ADAPTIVE INTELLIGENT TRANSPORTATION SYSTEM FOR METROPOLITAN AREAS

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ABSTRACT

We study the problem of congestion in metropolitan areas and propose an adaptive Intelligent Transport System for Metropolitan Areas (ITSMA) – a traffic congestion management system that manages high occupancy vehicular traffic, commercial truck traffic and helps in coordination of commuter and ride share traffic. Most of these components are already available in parts – in form of stochastic algorithms for managing truck traffic, systems for ride share coordination using 5.9 GHz Vehicular Area Networks and numerous systems for HoV and toll management. The proposed ITSMA system consists of a prediction engine that takes multiple real time indicators to build a traffic congestion model. The decision engine component of ITSMA system takes the traffic congestion model, and using a database of previous actions and their impacts, proposes and implements actions in real-time. The outputs of the ITSMA system can be used to suggest routes, control high occupancy restrictions, traffic light durations, toll rates and access of commercial traffic. It can also aid in coordinating ride shares and public transportation units. Such a combined system can best leverage the investment at a metropolitan level and provide the best traffic congestion management solution.

Keywords

Traffic management, congestion management, urban area, real-time traffic monitoring

INTRODUCTION

Traffic in metropolitan areas is a recurring and persistent problem. On certain days, commute times even four to five times higher than normal are reported, due to local factors which are in part predictable, and in part unpredictable. The transportation infrastructure on the other hand is driven by policies that are typically designed and implemented in order of months, years and decades. The traffic operations centers (also known as traffic management centers) are typically the only entity making decisions in a shorter time frame (1), and their role includes incident response, route guidance and traffic lights monitoring and adjustment (1,2). *Clearly, a major discrepancy between the infrastructure consumption and design is the limited scope of adaptive decisions that can be made to alleviate congestion problems in real-time.*

We propose a system that continuously monitors the traffic congestion through a variety of indicators, and implements actions in real-time that are directed at decreasing the congestion. The system builds on components, many of which are available today and uses technologies that have been developed and deployed.

There are many approaches to managing traffic that have been studied. For example (4) describes network models and how they are applied in transportation, (5) describes a capacity management approach, and (6) describes a variable tariff based approach. As a broad way of classification, most of the urban traffic management approaches can be classified into two categories: (i) capacity based approaches, and (ii) incentive (or variable fee) based approaches.

For example, a capacity based system manages traffic by limiting entry to the system, typically by way of using traffic lights, or by way of gates to entrance ramps of highways that open with a certain frequency.

An incentive based (variable tariff) system uses market forces of demand and supply to regulate and manage traffic. For example, it can impose a higher tariff during the normally congested hours, and impose a lower tariff during the hours that have surplus capacity. A significant advantage of such systems is that they do not try to impose change; instead, they create incentives for other actors to change their behavior. One disadvantage of these systems is that they can require frequent “calibrations”, for example, the values of the different tariffs may need to be continuously adjusted to cause desired behavior. Thus, a concern with incentive based systems is that if the system is too dynamic, then the users of the system may not find the system easy to comprehend. If, on the other hand, the system is too static, it may not meet its objectives. An interesting study of the impact that incentives have on toll road usage by trucks is presented in (7). Another interesting project “HOT Lanes on I-95 in Miami-Dade County” involving the interstate 95 is presented in (8).

It may also be observed that High Occupancy Vehicle programs also use an incentive based approach by dedicating resources (typically lanes) for vehicles meeting the occupancy requirements. A usual dilemma that the traffic administrators face regarding HOV programs is the determination of the number of passengers that are required, for the vehicle to be considered high-occupancy. For example, it may happen that HOV-2 program does not lead to any significant incentive as the number of cars meeting that criteria exceeds the capacity of the dedicated lane(s), and that HOV-3 program creates strong incentive but very few cars are able to utilize that incentive. Similarly, the times that the HOV program should be enforced may also need to be regularly updated for maintaining effectiveness, and that needs to be balanced with the need of commuters to have a predictable schedule.

A combination of HOV and toll programs is now in effect in many states, and this is usually referred to as a High Occupancy Toll (HOT) program. (8) and (9) contain details of programs involving HOT lanes.

A schematic of these traffic management approaches is presented in Figure 1. We also observe that an appointment based approach is commonly used in freight traffic management system, but doesn't have an analogous approach in passenger traffic. A comparison of approaches used within the context of freight traffic management can be found in (10).

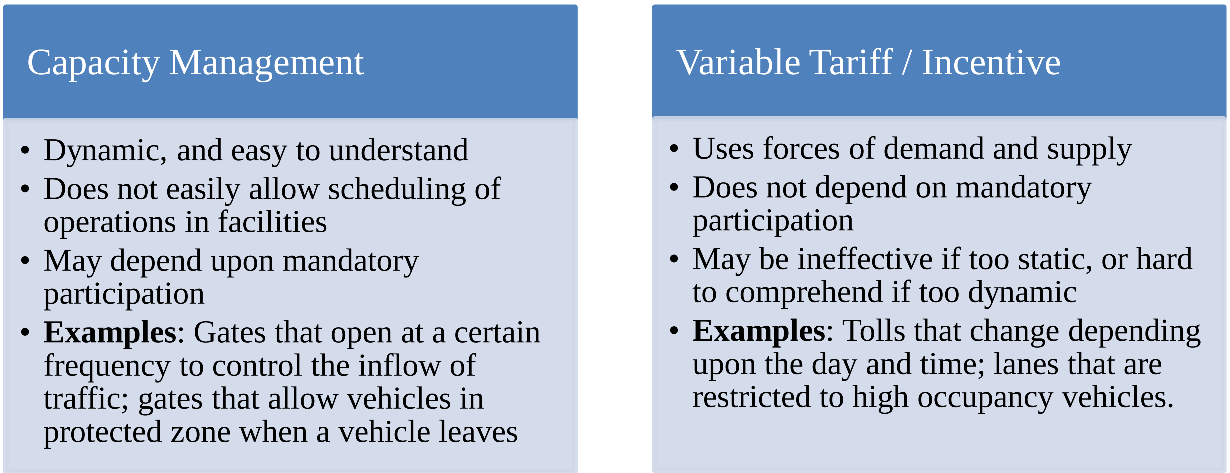

Figure 1: Two main categories of traffic management approaches

SYSTEM MODEL

Firstly, we construct the system model, wherein we discuss the various inputs to the system as well as the outputs of the system. The outputs of the system are especially interesting, and require dynamic and path breaking policies.

SYSTEM INPUTS

The system has the following distinct inputs as its situation indicators. These are all elements that can affect the traffic congestion. For each of these indicators, certain training and calibration data is used to understand the impact it has on the congestion situation, which is used by the prediction engine described in later section. More elements can be considered based on city and region specifics.

- **Inflows and outflows due to incoming mass transit platforms, such as airports, trains, buses:** Each arriving or departing passenger in an airplane contributes an approximate number of cars driving to and from different regions of the metropolitan area. These numbers can be obtained through surveys and training sets. The aggregate numbers of inbound and outbound passengers can be obtained from the airports and other transit systems.
- **Inflows and outflows due to commercial traffic movements such as cargo planes and ocean vessels**: In many cities around the world that are also major cargo hubs and port cities, the inflows and outflows can be predicted to days and hours in advance. For

example, an ocean vessel that transports ten thousand containers will lead to an outflow of an equivalent (or proportional) number of trucks on road segments leading first towards, and subsequently away from the port, starting a few days after the vessel arrival date. The delay in days can be predicted from historical sets, as well as tracked in real time from ocean terminals, and terminal processing times and delays.

- **Special events planned in a city and their start and end times**: Sports and entertainment events routinely have audiences of thousands, and can have an impact on traffic congestion drastically in a short duration of time.
- **Location from participating trucks**: This indicator can supplement the information received from the major seaports, and has been successfully used in managing traffic congestion in port cities and cities with border crossings, for example, Aqaba Jordan.
- **Real-time traffic delays and vehicle speeds on access roads**: These indicators are in the farthest state of deployment, and numerous commercial and public services exist that provide this data in real-time in a structured format, for example, transit time between key points. These indicators are usually a significant input to regional traffic control centers.
- **Road and lane closures, detours and construction activities**: Like the real-time traffic delays, these indicators are also widely available, and are widely used in the current scope of the traffic operations centers. A significant portion of current ITS literature and product offerings span these indicators. Work presented in (11) discusses an ITS component focused on safety markers for work crews.

SYSTEM OUTPUTS

Herein, we describe the various mechanisms using which the system can try to decrease traffic congestion. These are the actions that can be done in real-time, mostly using existing communication infrastructure, and many of them are already in implementation in various stages.

1. **Access to commercial traffic:** Commercial truck traffic is frequently regulated, and a few cities have programs in place that provide or deny access to truck traffic during certain hours, or regulate fee changes based on hours.
2. **Toll rates**: Interstate highway I-95 has implemented a variable toll rate that takes the traffic congestion into account, and has been fairly successful. Some toll roads also have a policy that in case of long wait times at the toll booths, the booths can be made freely open. Each of these actions has a different outcome and its expected impact can be used by the decision engine.
3. **HOV lanes management**: This is an interesting action that can be used in at least two different ways. In metropolitan areas, some lanes are dedicated as HOV-2 or HOV-3 or HOV-4, which controls how many passengers a vehicle should have to be able to drive in those lanes. Based on the situation, the occupancy requirement of a lane can

be dynamically increased or decreased. [An interesting case also arises when HOV restriction needs to be dropped entirely, and still allow only a limited number of vehicles onto the HOV lanes. An interesting solution to this problem can be obtained by using a discriminator on vehicles, for example, using the month number of safety inspection date.]

4. **Route suggestions and expected transit times**: This is an action that is currently available, but in a general broadcast sense. It can be further improved to provide specific trip and itinerary based times as opposed to general broadcasts. Currently, route suggestions are created dynamically by the in vehicle navigation devices, but those devices only have a limited amount of information. Using Vehicle to Infrastructure (V2I) communications, or by using client side mobile applications, the route suggestions can be directly disseminated to the users. This involves a significant increase in the scope of the network operation center and involves increased processing and communication infrastructure, and can also involve consideration of revenue models.
5. **Extra metro bus frequency:** In certain cases, extra metro buses can be used to cater to special traffic situations.
6. **Metro train frequency, number of cars and metro fare drops:** Extra cars can be added if heavy load is anticipated, and in other situations, metro fares can be dropped to create incentive for commuter travel in cases.
7. **Working hours and telecommuting options:** Principle employers in a metropolitan area, city governments, and other civic community minded employers can participate in a program that can change working hours and telecommuting options at relatively short notice in response to traffic situations. Although very limited, there are currently cases of private companies as well as city governments allowing telecommuting on days with major events in the region. A study of user behavior factors is presented in (12).
8. **Rideshare and carpool coordination:** While many offline mechanisms are currently available to coordinate rideshares, the proposed system can provide real-time coordination and route guidance. A subsystem focused on coordinating rideshares is presented in (13).

PROPOSED SOLUTION

Next we describe the high level design of the proposed system. The system consists of following main building blocks.

1. Event to Traffic Impact Trend Generator
2. Action to Traffic Impact Trend Generator
3. Traffic Predictor
4. Action Decision Engine

Next, we describe each of these building blocks in detail. A schematic of how these building blocks interact with each other is represented in Figure 2.

EVENT TO TRAFFIC GENERATOR

This building block consists of a genetic algorithm that takes as inputs which are events and past traffic historical records, and uses that to create a model of events to traffic. This algorithm has been described in greater detail in (10) and generates functions (curves) for each event type, such that the aggregates of the curves fit the historical data within a pre-specified margin of error. The output model consists of a mathematical function for each event type which captures the traffic generated by that event type. The complexity of the mathematical function may be changed depending upon available computing resources.

This module is used to create the models, and is not used for each transaction, so it is acceptable for this module to take a significant processing time.

ACTION TO IMPACT GENERATOR

The objective of this building block is to estimate the amount of impact that a certain action is likely to have on the traffic. For example, if an extra car is added to a metro train at a certain time, how much reduction does that lead to in the number of passengers waiting in the train station? Similarly, consider the possible action that the toll for a special lane in the highway is increased from $2 to $2.50. How much decrease in the number of cars in that special lane of the highway will this increase in toll lead to? If trucks are disallowed from a lane for an additional two hours, what impact does that have on the traffic? These kinds of correlations can be generated from the past history of events, and the resulting traffic scenarios. Like the Event to Traffic Impact Generator, this block is used to create the models, and is not used for each transaction. Thus, it is acceptable for the Action to Traffic Impact Generator to take significant amount of time (for example, a few hours) to run. Once the models have been created, they can be refreshed on a weekly or monthly basis depending upon the age of the data in the system.

We further observe that a certain cost can be attached to each action. The cost may or may not be the direct operational cost of the action that is to be borne by the transportation service providers. For example, changing the frequency of traffic lights or the ramp gates may involve minimal cost. Similarly, adding a car to the metro train may have a negative or a positive cost, depending upon the financial impact of the action on the transportation service provider. Similarly, recommending a change in telecommuting policy for a day may be deemed to have a high cost, even though the transportation service providers may not experience an operational cost for that action. The costs of the various actions are not derived statistically, rather are input manually, as there may not be any training data available for the costs of actions. The costs are only used for ranking the actions, not for qualifying the actions selected by the action decision engine.

TRAFFIC PREDICTOR

This block takes in all traffic indicators and predicts a traffic congestion model that is likely to exist at a given time. Specifically, this takes into account the model generated by the Event to Traffic Generator, as well as the real time traffic indicators to predict the traffic at given times, which may typically be a few hours to a few days in future.

ACTION DECISION ENGINE

The action decision engine is the main operational module of the system and runs in two separate instances:

1) Action Decision Engine instance for the traffic operation center suggests the metropolitan area wide actions. It takes the predicted traffic congestion model and the pre-computed correlation models as inputs and proposes and implements actions in real-time. Using a multi criteria decision analytic approach, the block attempts to find the least costly actions, such that by using those actions, the sum of the impact of the actions results in a predicted traffic model that is considered acceptable. The actions are then presented to the operator for review. The algorithm for this instance of Action Decision Engine is shown in Table 1.
2) Action Decision Engine instance for end consumers provides individualized trip suggestions to end customers either directly, or via 3rd party application providers.

All the modules of the system are shown in Figure 2. The instance of the action decision engine that focuses on the end consumers is shown in Figure 3. Both the models use the same predicted traffic model.

Algorithm FindActions

Input: Predicted Traffic Model, Input: Action to Impact Correlation Model

Output: Set of Suggested Actions

1. For each possible subset of actions:
    a. Find the total impact and the total cost.
    b. If the total impact results in acceptable traffic model and the total cost is the best found so far, consider this subset to be the best one.
2. If one or more feasible solution found, return the feasible solution with the least cost.
3. If no feasible solution found, return the one that maximizes the benefit to cost ratio.
4. Present the selected subset and the performance parameters to the user for manual review.

Table 1: Algorithm used by Action Decision Engine

Time Complexity Analysis

We observe that since this algorithm considers each possible subset of actions, the time complexity of this algorithm is $O(2^n)$, where n is the number of possible actions. While this is exponential, it may be acceptable since the number of possible actions is usually less than twenty (which results in about 1 million possible subsets). However, we do note that if there are a lot of possible actions, then a greedy algorithm has to be used which finds the actions in a sequential manner. While the greedy algorithm is not optimal, it is feasible in terms of time complexity and an acceptable choice when the number of actions does indeed exceed a certain threshold.

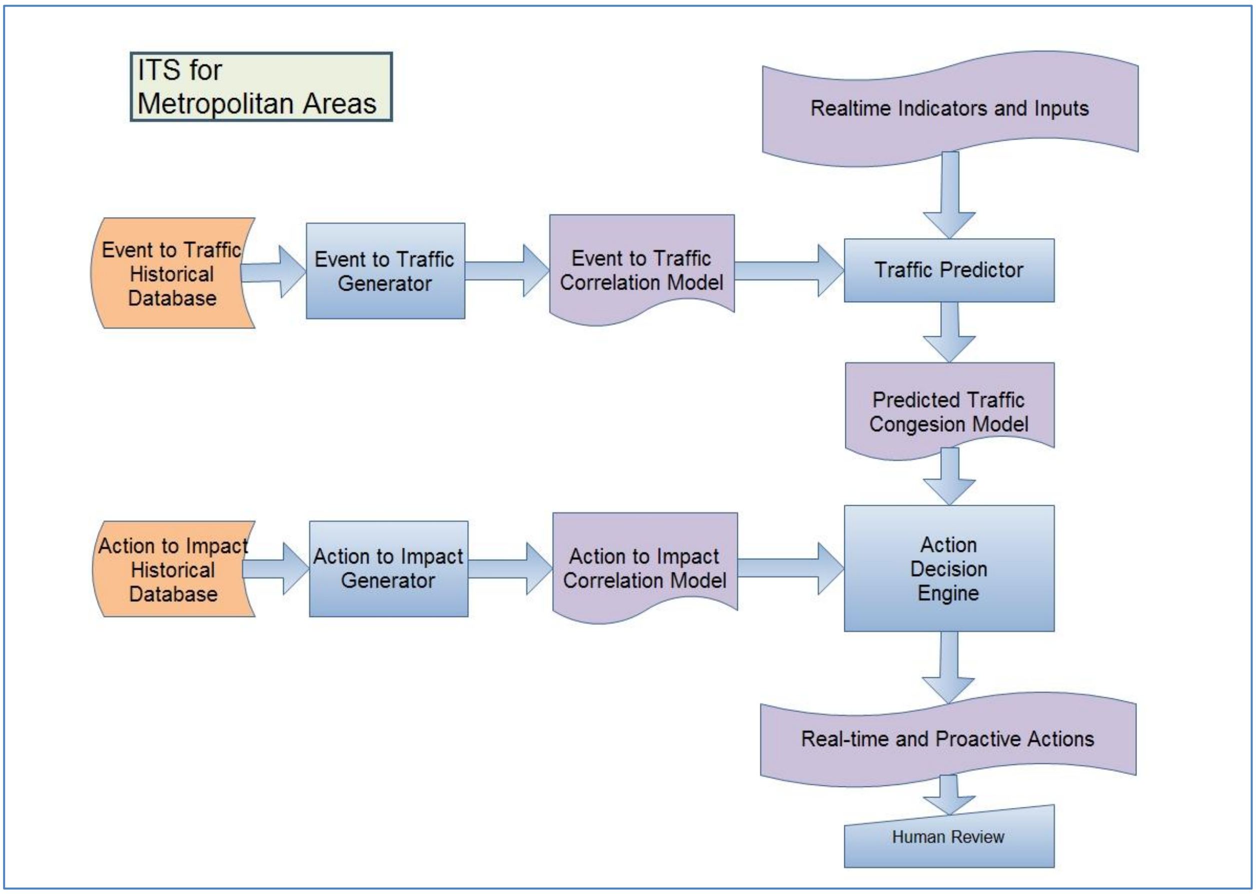

Figure 2: Schematic of Intelligent Transportation System for Metropolitan Area

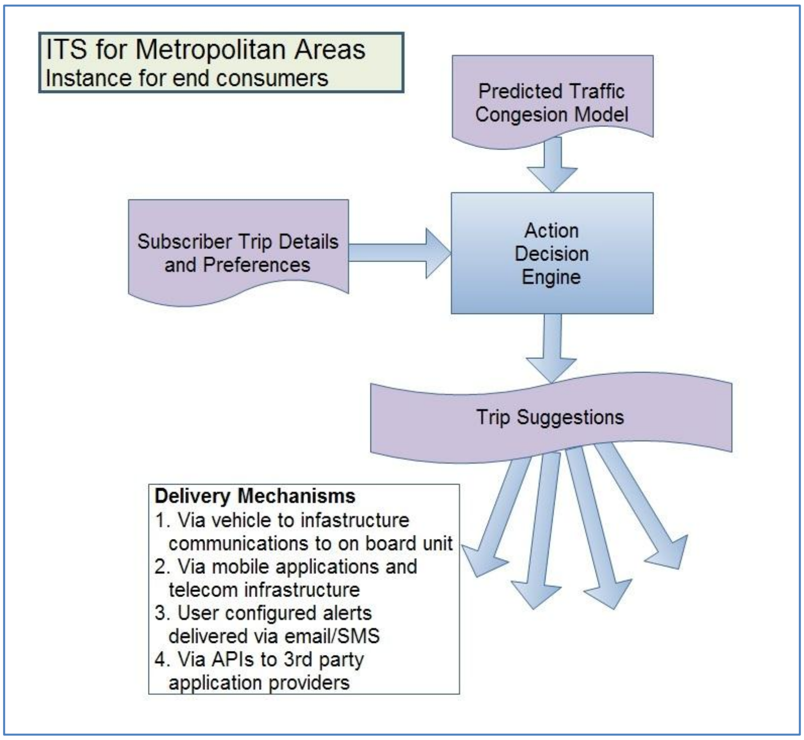

Figure 3: Instance of Action Decision Engine, as applied for end consumers

CONCLUSIONS

In this paper, we have proposed an adaptive Intelligent Transport System for Metropolitan Areas (ITSMA) that monitors the traffic congestion in a metropolitan area in real time and suggests and implements actions in real-time. At the heart of the proposed system is a rule based action decision engine that takes the various correlation models and computes the best course of actions to take. The proposed system expands the scope of the traffic operations centers, firstly by proposing that some end consumer applications be able to utilize the detailed traffic models available at the traffic operation centers. More importantly, we also propose considering some options that may require new policies. For example, depending upon the circumstances, the traffic operations center could temporarily eliminate the HOV requirements, or choose to allow a limited number of non-HOV vehicles on the dedicated lanes.

The primary benefit of such as system is fewer and less-severe traffic delays, resulting in overall improvements in productivity. However, there are also secondary benefits, such as less idling that result in cost savings and decreased emissions. Due to the combination of impacts on individual productivity as well as on the movement of goods, overall trade and economy can experience significant benefits.

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