Shockwave Traffic Theory

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There are few things in life that offer us absolute certainty; one of them is the fact that drivers are annoyed by traffic congestions. This is a universal truth that will stay with us for as long as we have roads and people using them.

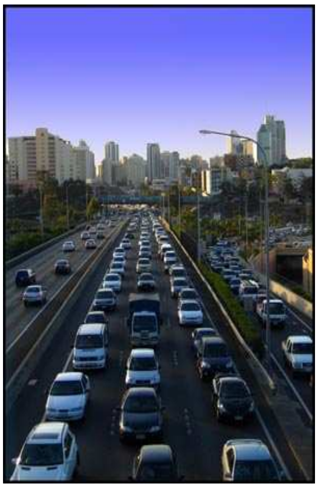
Traffic congestion has a long story, dating back to ancient Rome (when all roads lead to it). The road system of the Ancient Romans was one of the greatest engineering accomplishments of its time, with over 50,000 miles of paved road radiating from the center of the City. Although the Roman Road System was originally built to facilitate the movement of troops throughout the empire, it was inevitably used for other purposes by civilians, thus starting the first traffic congestions. One Roman Emperor was so unhappy about commercial carts clogging Rome's streets every day that he decreed those vehicles could enter at night only, but the clatter of horses' hooves on the cobblestones and the noises of countless animals kept so many people awake that he quickly rescinded the decree. [i]

Today, our freeways are trying to cope with the massive volume of automobiles that crowd our cities, peak hour congestions remain a constant factor in civilized urban life all over the world.

Causes of Traffic congestion

There are many theories about traffic congestion, in 2005, the U.S. Federal Highway Administration released a study that stated there are six root causes of congestion[ii]. The study lists the following summary of its findings for traffic disruption:

1. Bottlenecks 40%
2. Traffic incidents 25%
3. Bad weather 15%
4. Work zones 10%
5. Poor signal timing 5%
6. Special events/other 5%



There are many theories and approaches to try to find a way to understand how traffic congestions occur; generally, traffic engineers have based their models in either a mathematical or an economical approach.

Mathematical theory

This theory attempts to apply the rules of fluid dynamics to traffic flow, likening it to the flow of a fluid in a pipe. Congestion simulations and real-time observations have shown that in heavy but free flowing traffic, jams can arise spontaneously, triggered by minor events, such as an abrupt steering maneuver by a single motorist.

Traffic theorists liken such a situation to the sudden freezing of super cooled fluid.[iii] However, unlike a fluid, traffic flow is often affected by signals or other events at junctions that periodically affect the smooth flow of traffic; to simulate these disturbances, the model considers the effects of this by grouping vehicles and randomly changing the flow patterns within individual segments of the network.

Economic theory

Congested roads can also be seen as an example of the tragedy of the commons. Because roads in most places are free at the point of usage, there is little financial incentive for drivers not to over-utilize them, up to the point where traffic collapses into a jam, when demand becomes limited by opportunity cost, making traffic demand greater than the available road capacity.

Congestion can also occur due to non-recurring highway incidents, which may reduce the road's capacity below normal levels. As this is an economical model, privatizations of highways and road pricing have been proposed as measures to reduce congestion through economic incentives and disincentives.

Shockwave Traffic theory

Current traffic theories still cannot fully predict under which conditions a "traffic jam" (as opposed to heavy, but smoothly flowing traffic) may occur. Up until now, theories about the causes of traffic jams have been computer modeled. The main problem with the models is trying to account for the way real drivers (and their cars) behave. When engineers model the way road traffic flows they break the traffic down into three categories: freely flowing jammed, and an intermediate state called synchronized flow in which dense traffic moves in unison, like marchers moving in step[iv].

But this synchronized flow is unstable. One car pulling into another lane and forcing the driver behind to brake hard is enough to start traffic bunching up. This can quickly develop into a jam that propagates backwards through the traffic like a wave. Failure to predict this "shockwave effect" has stymied past attempts to model traffic flow. It has been found that individual incidents (such as accidents or even a single car braking heavily in a previously smooth flow), may cause ripple effects which then spread out and create a sustained traffic jam when, otherwise, normal flow might have continued for some time longer. A shockwave in traffic exists whenever varying stream conditions meet. For example when traffic slows down for an accident and where a platoon of vehicles meets free flow conditions

Researchers at the University of Duisburg-Essen in Germany have developed a computer model that successfully reproduces the shockwave effect. "It is the first model to reproduce all known traffic states," says team member Michael Schreckenberg[v]. The team's aim is to be realistic about driver's behavior. Some drivers simply don't pay enough attention to the road, often from using their mobile phones, or because they are driving tired from an extensive shift at work, or because they eat or talk while they drive. Not a few exceed the posted speed limit and some become openly antisocial. It is almost impossible for a current computer models to recreate such behaviors.

Schreckenberg's computer model divides the road into a regular grid, with one line of cells representing each lane on a highway. Cells in the grid are marked as either containing a vehicle or empty. The number of empty cells between the virtual vehicles depends on the way the drivers are behaving. Accuracy not seen before has been achieved by modeling two behaviors, these are dubbed "aggressive" (in which drivers both get too close to the car in front and are forced to brake, or in which they change lanes too quickly, forcing others to break). The second behavior is "defensive", in which they drive at a generally safe distance.

As the model runs, it moves vehicles according to rules that embody realistic rates of acceleration and deceleration. No infinite decelerations are allowed, for instance. The result is a software model that combines realistic driver behavior with realistic physics. The model is already being used to forecast traffic on the autobahn network around the city of Cologne, based on traffic data gathered in real time from sensors buried in the road. Its forecasts, which predict conditions up to an hour ahead, are displayed on the web at www.autobahn.nrw.de. More than 90 per cent of time, it correctly predicts traffic density.

But the website has already become a victim of its own success; some of the 300,000 people a day who are visiting the site are changing their journeys on the basis of its forecasts, and this is beginning to make the forecasts themselves less accurate. And soon it could get even worse when the website becomes available on mobile phones.

So the researchers are now trying to adjust the way the traffic information is provided to drivers to take this destructive effect into account. One idea, might actually be to provide less complete traffic information to encourage drivers to adopt more varied strategies for evading congestion, so they do not all flock to the same exits.

End of mathematical models

In order to avoid these problems, a team of Japanese scientist decided to try a different approach: they put 22 cars on a 230 meters single lane circular track and told them to drive about 20 mph. At first the traffic moved freely, but the effects of shockwave traffic jam (the kind where you slow down and speed up with others behind you doing the same) were soon evident. As predicted, a few laps in, uneven gaps appeared between the cars. Then a group of cars created a "group". The people at the back of the group sometimes had to come to a stop. The car at the front of the group would speed away, only to rejoin the back of the group on the other side of the circle. *All this occur without a single sign or light controlling the traffic flow!* The shockwave jam travelled backwards through the ring of vehicles at roughly 12 mph, which is the same as the speed of the shockwave jams observed on roads in real life, says lead researcher Yuki Sugiyama, a physicist in the department of complex systems at Nagoya University[vi].

You can watch a video of the test track at:

www.encomwireless.com/shockwave.html

Human error is the culprit

Sadly, the results conclusively show that human error is to blame for traffic flow disruptions. Pinpointing the causes of shockwave jams is an exercise in psychology more than anything else. "If they had set up an experiment with robots driving in a perfect circle, flow breakdown would not have occurred. Human error is needed to cause the fluctuations in behavior," says Tim Rees of TRL, a UK transport research firm. Rees's team is calibrating detailed models of traffic flow through different road designs to minimize the probability of shockwave jams. One strategy already in use to reduce shockwaves is imposing temporary speed limits, but in order to do that, it is essential to add information and communications technology to transport infrastructure and vehicles in an effort to manage factors that typically are at odds with each other. That's why Intelligent Transportation Technologies are so relevant today.

Intelligent transportation technologies

Intelligent transportation systems vary in technologies applied, from basic management systems such as traffic signal control systems, variable message signs, traffic detection, container management systems, automatic number plate recognition or speed cameras to monitoring applications such as security CCTV systems, and then to more advanced applications which integrate live data and feedback from a number of other sources, such as parking guidance and information systems, weather information, bridge de-icing systems, and the like. Additionally, predictive techniques are being developed, to allow advanced modeling and comparison with historical baseline data.

Wireless communications

Various forms of wireless communications technologies have been proposed for intelligent transportation systems. Short-range communications (less than one mile) can be accomplished using IEEE 802.11 protocols, a standard being promoted by the Intelligent Transportation Society of America and the United States Department of Transportation.

Longer range communications (up to 25 miles) are in use with a mix of FHSS and DSSS products[vii]. Thousands of these units are currently deployed all over North America. There have been attempts to standardize the future infrastructure of wireless networks. Ideas such as Wi-MAX (IEEE 802.16), Global System for Mobile Communications (GSM) or 3G for mobile units have been proposed. But long-range communications using these methods, unlike the current FHSS and DSSS installations, these methods require a extensive and very expensive infrastructure deployment. There is lack of consensus as to what business model should support this infrastructure.

Floating car data/floating cellular data

You can virtually find a mobile phone in every car in North America these days. These mobile phones routinely transmit their location information to the network – even when no voice connection is established. These cellular phones in cars could be used as anonymous traffic probes. As the car moves, so does the signal of the mobile phone. By measuring and analyzing triangulation network data you could convert it into accurate traffic flow information. The more traffic congestion there is, the more mobile phones transmit data thus creating more probes for the system.

There many things to consider with this model: First there is a question of privacy: nobody likes to be constantly monitored by "Big Brother", and then there is the issue of non-metropolitan areas, where the distance between mobile antennas is larger and, thus, accuracy decreases.

Sensing technologies

Vehicle sensing systems include deployment of infrastructure to vehicle and vehicle to infrastructure electronic beacons for identification communications and may also employ the benefits of CCTV automatic number plate recognition technology at desired intervals for increased sustained monitoring of suspect vehicles operating in critical zones. Technological advances in telecommunications and information technology coupled with state-of-the-art microchip, RFID[viii], and inexpensive intelligent beacon sensing technologies would probably enhance the technical capabilities that will eventually facilitate motorist safety benefits for intelligent transportation systems globally. But the technology is still in its infancy.

Video and radar vehicle detection

Most video detection systems require some initial configuration to "teach" the processor the baseline background image. This usually involves inputting known measurements such as the distance between lane lines or the height of the camera/ radar detector above the roadway. A single detection processor can detect traffic simultaneously from one to eight cameras, depending on the brand and model. The typical output from a video detection system is lane-by-lane vehicle speeds, counts and lane occupancy readings. However, some systems provide additional outputs that include gaps, headways, stopped-vehicle detection and wrong-way vehicle alarms. This gives traffic managers a powerful toolkit for mitigating roadway congestion by modifying traffic signal timing or detecting incidents quickly.

Summary

The level of traffic congestion that society tolerates should be a rational (though not necessarily conscious) choice between the costs of improving the transportation system (in infrastructure or management) and the benefits of quicker and better travel. City Planning and urban design practices can have a huge impact on levels future traffic congestion, but they are of limited relevance for short-term change. Traffic flow is constantly being modified by an ever increasing number of vehicles on the road, which usually translates in slower speeds, longer trip times, and increased queuing.

We must take a deeper look at the currently available and emerging computer and real flow models of traffic congestion as well as at the current and emerging communication and control technologies for transportation systems. We have the potential to improve traffic conditions and reduce travel delays by facilitating a better utilization of the existing capacity of our traffic arteries. Although we now can officially blame individual drivers for traffic delays, it is still our professional responsibility to come up with a real “ITS answer” for this problem.

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