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A New Look at the Traffic Management Problem and Where to Start

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Abstract—Traffic management is a major concern for cities around the world. The conventional traffic problem has been cast as a mismatch situation between supply and demand. We argue that this formulation is incomplete in that it admits solutions that ignore the impact on citizens all together, and hence unsustainable in the long run. In response, we propose a new formulation of the traffic management problem and outline focus areas while solving them for cities in developed and emerging geographies.

I. INTRODUCTION

The traffic of a city impacts all aspects of its citizens' economic and personal activities. At a general level, the traffic problem is understood as a situation of mismatch between supply (i.e., roads and their capacity) and demands (i.e., travel needs). Whenever this mismatch increases, the city administrators have tried to balance it by creating infrastructures (e.g., new roads, expanding capacity) or policy changes (e.g., banning traffic movement during major games)[14].

A weakness of this formulation is that it admits solutions to the traffic management problem which can completely ignore the impact to the citizens or city's resources. After all, if all citizens are restricted from travelling in the city or prohibitively charged, there is no demand to meet. Or, if cities can always fund new roads to everywhere, there is no supply problem. But adopting such unilateral, often short sighted, kludges can lead to long-term impact to the economy of a city like citizens or businesses finding the city incompatible to their day to day activities, or city without any budget.

We recognize that the real problem comes when one tries to optimize on both fronts: public city's resources and private citizens' resources. This is the basis of our proposed problem formulation.

II. NEW TRENDS AROUND TRAFFIC

Traditionally, traffic management has been funded only by city governments and they had no framework to access citizen's information related to travel. Both are changing. Given the importance of traffic to citizen's daily lives, traffic information is being provided as a value-added service by businesses (e.g., radio stations, mobile phone operators) and citizens (and businesses) are willing to pay directly or indirectly. Furthermore, technology is enabling citizen's traffic demands to be available on a more regular basis than previously possible using demographic surveys.

So, a more general problem statement is needed, and, we believe, can be solved.

On the side of city administrators, another way of managing traffic has emerged – Intelligent Transportation Systems [13]. To reiterate, some dimensions along which a city can manage traffic are:

- [Method-1] Creating physical infrastructure, e.g., new roads, expanding capacity of existing roads
- [Method-2] Making policy changes, e.g., banning traffic movement during major games, changing traffic direction, making road usage chargeable
- [Method-3] Intelligent Transportation System (ITS), which seeks to use IT infrastructure to measure and manage traffic based on cities policies. It is not one specific technology or usage scenario (e.g., using GPS for Region-based Charging) but a broad term for any IT-based traffic measurement cum management solution.
- [Method-4] Hybrid representing any combination of above methods. For example, making a road chargeable may mean a policy change and an adoption of ITS solution.

III. THE TRAFFIC MANAGEMENT PROBLEM

A city has public resources at its disposable like physical infrastructure (e.g., roads, buses, metros), personnel (e.g., traffic police) and finances (e.g., operational budget, long-term budgets). Citizens have their own resources that they can expend on their travel needs like acceptable commute time and daily commute budget. Furthermore, physical infrastructures take time to build and need long-term planning and funding running into years. So, we consider two problem formulations – one of shorter term horizon and another of longer term.

A. Traffic Management Problem (Short Term)

Problem Statement: Match traffic demand to supply with optimal usage of available public resources and concomitant optimization of citizens' private resources for travel needs.

Informally stated for road traffic, the problem can be seen as seeking to manage traffic optimally on a road network using available public resources while allowing citizens to complete their daily travel needs optimally. An example of the problem is: For a given day, minimize over-time

payments to traffic personnel while minimizing average commute time per km. Service objectives can also be stated like average commute time per km be below 10 mins/ km.

Implications: The problem statement brings out the two stake holders of traffic management which can at times be at odds – public resources and private resources. Traditionally, traffic management has been funded only by city governments and they had no framework to access citizen’s information related to travel. Both are changing. Given the importance of traffic to citizen’s daily lives, traffic information is being provided as a value-added service by businesses (e.g., radio stations, mobile phone operators) and citizens are willing to pay directly or indirectly. Furthermore, technology is enabling citizen’s traffic demands to be available on a more regular basis than previously possible using demographic surveys. So, a more general problem statement is needed, and, we believe, can be solved.

B. Traffic Management Problem (Long Term)

Problem Statement: For a known future period, match traffic demand to supply with optimal usage of available and planned public resources and concomitant optimization of citizens’ private resources for travel needs.

Informally stated for road traffic, the problem can be seen as seeking to manage traffic optimally on a road network, by operating and planning for demand in the known period, while influencing and allowing citizens to complete their travel needs optimally. An example of the problem is: For the next 3 years, minimize city’s expenses (annual operational budget and capital investment in the period) while minimizing average travel time per km and average fare per km. Service objectives can also be stated towards citizens like average commute time be below 10 mins/ km and average fare be below \$1/ km.

Implications: The problem statement brings out the fact that supply cannot be created in a city in a short term. However, given a time period for which one decides to plan, one can create policies and physical infrastructure to create supply and reduce demand while taking the public and private resources into consideration. Urban planners have long tried to achieve the same effect but without having access to fine-grained citizen’s information related to travel. Moreover, they were not considering solving the traffic problem with ITS technologies.

C. Where to Start for Solving the problem?

It is a popular maxim that one cannot manage any system for which there is no measurement, and the same applies for traffic. The starting point for any solution to manage the proposed traffic problem requires the ability to measure at a continuous basis accurately. But how continuous and accurate should it be? The second issue is how funding of the solutions should happen so that the problem can be effectively tackled in practice.

In the next section, we look at the traffic characteristics around the world, and then address the questions.

IV. CHARACTERIZING TRAFFIC IN CITIES AROUND THE WORLD

In the table below, traffic from select cities around the world are summarized along how cities manage their traffic, how they collect their data, the variety of vehicles that move on its roads and how they are driven. It shows that there are two broad patterns emerging. Category 1 has cities where traffic is managed primarily automatically, a variety of data

	Characteristics	New York City, USA	New Delhi, India	Beijing, China	Moscow, Russia	Ho Chi Minh City, Vietnam	Sao Paulo, Brazil
1	How is traffic pre-dominantly managed	Automated control, manual control	Manual control	Automated control, manual control	Automated, manual control	Manual control	Automated, manual control, Rotation system (# plate based)
2	How is data collected	Inductive loops, cops, video, GPS	Traffic surveys, cops	Video, GPS, cops	GPS, some video, cops	Traffic surveys, cops	Video, GPS, cops
3	How can citizens manage their resources	GPS devices, alerts on radio, web, road signs (variable)	Alerts on radio	alerts on radio, road signs (variable), mobile alerts	GPS, radio, road signs, mobile alerts	Alerts on radio	GPS devices, alerts on radio, web
4	Traffic heterogeneity by vehicle types(Low: <10; Medium 10-25; High: >25)	Low	High	Low	Low	Medium	Low
5	Driving habit maturity (Low: <10 yrs; Medium: 10-20; High: > 20)	High	Low	Low	Low	Low	Medium
6	Traffic movement	Lane driving	Chaotic	Lane driving	Lane driving	Chaotic	Lane Driving

collection methods are used, the types of vehicles are low-medium and vehicles move orderly due to driving culture and traffic laws enforcement. In Category 2, traffic is managed mostly manually, few data collection methods are used, there is high heterogeneity in the types of vehicles, and vehicles move chaotically. New York follows the first category while New Delhi and Ho Chi Minh City follow the second category, and Beijing, Sao Paolo and Moscow have elements of both, but skewed towards Category 1.

V. TRAFFIC DATA COLLECTION NEEDS

We now revisit the issue of how accurately and continuously should traffic data be collected. We argue that both are answered by knowing the granularity at which traffic will be managed. This flows from the theory on “Value of Information” (VOI) which, quoting from [1], “has concluded that value of models of information mostly depends on following factors:

1. How uncertain decision makers are;
2. What is at stake as an outcome of their decisions?
3. How much it will cost to use the information to make decisions; and
4. What is the price of the next-best substitute for the information?”

Information is of little value if one cannot act on it or has low cost for wrong decision. Information starts becoming valuable if one can take responsive actions or wrong decisions have large cost implications.

Recall that most of the emerging geographies around the world are managing traffic manually, e.g., by sending traffic police personnel on traffic junctions during jams, or employing red lights. For manual control, one needs to know traffic state at a coarse level (e.g., jam, free-flow and slow moving) and make decisions. In contrast, for automated control, since one can make decisions at a more precise level, e.g., have red light for 30 sec v/s 120 sec; one would want traffic information at a more fine-grained level. The cost of wrong traffic management decision itself is considered high world-wide.

The starting point for any solution to manage the proposed traffic problem requires the ability to measure accurately at sustained, continuous basis, at a rate that helps effective traffic control.

VI. TOWARDS SOLUTIONS

We now propose what focus areas should be to solve the proposed traffic management problem.

A. Focus area of developed cities

In developed cities (category 1 in Section IV), data is already being collected by numerous methods. Hence, cities can explore various methods (ITS, physical infrastructure and policies) to solve the proposed short and longer term traffic problem.

There are initial attempts which focus on optimizing only public resources. For example, the Los Angeles Department of Transportation (LADOT) maintains an Adaptive Traffic Control System (ATCS)[15]. Every second, a computing cluster in ATCS receives direct traffic data from loop detector sensors distributed throughout Los Angeles, computes and sends out control (actuation) commands to approximately 4000 traffic lights. This system typifies traditional closed traffic management systems where all components are owned by the transportation agency.

Regarding funding, any solution to traffic management has not only to be created but also operated and maintained. With limited scope to increase cities’ budgets in the midst of increasing traffic demand, new thinking for funding is needed. We hypothesize that a solution for sustainable traffic management must have at its core, an *ecosystem* which has incentives for all participants to contribute for individual gains, while at the same time, realizing the collective aim of an efficient city-wide traffic management. Citizens and businesses can contribute their data that can be converted to traffic data using analytical methods, and the improved cumulative traffic information can be used by citizens and businesses to make better decisions and even revenue-earning opportunities. The ecosystem will allow for better traffic management by creating incentives for individuals, businesses and city government for its sustainability. Techniques in services sciences arena [16] could help in realizing the ecosystem at business and IT implementation levels.

B. Focus areas for cities of emerging geographies

In cities of developing countries (category 2 in Section IV), traffic data is not available in a continuous manner. However, since they are mostly managing traffic manually, having methods that can measure traffic intensity at coarse-granularity may be sufficient in the beginning. Moreover, existing methods that track vehicles to give traffic measurement may not work since there is high diversity of vehicles, and their movement is chaotic.

Hence, for such cities, we argue that the basic problem is:

[Basic Problem Statement for Emerging Geos] Measure traffic intensity on a road network (e.g., average speed and volume) on a sustainable basis

Once it is in place, the secondary problems are:

[Secondary Problems]

- Migrate cities to Intelligent Traffic Systems (ITS)

- Since funding is limited, cities should try to build an ecosystem for citizen and business participation; mitigate costs and create new opportunities

Regarding funding, in emerging geographies, due the criticalness of traffic to regions' growth, city administrations have access to increased budget than ever before. However, existing traffic infrastructure (e.g., mechanical red-lights) is old and replacing them with modern infrastructure amenable to better traffic control (e.g., digital red-lights whose duration can be modified remotely) is expensive. Hence again, the need to create a shared ecosystem for all stake holders is still critical.

VII. RELATED WORK

Traffic management is a key responsibility of any city management as part of its mandate to provide quality infrastructure to its citizens. At the core of traffic management is the problem of knowing the scale of traffic on the roads. Traffic measurement has remained a high priority topic in transportation community. It gained pace with technologies like inductive-loop in 1960s, video image analysis in 1970s, floating car in 1990s and mining from telecommunication providers' data in 2000s. GPS based devices is the current rage [8][9][10].

Most previous work has focused on traffic dominated by vehicles following regular lanes of developed countries[12]. There has been limited work in measuring traffic for developing regions where the traffic pattern is dominated by slow-moving vehicles like motor-cycles and cycles. In India, there is large diversity in the type of vehicles on the road (with a recent article quoting 48 different vehicle types[11]) and their movement is chaotic (e.g., not following lanes). Furthermore, existing methods deployed in developed cities are not directly applicable here since they are very costly (e.g., sensors), or make different assumptions (e.g., low penetration of GPS-enabled devices, traffic not regular), or have not been attempted at the much larger traffic scale that one gets in India. There is a critical need to acquire traffic data at city scale at low-cost and in a sustainable manner and yet, there are no satisfactory efforts yet in this direction.

Many researchers have started working for traffic data in India-like conditions. In [3], a method for traffic measurement is described based on mobile calling patterns and [5] is another example of it. In [4], honks on the road is used as an audio sensor for traffic measurement. We foresee more innovations in this space which needs nurturing by a supportive ecosystem.

Once traffic information is available, a lot can be done in controlling it. For example, one can visualize it as part of a command center, implement region-based charging and potentially predict future traffic situations [2][6]. The key bottleneck though in traffic management remains getting

traffic measurements on a sustainable basis, and if that is solved, it opens up unlimited potential.

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