive, park, drive, etc.–we can perform a data check looking for gaps in the travel log.

A system to collect taxes is considered liability-critical and must have this level of reliability.

Society

As a whole, society has concerns that span and overshadow those of government or motorists alone. Economic efficiency, privacy and voluntary use–all components of fairness and freedom–are important to most developed societies, and in ways that take longer to gel and longer to change than individual opinion. For these three components to meet with social acceptance requires a majority of individuals in a target social group to exhibit a high degree of compliance and a low incidence of complaint.

Economic efficiency

For any society, government programs initially meet with general excitement or derision, which settles over time. In some ways, this opinion is informed by how well a program provides social value compared to its cost.

For society, economic efficiency means: Is the congestion program effective? Is it fair? Does it reduce congestion? Does it improve transit? Does it improve mobility?

In many ways, these are largely policy matters, and we only provide policy enablers.

What we have done to ensure economic efficiency in this larger framework is to make sure our design admitted all of Nobel economist William Vickrey's principles of efficient congestion pricing[2]. Vickrey was specific about charging for the marginal social cost of each trip, that charges vary smoothly over time, and that they be determined by the congestion conditions at the time of each trip. While Vickrey wrote prior to the conception of GPS, his was the earliest and clearest description of a TDP charge.

Vickrey went further to describe how taxis, parking and courier vehicles should be handled. We incorporated methods to comply with those proposals, then added PAYD insurance as well. Doing this signalled a break from the usual thinking about using GPS to meter distance driven on a road at a particular time, i.e. simple TDP pricing. Making a system cover all possible uses of shared transport infrastructure means we can maximize economic efficiency by maximizing pricing signals. We wanted one platform, one bill, partially as a simplifier for the motorist so that drivers have a very clear, itemized picture of the cost of each trip that they can use to make driving choices.

Privacy

While the degree of privacy desired is an individual matter, privacy as a social issue is critical to consider. Any system to measure an individual's use of the road must comply with the privacy rules of a national or state government. This has impacts on data handling, and the visibility of that data to a motorist for self-audit functions. We had to consider and address cases of fleet vehicles owned by someone other

than the driver, police subpoena, record retention and destruction, encryption and payment at the vehicle.

We went further to provide full anonymity as an option, where permitted, but this adds an incremental enforcement expense and demands that the meter be prepaid.

Voluntary use

There are three reasons the use of such a meter must be voluntary. The obvious one is that some people will simply not accept such a meter in their vehicle due to mistrust or misunderstanding of how it works regarding vehicle tracking (it does not track vehicles). The second reason is that some drivers who live in regions that do not have road user charging might visit regions that do. There must be a way to allow such vehicles to enter other regions without acquiring a meter for such an occasional visit. The third reason is that a driver who experiences a failure of his or her meter must still be permitted access.

For these reasons, our data management designs include three ways to pay for road use: TDP meter, daily or weekly guest passes associated with the vehicle licence plate, and citations. This is conceptually identical to using a parking garage: you can use the meter, buy a monthly pass or take the risk of getting a ticket.

Personal

We understood that individual motorists would have many possible responses to road pricing programs and to this new technology. There are a few issues that are specific to individuals: fairness, simplicity and freedom of choice.

Fairness

Fairness encompasses many things. For example, governments must take some care to set fair charging rates, and to carefully consider whether to handle exceptions directly in the payments system or with tax credits in the income system.

Enforcement also leads to a set of fairness issues. On one hand, all users must be treated similarly–e.g. it would be unfair to paying motorists if other motorists were able to drive free due to lack of adequate enforcement. On the other hand, there are many possible exceptions: emergency vehicles, service vehicles, taxis, smaller vehicles, low-emission vehicles, handicapped drivers, local residents, etc. Some have argued that lower-income drivers should pay differently. While all of these matters are addressable with policy, we have provided ways to handle each of them, with one exception: our system is associated with a vehicle (it is essentially an electronic licence plate), so that a registered vehicle owner with a specific payment exception may allow another driver who does not enjoy that exception to use his or her vehicle. While this can be readily handled during routine spot checks, it is not fully automated, as is every other aspect of the system. Without spot checks, it is subject to the kind of abuse we are familiar with for handicapped parking.

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Fairness also means the payments made provide benefits to the traveller: less congestion, better transit, better and safer roads, confidence about trip length estimates, etc. These issues, while addressable with enabling technology, are also bound up in government policy. Ours is truly a "technology enables policy and policy demands technology" area of innovation.

Simplicity

From the beginning, we were concerned about the user interface perspective. We didn't want drivers to have to "learn" how to use the system. We understood that failures due to user error would be costly and unnecessary. For that reason, we provide no user interface in the vehicle except a visual and auditory alarm that functions as a trouble indicator. Installation is easy (peel and stick). And all trip pricing and cost estimators, etc., are handled either by other software on personal handhelds or offboard on the web.

Freedom of choice

We discussed the voluntary issue from a societal perspective earlier, but it is worth noting that, from an individual perspective, program compliance without a meter has to be very simple. For that reason we admit daily, weekly, monthly access permits (guest passes) acquired by phone, web or kiosk. It would be easy to set up automated expiry notices over phone or email as well.

Our system design also admits the kind of automated guest pass that Toronto's Highway 407 uses: pass under a gantry and your payment is automatic. Such an entry gate is expensive and a city might deploy only a handful for motorist convenience. Also, the motorist would pay an extra fee each time their licence plate is interpreted, as is currently the case with the 407.

Where are we now?

Flat taxes, such as vehicle registration taxes and even the fuel tax, actually generate congestion. This is gradually being recognized so that a number of national transport ministers in countries such as the United States, Britain, the Netherlands and Singapore are speaking out to encourage the shift from these forms of taxation to a pay-as-you-go form of taxation. In the meantime, governments will struggle with the design of policy and program deployments as we inch our way toward the necessary tax shift.

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