“Dynamic models have been developed that capture traffic dynamics and interactions, including capacity breakdown and recovery.”
Viewpoint:
The growing role of dynamic modelling

If only the world were static
Most of our roads have been planned and designed using static assignment models. These are models that were designed by mathematicians and as such they had to have properties that mathematicians like: they had to be differentiable, continuous and in general present a convex, solvable problem of how people get from A to B and what that means for traffic on the roads. Unfortunately this also meant they had to assume that roads behave something like balloons, being able to expand to accommodate any amount of traffic, be it at an asymptotically increasing amount of travel time for those vehicles.

Reality works rather different. Roads have an absolute maximum capacity and travel times increase suddenly when this capacity is approached. In addition, adding only a few more vehicles than a road can take will result in queues (called capacity breakdown) and the recovery capacity is much lower, meaning that the queues will only disappear when the traffic decreases far below the original maximum capacity.

While it is clear why planners prefer models that do not suddenly produce chaos while they are planning the road network, unfortunately real traffic does behave in this way.

In addition, these models usually work on a whole day’s worth of traffic and assume that traffic demand and road capacity are static for the whole day. In effect this presumes that traffic can be evenly spread over the whole day, nobody has to be anywhere at a specific time, and rush hours do not exist.

While these assumptions greatly simplified the problem and made it possible to make computer models that would run on the computers available in the eighties and nineties, it also means that many of the current roads that were planned with such models never come close to being able to deal with the current traffic, especially when it counts: in the morning and afternoon rush hours.

According to Wilco Burghout of the Royal Institute of Technology, Stockholm, planners have to give up static traffic modeling and adapt to an age of dynamic modeling and real-time data.
“the addition of a road to the network can actually make everybody worse off by increasing the travel times on all routes”

From static to dynamic

However with today's computing power there is no need to stick to models that massage reality to such an extent. Dynamic models have been developed that capture traffic dynamics and interactions, including capacity breakdown and recovery. Unfortunately, they behave a lot more like real traffic and are therefore unforgiving: producing large traffic jams for even minor road design errors, which makes them much more difficult to calibrate.

Planning agencies are therefore still reluctant to move from their trusted, well-behaved static models, even if their results are very different from reality. However, in recent years dynamic models are used more frequently, although often in addition to static models.

Another challenge that arises when dynamic models of traffic are used is that they need a dynamic description of the travel demand. This means modelling not only how many people want travel from A to B, but also when they leave A (or need to be at B). In addition, travel patterns vary with the time of day, with morning rush hours having most of the demand from peripheral origins to destinations in city centers and the afternoon peak in the opposite direction.

This means that the static demand matrices need to be factored into unequal chunks for different times of day. These dynamic matrices are then re-estimated together with the traffic model to match the observed flows and speeds for each time of day.

In many cases there is a need to model why people travel in the first place, how they plan their day and how they adapt their plans in reaction to traffic conditions. This is especially important for planning and managing dynamic congestion charging networks (e.g. Stockholm and Singapore), where varying charges given the time of day are used to try to spread traffic peaks over a longer period. Such dynamic modelling of travel demand (activity based demand models) is developing fast, but adds another layer of complexity and requires large amounts of data to calibrate.

The way these models operate is by using demographic and socio-economic data to create a synthetic population of the area, where each synthetic household has characteristics such as income, number of children, access to car(s) etc which on aggregate are typical for that neighbourhood. On the other hand, socio-economic characteristics of people at typical attractors (work places, shopping malls, schools etc) in the cities are cross-referenced against the synthetic households to generate travel patterns, which are then calibrated using overall travel demand data. These synthetic individuals and their travel patterns are therefore representative of their real life counterparts and follow similar trip chains such as dropping off the children at school in the morning, driving to work, doing the groceries and pick up the children on the way home. These synthetic individuals learn from their experience and may try to optimize their activity chain and times, in response to experienced traffic conditions.

So when evaluating the effects of dynamic congestion charges as a tool to try to spread the traffic peak hour, one can study not only the effects on peoples routes, but also departure times, and their travel behaviour in general. For instance, one can model people doing the groceries at a different mall to avoid traffic jams, or picking up the children before doing the groceries. It also provides information on the socio-economic effects of such measures, for instance which income groups or areas are benefiting most from certain measures and which areas may be negatively impacted. This allows for a much more accurate appraisal of proposed policies.

Braess Paradox: the price of anarchy

From the 1960s mathematicians have been aware of a counter-intuitive phenomenon called Braess' Paradox. This says that under certain circumstances, the addition of a road to the network can actually make everybody worse off by increasing the travel times on all routes. In particular, in case of congested or near-congested networks, the addition of a sufficiently attractive shortcut (such
as a bypass) is likely to ‘activate’ Braess’ Paradox.

Recently researchers have shown the occurrence of the paradox in real networks1 using modelling analysis of the main road networks of New York, Boston and London. These showed that closing certain roads during rush hour would actually reduce the average travel time for everyone in the network. In addition, such ‘hidden bottleneck’ analysis has led to modifications of the road networks in Stuttgart (Germany) and Seoul (South Korea).

**Everyone is a probe**

Another issue with dynamic models used to be the amount of data needed to calibrate and validate such models to reality. Traffic sensors used to be built into roads, which made them expensive to place and maintain. As a result relatively few links in the road network would provide data on traffic flows and speeds. However, in the last decade this has changed radically. Overground sensors based on microwave radar, image recognition and magnetic resonance and using wireless communications, have reduced the cost of traffic data collection.

In addition, two technologies in particular have increased the accuracy and abundance of data available to modellers. Mobile phone network operators can follow the location and movement of everyone with a mobile phone, which when filtered, anonymised and mapped onto the road network provides a plethora of real-time data on congestion and traffic flows. The second technology is the use of sat nav devices which report back to operators to continuously improve the routing of all drivers using that service. The main challenge is now finding methods for treating such large amounts of raw data in real-time so that they can be used while they are still fresh.

**Route Guidance for all**

Sat navs are a quickly expanding market (7.5m UK drivers have one), and are having an increasingly noticeable impact on route choices. Current models use the latest traffic data (from roadside sensors, mobile phones and other sat nav users) to provide drivers with dynamic re-routing, attempting to avoid traffic jams and minimize delays. The next step in this technology is using dynamic modelling for short-term predictive routing. The real-time traffic data on which the current re-routing is based, is already old when the driver gets to the respective roads in the network, leading to inaccurate estimations and drivers avoiding traffic jams that no longer exist.

Dynamic traffic models are re-calibrated to the real-time data on the fly and can provide a short-term prediction of the traffic conditions, producing improved routing advice, and the resulting traffic conditions, producing improved routing that takes into account how traffic jams develop over time.

There are political and ethical issues with the pervasiveness of sat nav and the dynamic re-routing, especially when one producer has a large market share (TomTom has currently 50% of the EU market). In effect it becomes unclear who is directing the traffic on the roads, and whether at some point some traffic jams observed on the roads are more a result of the advice from sat nav systems. One large sat nav firm has been asked by the Dutch government to show how their services may affect or cause traffic jams on the roads, at different levels of market penetration.

Another issue is that any predictive routing advice will invalidate itself if enough drivers follow it. This self-consistency problem is perhaps the most complicated issue that sat nav producers and government agencies have to deal with. Giving some users ‘bad advice’ for the good of the mass will undermine their credibility. The most promising direction seems to be using the uncertainty that is inherent in the travel times. Whereas currently average link travel times (for that time of day) are used, in reality there is a considerable amount of spread in the link travel times. This also means that in reality there often is no single optimal route, but a set of routes which are all ‘close enough’ to optimal, and it may depend on small variations in actual link travel times as to which would be ‘best’.

When explicitly accounting for this uncertainty, models are able to create a set of alternative routes which together may represent the best possible route, and which together will be able to accommodate all drivers trying to avoid the traffic jams.

In addition, the dynamic models try to capture their own effect by explicitly modelling the drivers’ reactions to their routing advice, and the resulting traffic conditions on the roads. In a number of iterations the advice is adapted until it is consistent with the resulting traffic conditions.

In many cases dynamic traffic models help analyse the crucial aspects of a problem and test suggested solutions. While it may be tempting to stick to static models for their simplicity, this may be a case of the proverbial drunk looking for his house keys under a street light, because it is too dark to search where he lost them.

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Figure 1 (Source: Hyejin, Gastner and Jeong 2008) Networks of principal roads (both solid and dotted lines; the thickness represents the number of lanes). (a) Boston-Cambridge area, (b) London, UK, and (c) New York City. The color of each link indicates the additional travel time to all drivers if that link is cut (blue: no change, red: more than 60 seconds additional delay). Black dotted lines denote links whose removal reduces the travel time, i.e., allowing drivers to use these streets in fact creates additional congestion.