A Review of Existing Traffic Jam Reduction and Avoidance Technologies

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***Abstract*—Traffic congestion has become a growing problem in many countries since the innovation of engines, and consequently, the mass production of commuter vehicles in the 19th century. A number of solutions have been sought to reduce its impact. Through a literature survey, this paper attempts to categorize a number of current approaches and identify the strengths and weaknesses of each solution or a combination of such solutions, in order to build a good background study. From this survey it has become clear that for success any solution most likely will have to integrate technologies from the different categories. For example, technical solutions must be combined with good traffic rules and regulations. Public education and the announcement of new regulations for commuters must be performed in stages and repetitively to increase public awareness.**

***Index Terms*—traffic jam avoidance, congestion, integrated and intelligent system.**

I. Introduction

CURRENTLY there are numerous problems associated with traffic jams. Aside from the delays that a traffic congestion may cause, it can also affect people psychologically (in terms of stress) as well as physically (causing tiredness, accidents, noise pollution and breathing problems due to air pollution). Traffic jams can be caused by obvious factors, such as the overflow of vehicles during busy hours or at special events, accidents, slow vehicles obstructing fast lanes, etc. and also by not so obvious reasons like (i.e. ripple effect which causes phantom traffic jams [1]).

Many researchers have offered various approaches to tackle the traffic jam problem. The cost to reduce its impact has also been growing, which makes many developing countries lag behind in their effort to overcome it. For example, in 2003 to 2004 alone Great Britain [2] has spent 242 million pounds to start its *Making Better Use* (MBU) program, which is part of its Highway Agency program. This program includes (but not limited to) the installation of automated incident detection and warning system, CCTV cameras, advanced road side message signs, spot improvements on needed areas (such as improving layouts of lanes and junctions and signaling at various junctions), finding novel approaches to traffic management and the management information systems necessary to support the agency's work, as well as research and development of a national traffic control center.

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Each approach can use one particular technology or a combination of them. A couple of common technologies used in many relatively advanced countries are ETC (Electronic Toll Collection) which was started in 1986 in Norway, and VICS (Vehicle Information and Communication System) which was started in the 1990s in Japan [3]. ETC allows drivers to pass a toll gate without stopping for payment and is installed in many cars. The VICS system [16] is a service using FM broadcast and optical beacons on the roadside to deliver traffic jam information to drivers so that their car navigation systems can display congested areas/roads on the map and navigate them avoiding the congested areas. Both systems can reduce the possibility of traffic jams, but requires supporting devices on the roads and on each vehicle. The ETC method not only requires a device on each vehicle, but it also assumes that each vehicle owner abides by the regulation; otherwise the automatic bank-account deduction mechanism will not work. Additionally, there is the extra cost incurred when the authorities want to persecute negligent vehicle owners.

Similarly in the VICS system, although VICS is useful there could be a time lag between the disseminated information and the real situation faced by the driver. This is because VICS collects all traffic jam information to one location (e.g., a central server), and disseminates it after processing. Also, if all cars in a certain road receive the same information and change their route in the same way according to the information, then the selected route will be congested quickly. Additionally, VICS requires many devices to be installed on the roadside for monitoring traffic conditions, and thus it is costly to deploy the VICS system on small roads (which can be used as alternative routes during a traffic jam). The cost is even higher when considering coverage for a large metropolitan city.

II. Research & Review Method

This paper attempts to categorize a number of current approaches, as well as identify the strengths and weaknesses of each solution or a combination of solutions. The aim is to build a good background study, before proposing new ideas. The method used is through a literature survey. The survey includes browsing about this topic in the internet and in IEEE's digital library, as well as looking in to a number of books.

III. A NUMBER OF APPROACHES IN TRAFFIC CONGESTION REDUCTION

Three approaches are surveyed in this paper. Namely, the approach which is: a) based on meticulous traffic design [2], [5]-[6], [9] and [6]; b) using inter-vehicle communication and traffic flow simulators [3], [8], [10], [12]; and c) using road travel time on Variable Message Signs (VMS) [7], [14]-[15].

A. Meticulous Traffic Design Approaches

The meticulous traffic design approaches involves steps such as regional traffic planning, intersection optimization design, pedestrian crossing optimization design, and operable management measurement (implementing regulations). These steps have shown to be able to improve urban traffic conditions and ease the traffic jams, such as shown in the case of Wanjiali road, Changsha, China [6].

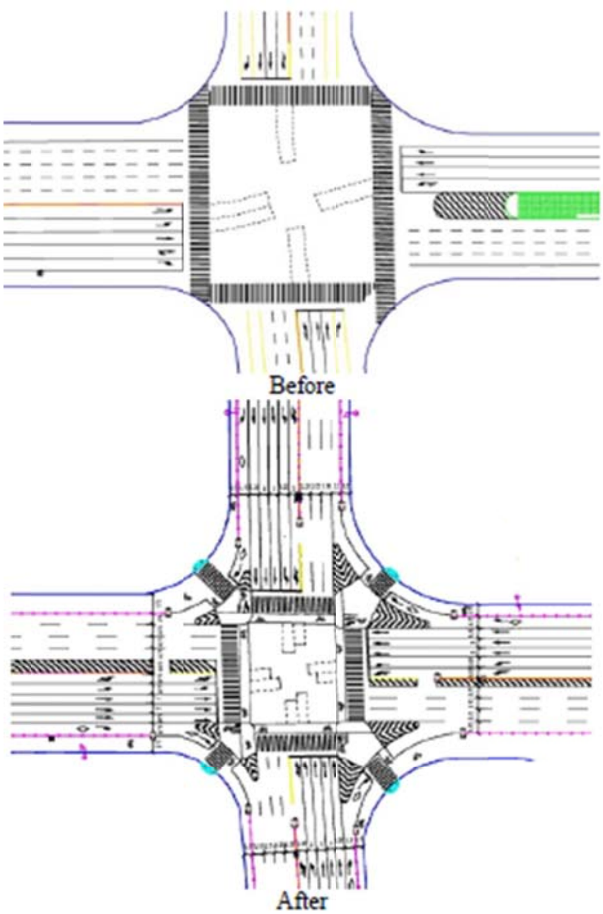

Figure 1: Intersection before and after meticulous design

Research shows that 60% of accidents and most of traffic jams have occurred in intersections [6]. The work of [6] shows that efficiency can be increased by 66.67%, through meticulous transformation design. The transformations includes the reduction of the intersection area, wider left turning wait area, reasonable signal timing, and making the right of way between vehicles and pedestrian clear (see figure 1 and Table 1 [6]).

Another reason for traffic jams is that the number of input-output lanes does not match that in the intersection node. To overcome the over flow of vehicles in the intersection, the center line of the roadway is shifted to reduce the width of the original lanes. The minimum width in single input lane is made to be 2.75m. After a long period of observation, it was noticed that traffic accidents were not increasing and thus this approach was considered to be a feasible solution [6].

Traffic management can also improve the load of the roads, by restricting peak hour traffic through regulation (e.g. applying single-double license plate, and set allowable times, for example during Beijing Olympic Games). Commuters are also encouraged to travel by bus; otherwise they should use the toll road. Tax is applied for privately owned vehicles and other taxes are added, such a mileage tax, a fuel consumption tax, an exhaust emission tax, parking fees and so on. Added to this, parking in the heavy traffic areas is controlled (e.g. limited parking time and limited parking spaces).

Advanced traffic control methods and information technology are usually adopted in meticulous traffic design approaches. This includes making driving route guides and traffic-information available (such as in the VMS system discussed further below), applying managed parking, applying traffic flow control, as well as providing automatic control for public transport.

Other references [2, 5, 9] discuss more regulations and public education, including the following:

(i) Implement employee parking cash-out (equalizing the parking subsidy). This would have an immediate impact of reducing car commuting by 25%.

(ii) Abolish all automobile subsidies (direct and indirect) and pay for this from the gas tax and/or other auto user fees. Similarly, eliminate all "traffic mitigation fees" and "developer fees" and "parking assessment fees" that subsidize the automobile. Alternatively, use these fees for constructing guide way transit instead of automobile-related construction that encourages greater auto use (and make people want to own more vehicles).

(iii) Institute "Fare Lanes." These let anyone use carpool lanes, but charges them a fare per car. Use existing lanes of roads or making better use of motor ways and trunk roads [2]. Do not add more lanes.

(iv) Eliminate parking requirements in industrial areas (and ideally, everywhere). If necessary, implement parking permits for neighborhoods (already common in some cities). Note that this approach will only work if good public transport is available in those industrial areas.

(v) Implement traffic calming to create a more livable neighborhood and decrease automobile dependency. This will also decrease auto usage.

(vi) Use congestion pricing. Any congestion still remaining will be eliminated by the use of congestion pricing. This means charging for road use an amount that varies so that traffic is kept moving. As rush hour approaches, the price increases in stages in order to keep total cars using the facility at the same optimal flow level. The money raised could be used to build guide way transit because road users also benefit by paying for potential motorists to use alternatives. Congestion pricing also increases highway capacity, while reducing political pressure for more highway construction.

(vii) The government (or its appointed agency) should adopt a more expansive approach to testing out the range of measures at its disposal, carrying out more trials at more sites to increase its chances of success, whilst managing the risks involved.

(viii) Before implementing any new road policies the government or appointed agency should seek to educate the commuters or convince users about the benefits they would bring to them, as a means of gaining public acceptance.

Qualitative analysis [2] shows that good design improves intersection traffic capacity and reduces delay, as shown when all the intersection input lanes are changed from 4 to 6, and the number of output lanes is kept invariant. Also, by optimizing open-ends setting, adding signal control, good design is able to eliminate the interference between vehicles and pedestrians, which in turn helps pedestrians cross safely and enables the traffic to flow smoothly. Moreover, quantitative analysis shows that the traffic capacity increases by 15%, delay is reduced by 20%, travel speed can increase by 10%, and conflict point is reduced by 80% [2].

It is clear that the meticulous traffic design approach is very effective, as it combines a number of technologies to reduce the traffic congestion problem.

Step	Improvement
Intersection optimization design	• Increase input lanes by shifting lane center and reducing lane width. • Set pedestrian and bicycles waiting areas by marking / channeling island and railings at corners. • Set left turning waiting area and optimize signal timing.
Open-ends treatment	Close a few open lanes, optimize pedestrian ways, and add signal control at reserved open.
Public traffic	Adjust the station lay-out and improve facilities.
Parking management	Prohibit parking near road-side and across.

TABLE I. Wanjiali road meticulous traffic design [6]

B. Inter-vehicle Communications & Traffic Flow Simulators

Traffic information can be obtained by gathering statistical traffic data using inter-vehicle communication (i.e. short range wireless communication, GPS and small computer in each car) [3]. Consequently the data (the time to get to a certain destination) can be analyzed to detect movement – where slow movement indicates there is a traffic jam. In this method cars are equipped to autonomously collect and share traffic jam information using inter-vehicle communication based on the IEEE 802.11 wireless communication protocol, without using additional devices on the roads. This method allows the onboard device to estimate the time required to get to certain destinations. The steps involved are: (a) measurement of time to pass each route, (b) calculation of the statistics of time to pass each route by exchanging the measured time and statistics among cars, and (c) estimation of time required to get to destination.

Figure 2: Division of traffic into areas (after [3])

In [3] it is assumed that a given road map can be treated as a graph where each node and link corresponds to an intersection and a road between intersections, respectively. The time to get to a destination from the current location of a vehicle can be estimated theoretically by summing up time to pass each link to the destination.

Consequently, a target geographical region can divided into square shaped areas with distances of several hundred meters from one square to another, as shown in Figure 2 [3]. The links through which a car enters and exits an area are called *incoming link* and *outgoing link*, respectively. A pair of incoming and outgoing links is called a *link pair*. Secondly, the time needed to pass each area for every link pair is measured and is called the *area passage time*. The dotted lines indicate boundaries between areas (see Figure 3). As for the area on the center of the figure, there are 5 links across boundary, indicated as α, β, γ, δ, and ε (also Figure 3). When a car passes this area, the car passes two of these links, and thus there are 5 x 4 = 20 combinations of link pairs. When a car crosses boundary of an area, the car records the current time. The area passage time is the difference of recorded time at incoming and outgoing links of the area.

This method was then evaluated using a traffic flow simulator called NETSTREAM, which has been developed by Toyota Central R & D Labs [12]. NETSTREAM was used to estimate traffic jam at Nagano Olympic Games in 1998 and it was successful in generating a good estimation (i.e. with realistic traffic flows on an actual road system). Moreover, NETSTREAM has the ability to support more than 1000 cars running on a given map simultaneously. It also has a function to construct an arbitrary road system consisting of roads (links), along with legal speed limits and certain number of lanes, intersections (nodes) with traffic lights. It is capable of using specified time intervals to change colors and so on using a graphical interface. NETSTREAM simulates traffic flow on the given map as follows. It reads the map data, the information on links and nodes, and other information such as the time intervals of traffic lights. Its initial information of cars is configurable, along with the number of cars which follows each link or route, and making each car run on the specified link within the legal speed limit. It also records logs including locations of all cars every second. In this simulation experiment up to 300 cars are used. Each car measures the time to pass an area (called area passage time) for each entering/exiting pair of roads (called link pair) of the area, and traffic information statistics are generated from cars which have passed the same pair of roads. By measuring the average area passage time for each pair of roads crossing an area boundary, the time difference between multiple routes with the same link pair can be considered by taking into account also the waiting time at traffic lights and/or turning at intersections. Results show that about 55% of link-pairs time has a difference of less than 10%, which means that this method is accurate enough for practical use [12].

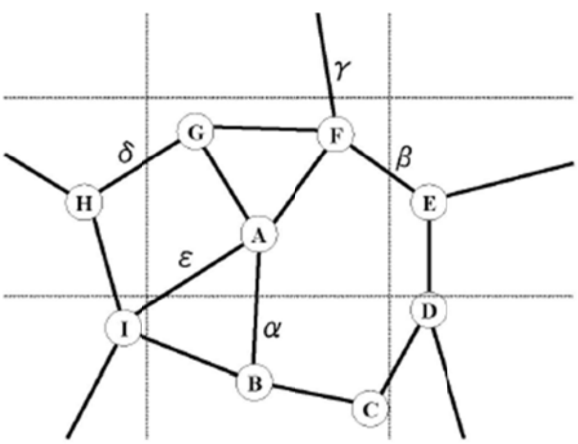

Figure 3: Links across area boundaries (after [3])

Another simulation software currently available is *Legion* for Aimsun [8]. It is a fully integrated pedestrian and vehicle simulation solution which uses mainly video cameras (see Figure 4). Legion has patented its pedestrian simulation solution and its movement algorithms have been calibrated to actual measurements of walking speeds, personal space preferences and the elastic tolerances of these measurements. It claims to have an accuracy of 95% for a prediction of how people will move in spaces and to have been used by independent agencies including London Underground, Madrid Metro and the London Fire Brigade. With Legion the user can evaluate and predict evacuation times, density analysis, journey times between locations, delay, route choice and other metrics. Other prediction software simulations are discussed in [9,10] and [12].


Figure 4: Inside a traffic command centre - video cameras are used in most major cities (after [6, 8])

C. Road Travel Times on VMS

Unlike inter-vehicle communication which uses beacons generated by onboard device on each vehicle, another approach relies on sensors which are embedded on the surface of the road [14]-[15]. These devices can provide data so that drivers can know how much time is required to reach their destination. Integrated with software, this approach helps to improve the flow of traffic according through a self-regulating process: the driving time between two points is displayed in real time, so that drivers can evaluate the state of traffic and may choose another less encumbered route if need be.

Sensors embedded in carriage-ways are able to provide data in order to calculate several variables in real time. This includes data on traffic flow, speed and a representation of traffic density. In the VMS system [7] the other data items suggested to be included in the display (or FM radio) are information on what motorists should consider doing to minimize or avoid delay, alternative routes to help drivers bypass certain congestions (these routes can be suggested more intelligently, using various methods – e.g. ant-colony algorithm [4] or fuzzy algorithm [10]), and relevant information to drivers as they approach junctions to join motorways. These types of information allow drivers to consider other routes, the length of traffic jams and when the jams can be overcome (perhaps due to accidents), and how long it is expected time to clear jams. In the case of ant-colony algorithm, which is applied in North-West region of Delhi, India, consisting of 25 places, it is found that, this algorithm can provide new routes, resulting in an improvement of distance 3% to 47.9% comparing with existing jammed routes [4].

Figure 5: VMS device (signpost) on the expressway around Paris (Photo. INRETS) [7]

In the VMS system [7] the sensors are typically, spaced approximately 500 meters apart, along with the signposts (see Figure 5) and measurements are taken every minute. Further research by the transportation authorities shows that although drivers are for the most part (98%), glad to benefit from this VMS service, most of the time, they are no more likely to change their itinerary when the expressway is crowded [7], [15]. One study [7], [11] conducted in Paris, France, shows that the assumption that drivers wish to reach their destinations as quickly as possible is not valid for all drivers: out of 30 drivers (all of whom know alternative routes), only 23% of participants emphasized wanting to reach their destination as quickly as possible, and chose an alternative route because they were familiar it; 60% emphasized the comfort of driving; the remaining 17% opted to stay because the travel times to reach their destination displayed on VMS sign board were not too long.

IV. DISCUSSION

From this literature review we believe that the various approaches surveyed can be grouped into three (3) categories. These categories are as follows.

A. Improving the usage of the existing roads or building new ones [6, 9].
B. Installing new hardware:
   i. On the roads: video, sensors [4], [7], [13]-[14], and toll gates (e.g. Electronic Toll Collection [3])
   ii. On each vehicle: devices such as GPS, communication devices (both are usually integrated with software which can include simulations to predict possible traffic jams [8]-[10], [12] and various optimization methods (e.g. ant colony [4])).
C. Implementing regulations which manage traffic [2], [5]-[6].

The applicability of these categories mainly depends on the practicality of implementing each technology used, and the availability of funds. Furthermore, it is clear that there is no single category which can address the traffic jam problem effectively. These categories should be combined in order to free roads from traffic jams. It is also important to implement the most appropriate technology on the most congested roads. For example, the VMS system which requires sensors to be embedded on the target roads cannot be successfully implemented on congested roads which do not have suitable alternatives (capacity and distance wise).

There are number of weaknesses in the approaches surveyed in the current literature review. Certain approaches assume a certain quality of existing infrastructure and assume a certain level of education among the drivers. For example, the meticulous approach of [1] does not recommend building new lanes [9], because the existing lanes are big enough to be converted. In the VMS approach it is assumed that the majority of commuters are keen to read road-messages, which may not be a valid assumption in all deployment situations. Similarly, while certain regulations are practical, others may in fact create additional problems. Thus, for example, regulations prohibiting factory workers to use cars/motors can reduce traffic but its effectiveness is dependent on the existence of good public transportation. Along these lines, regulations imposing too much transport tax in certain countries may cause political unrest. In the case of subsidies, in certain countries subsidies are required to enable funding for infrastructure development. This is notable in developing nations because privately owned companies typically do not have sufficient funds to perform what is seen to be the government's role in infrastructure building.

Overall there are number of promising strong aspects of the various approaches. Many investigations have been conducted in this topic, and these can be used as a stepping stone for other novel solutions in the future, or for the existing methods to mature. Meticulous design has a better chance to succeed since it has combined several technologies and has proven to give good results in achieving better traffic conditions.

V. CONCLUSION

While there are a number of technologies which can aid certain approaches to reduce and avoid traffic jams, there is still a need to look for a solution that makes use of existing technologies (e.g. using existing hardware) in commuter-vehicles. This enables better integration and less cost to the commuters. Using existing technologies also has the benefit of familiarity on the part of the user (drivers), and reduces the need for buyer education regarding the related products. It is also clear that whatever novel solution might subsequently develop, most likely the solution will integrate aspects across the categories of approaches. Thus, for example, in the category of regulations, public education and the announcement of new regulations for the commuters must be performed in stages and repetitively to increase their awareness.

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