Identification of recurring traffic bottlenecks using ANPR cameras

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Recurring traffic bottlenecks

What are recurring bottlenecks?

Bottlenecks are one of the main sources of traffic *congestion*. In particular, recurring bottlenecks are characterised by their predictability: when and where they occur, and their impact on traffic flow. Recurring bottlenecks, as opposed to congestion caused by sporadic incidents, are of special interest to traffic managers because they are associated with operational deficiencies often eligible for remediation. The identification and ranking of bottlenecks, in terms of experienced delay and variability, is therefore crucial for the prioritisation of interventions aimed at mitigating bottleneck-induced congestion [1].

Figure 1. Several operational elements that may cause recurring bottlenecks.

Characteristics of a bottleneck

An active bottleneck has four distinctive features: (i) congestion upstream of the bottleneck, characterised by slower speeds and longer travel times, (ii) free flow conditions downstream of the location, (iii) operation under considerable demand and (iv) the existence of a specific point where traffic breaks-down and a queue starts to form upstream, in other words, a clear indication that congestion is localised rather than systemic.

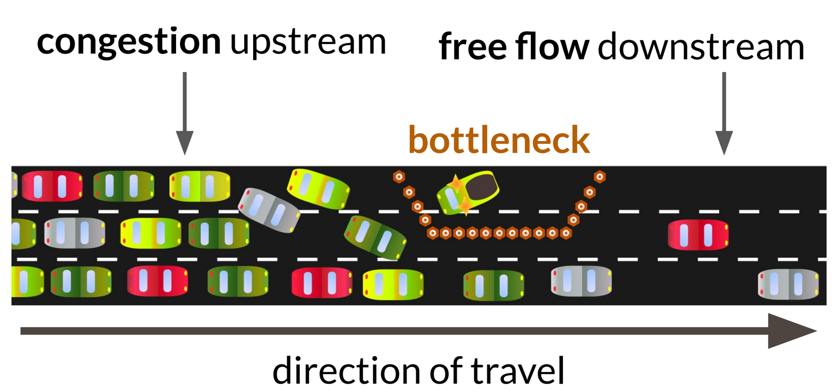

Figure 2. Schematic of a bottleneck.

Knowledge gap

Research on bottleneck identification and their impact has been done almost exclusively on *highways*:

- Highways carry large volumes of traffic and bottlenecks can incur severe economic and social costs.
- Highways approximate idealised roads, with few entry and exit points, which makes the measurement of traffic flow easier and less costly.

Local authorities can greatly benefit from extending the body of research to a larger variety of roads.

Opportunity: Automatic Number Plate Recognition (ANPR) cameras

Local authorities have started to employ large groups of ANPR cameras across urban centres to actively monitor traffic conditions, particularly travel time, and report them to back to drivers [2].

Figure 3. ANPR routes in Tyne and Wear as labelled by experts (left) and inferred (center, right).

Bottleneck identification

Motivating example

An instance of the bottleneck identification problem is depicted in Figure 4. The A1504 Killingworthway roundabout is a well known bottleneck which slows down vehicles that travelling North (location 'A') and then Westbound (location 'C' via 'B'). The effect can be observed in Figure 5, which depicts the count (left) and mean speed (right) of vehicles driving through each segment of the corridor, on 5-minute time windows. We can clearly see that vehicles move generally slower on the first segment, particularly during the evening peak-hour, a behaviour suggestive of bottleneck activation.

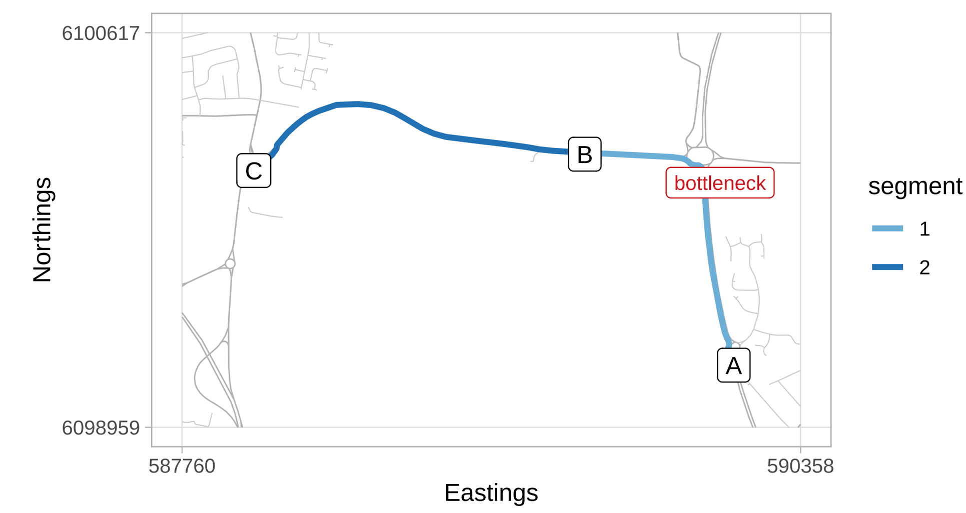

Figure 4. The A1056 Killingworthway infamous roundabout and associated North-Westbound ANPR corridor.

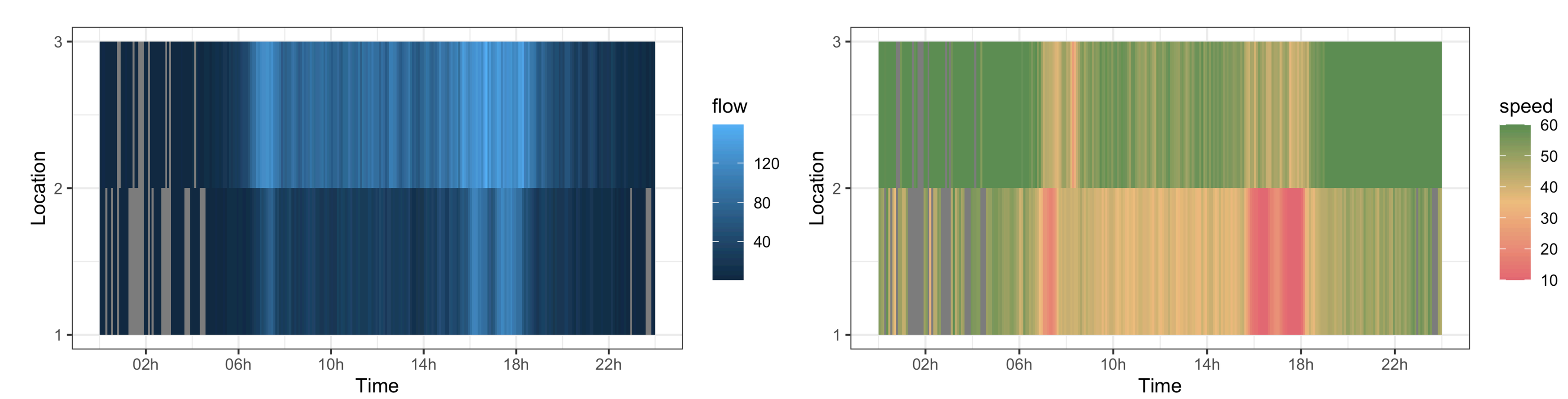

Figure 5. Speed and flow volume space-time plots for upstream (1-2) and downstream (2-3) camera pairs on 5 Mar 2018.

Activation model

We design our approach based on the model for freeway bottlenecks specified in [3]. Let $C = \{s_j\}_{j=1}^{n}$ denote a road corridor monitored by a series of ANPR cameras placed along its path, where s_j designates the jth segment (camera-pair) of the corridor. The sensors generate observations of traffic speed and flow, represented by $v(s_j, t)$ and $q(s_j, t)$ respectively, at each segment j and time interval t. We are interested in whether the segments of C are operating under localised congestion, particularly under the effect of a bottleneck. Let $A(s_j, t)$ be a binary variable which indicates the presence of an active bottleneck in segment j during time period t. We specify $A = 1$ if the following inequalities are met:

$$v(s_j, t) < \theta \cdot v_f(s_j) \tag{1}$$

$$\frac{v(s_{j+1}, t)}{v(s_j, t)} > \frac{v_f(s_{j+1})}{v_f(s_j)} + \phi \tag{2}$$

$$q(s_j, t) > q_m(s_j) \tag{3}$$

where $v_f(s_j)$ denotes the segment expected value of free flow speed; $q_m(s_j)$ indicates the typical-day median flow; θ is the upstream congestion factor; and ϕ is the factor that determines a substantial downstream speed gain.

Criterion 1 represents the presence of congestion upstream of the bottleneck; expression 2 symbolises improved traffic flow downstream, operating in or close to free flow; and condition 3 suggests user demand is within medium to high levels. We can not determine, however, the exact location of the bottleneck and where traffic breaksdown (we may be able to infer it in some cases).

Bottleneck activation results

We consider the parameters $v_f(s_j)$ and $q_m(s_j)$ to be free and estimate them heuristically using baseline speed and flow data. The two other parameters, θ and ϕ, are set according to values used in [3] and [4]. The initial results, depicted in Figure 6, are promising albeit not without its caveats (see below).

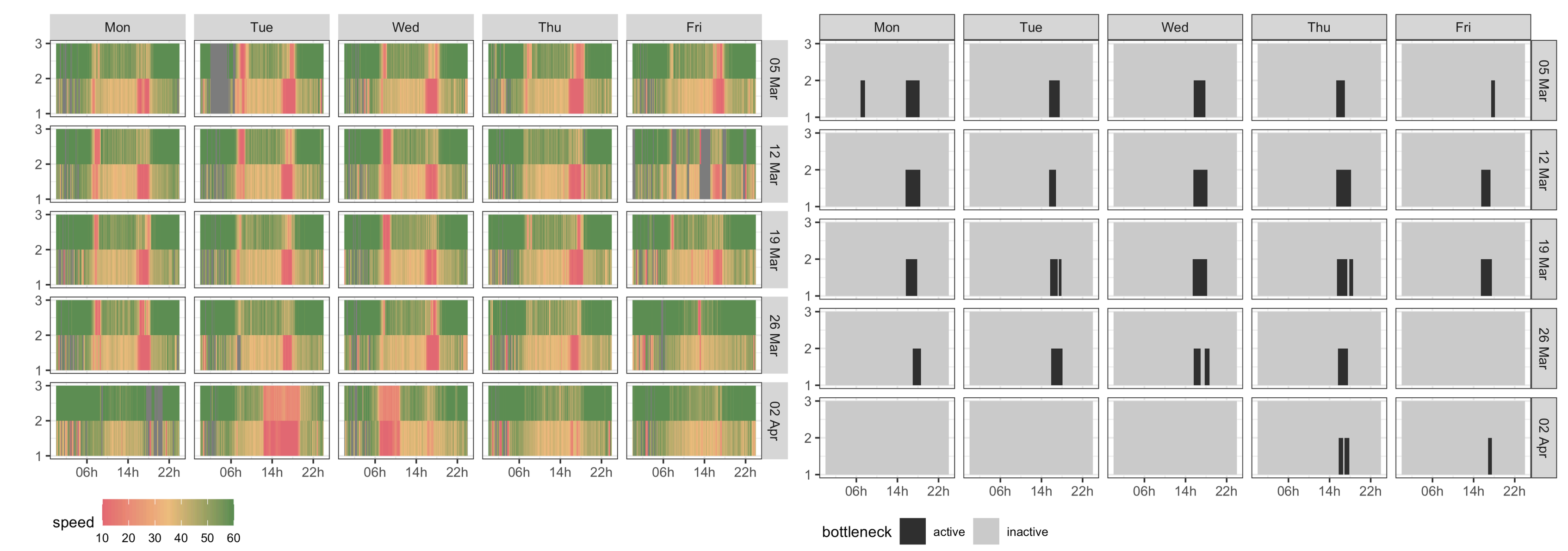

Figure 6. Speed and sustained bottleneck activation space-time plots for every weekday during a 5-week period in 2018.

Scaling identification across the whole network

The corridor labelling problem

To identify bottlenecks we are required to understand which camera tuples correspond to valid and popular vehicle journeys. We name these *corridors* and the process of discovering them *corridor labelling*.

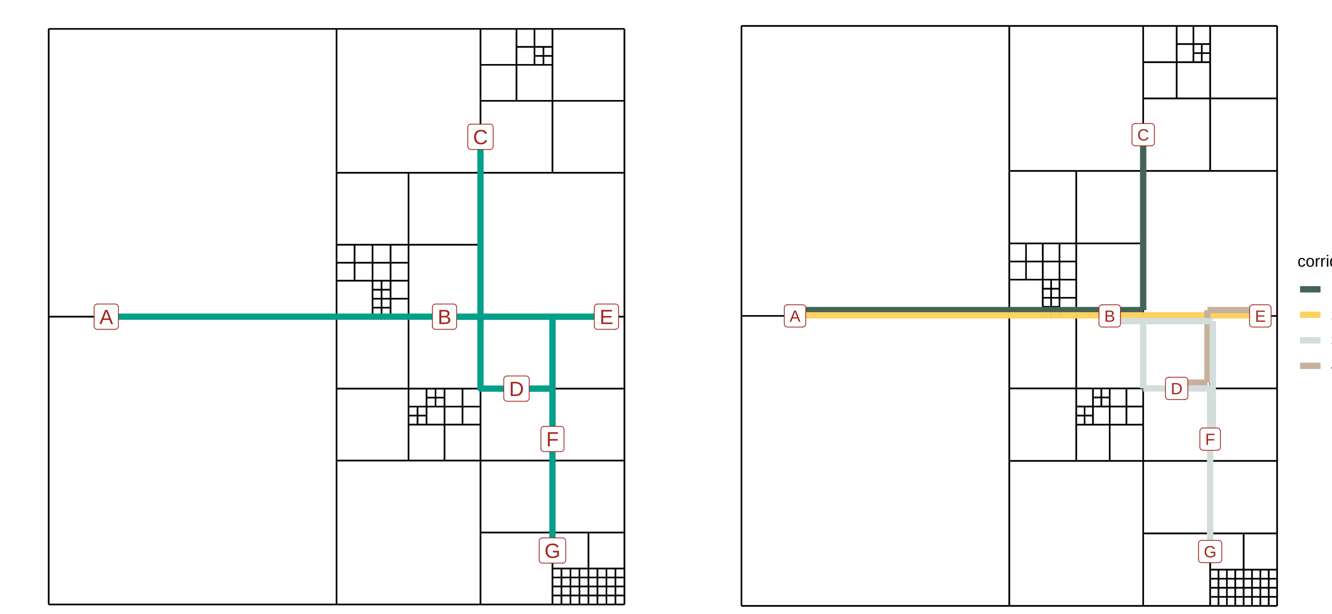

Figure 7. A conceptual example of the corridor labelling problem, input (left) and output (right).

Other challenges and limitations: Difficulty of evaluation, lack of a generative model, assumed trajectories, increased error rate with severe traffic congestion.

References

[1] N. C. Spiller, K. Blizzard, R. Margiotta, *et al.*, "Recurring traffic bottlenecks: A primer focus on low-cost operational improvements," 2017.

[2] P. M. P. Silva, M. Forshaw, and A. S. McGough, "Clustering vehicles based on trips identified from automatic number plate recognition camera scans," 2018.

[3] C. Chen, A. Skabardonis, and P. Varaiya, "Systematic identification of freeway bottlenecks," vol. 1867, no. 1, pp. 46–52, 2004.

[4] F. He, X. Yan, Y. Liu, and L. Ma, "A traffic congestion assessment method for urban road networks based on speed performance index," *Procedia engineering*, vol. 137, no. Supplement C, pp. 425–433, 2016.

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