

Using wavelet transforms for better interpretation of traffic simulation

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Simulation modelling is used by traffic engineers to measure various characteristics of roads and traffic. In this study, wavelet analysis methods were applied to a simple traffic engineering problem. An imaginary network was constructed using a microsimulation tool and four arbitrarily chosen

links were made one-way streets one-by-one in both directions. Synthetic data were then generated for these 16 different scenarios. The best directions for traffic for each of these four links to give minimum average delay over the network were studied. In order to ease congestion on this network,

continuous wavelet transform was applied. Results indicate that the proposed method offers a more flexible analysis of similarities in traffic conditions demonstrating the opportunity that wavelets could lead to a better understanding of similar problems in traffic engineering.

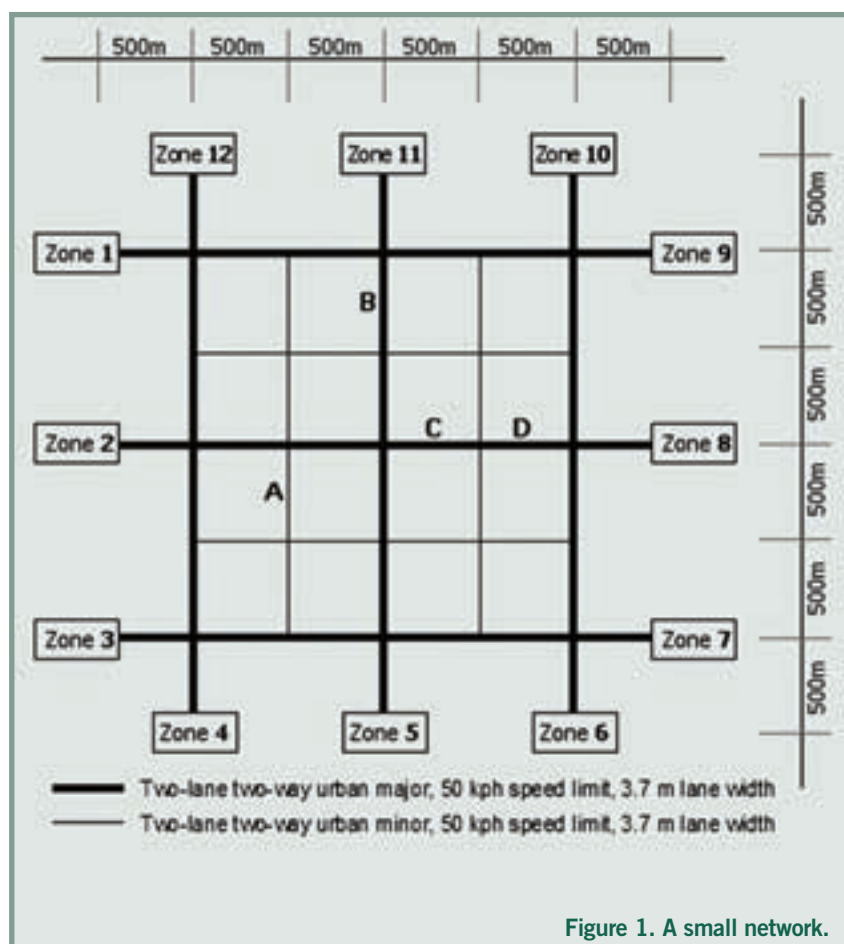


Figure 1. A small network.

INTRODUCTION

In many traffic simulation studies, the number of scenarios required may be numerous and the effects of all the factors involved may be too complicated to study and analyse. To overcome this, various tools and techniques may be necessary to interpret certain phenomena. In this paper we will demonstrate a different approach by using continuous wavelet transform (CWT). CWT is used to divide a continuous-time function into wavelets. Unlike the Fourier transform, the continuous wavelet transform possesses the ability to construct a time-frequency representation of a signal that offers very good time and frequency localisation. CWT gives more flexible analysis opportunities depending on time-frequency localisation. Wavelets and other analysis techniques are generally used for traffic accident and/or flow prediction (Cheng and Zhang, 2007).

The CWT is a multidimensional mapping of a mathematical signal, depending on a continuous time (or space) parameter t (or x), to a two dimensional function $\tilde{f}(a,b)$ depending on a scale parameter a and a shift parameter b . Mathematically, the CWT is defined by an integral transform (Daubechies, 1992). The width of the wavelet's kernel is controlled by the scale parameter a such that the wavelets are compressed for $|a|<1$, and are dilated for $|a|>1$. The positions of the dilated or compressed wavelets are controlled by the shift parameter b . The zero mean condition implies that the wavelet should oscillate and decay at infinity. However, it is often desirable that higher order moments vanish. The higher the number of vanishing moments, the better the smooth signals can be approximated with fewer wavelet coefficients. However, because of the orthogonality constraint,

the adequate selection of a particular wavelet is subject to a trade-off between the number of vanishing moments and the size of the support of the wavelets.

In practice, wavelets can be classified in three broad categories that can guide the selection of an appropriate wavelet kernel for a specific task. These are (i) the orthogonal, (ii) the bi-orthogonal and (iii) the analytic wavelets. The first two are mostly associated with the discrete wavelet transform (Teolis, 1997). The analytic wavelets are usually associated with the CWT (Khene, 2005). As the latter aims at separating out the frequency components of a signal, it is important that the wavelet kernel gives the best resolution in frequency. In other words, the shape of the wavelet coefficients at some scale should resemble a sinusoid at the corresponding pure frequencies. The best wavelet for this purpose could be a Gaussian modulated complex function with decaying exponential. As a matter of fact, one of the most widely used continuous wavelets in geophysics is the complex Morlet wavelet that consists of a plane wave modified by a Gaussian envelope and which is the origin of the development of the wavelet analysis. The CWT constitutes a robust and powerful analyzing tool (Khene, 2005).

The graphical representation of the wavelet coefficients for the different scales (wavelengths) as a function of depth is referred to as the scalogram. For more information about the CWT, see Khene (2005), Holschneider (1995) and Kaiser (1994).

A CASE STUDY

We looked at a typical simulation problem of introducing one-way traffic, which may be used as part of an area wide scheme to break up a road network into short sections, and by creating detours to discourage rat running (IHT, 1997). High speeds can also be achieved due to the absence of psychological lateral friction between the opposing lanes (Gunay, 2007). In high density areas, one-way street systems become quite attractive (Roess et al, 2004), whereas Jones (1986) emphasised possible disadvantages from neighbourhood planning perspectives. Karmeier (1982) reported that a conversion of a two-way street system to one-way operation resulted in reductions in average journey times, the number of stops and even the number of accidents. However the problem for the design or operational authorities is to determine which links should be made one-way and in which direction.

Here we artificially constructed and loaded a sample network with 52 links using Paramics microsimulation. Our problem assumed that four randomly chosen links (A, B, C, and D) in this small network (shown in Figure 1) may be made one-way streets for potential improvements in network performance. In deciding the best combination of the directions of those four links, we supposed that the decision maker runs all possible options.

Table 1 shows the origin-destination (OD) movements (in number of vehicles) throughout a one-hour simulation period. These values are randomly generated figures within a moderate range to produce a slightly congested

Zones	1	2	3	4	5	6	7	8	9	10	11	12	Total
1	0	25	53	34	78	82	73	11	46	82	31	18	533
2	16	0	74	58	41	105	51	92	106	32	84	12	671
3	88	28	0	21	79	16	65	61	17	93	22	92	582
4	74	20	20	0	78	77	16	95	39	84	107	53	663
5	40	50	28	26	0	56	41	109	14	60	11	66	501
6	105	101	78	86	60	0	99	96	38	29	80	35	807
7	93	44	67	59	32	38	0	48	86	40	73	91	671
8	78	20	71	43	43	61	98	0	37	80	20	56	607
9	94	90	46	27	23	84	89	68	0	49	19	64	653
10	58	17	32	80	87	54	77	81	86	0	72	65	709
11	44	61	65	62	96	79	54	53	78	53	0	59	704
12	87	17	25	73	27	94	20	88	20	74	52	0	577
Total	777	473	559	569	644	746	683	802	567	676	571	611	7678

assignment so that the effects of directional changes to the links A, B, C, and D can be seen. Too light and too heavy OD assignments are excluded from the study.

For the input of physical and kinematic attributes of all vehicle classes, the default values of Quadstone Paramics v6.3 were used. To minimise complexity, all junctions were give-way type junctions. Route choices for the origin-destination movements of each vehicle were determined by selecting those turns at every junction which give the shortest distance between corresponding origin and destination pairs. However, a perturbation factor of 40 and a network familiarity value of 85% (for all vehicle classes) were used to distribute traffic between the alternative routes for each OD pair. There were 16 possible one-way movements (referred to as 'scenarios' throughout the paper) for the four links identified in our example problem (Table 2).

Since three runs are made for each scenario (to smooth out random effects for the purpose of better statistical averaging), a total of 48 simulation runs were carried out. This was achieved by using random seed numbers. Identical seed numbers were used for the first runs of each scenario, and a different seed number was used for the second runs of the same scenarios, and so on.

THE FINDINGS

To examine the prediction performance gain, the proposed approach is compared with the traditional methods with a Gaussian-Mixture-Model predictor. We performed five different experiments on simulation results. First of all, Figure 2 shows CWT analysis of average delay where the Scenarios 2 and 6 (ie $\overset{\uparrow}{A}\overset{\downarrow}{B}\vec{C}\overset{\leftarrow}{D}$, $\overset{\downarrow}{A}\overset{\uparrow}{B}\vec{C}\overset{\leftarrow}{D}$) are more effective than the other scenarios as far as the average delay is concerned. In both of these scenarios, the Links A, C and D were left unchanged. As a result of this particular experiment, we found that changing the traffic direction of Link B, always had an increasing effect

Table 1:
The origin-destination matrix used in the simulation (number of vehicles per hour)

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1.	$\overset{\uparrow}{A}\overset{\uparrow}{B}\vec{C}\vec{D}$	5.	$\overset{\uparrow}{A}\overset{\downarrow}{B}\vec{C}\vec{D}$	9.	$\overset{\downarrow}{A}\overset{\uparrow}{B}\vec{C}\vec{D}$	13.	$\overset{\downarrow}{A}\overset{\downarrow}{B}\vec{C}\vec{D}$
2.	$\overset{\uparrow}{A}\overset{\uparrow}{B}\vec{C}\overset{\leftarrow}{D}$	6.	$\overset{\uparrow}{A}\overset{\downarrow}{B}\vec{C}\overset{\leftarrow}{D}$	10.	$\overset{\downarrow}{A}\overset{\uparrow}{B}\vec{C}\overset{\leftarrow}{D}$	14.	$\overset{\downarrow}{A}\overset{\downarrow}{B}\vec{C}\overset{\leftarrow}{D}$
3.	$\overset{\uparrow}{A}\overset{\uparrow}{B}\overset{\leftarrow}{C}\vec{D}$	7.	$\overset{\uparrow}{A}\overset{\downarrow}{B}\overset{\leftarrow}{C}\vec{D}$	11.	$\overset{\downarrow}{A}\overset{\uparrow}{B}\overset{\leftarrow}{C}\vec{D}$	15.	$\overset{\downarrow}{A}\overset{\downarrow}{B}\overset{\leftarrow}{C}\vec{D}$
4.	$\overset{\uparrow}{A}\overset{\uparrow}{B}\overset{\leftarrow}{C}\overset{\leftarrow}{D}$	8.	$\overset{\uparrow}{A}\overset{\downarrow}{B}\overset{\leftarrow}{C}\overset{\leftarrow}{D}$	12.	$\overset{\downarrow}{A}\overset{\uparrow}{B}\overset{\leftarrow}{C}\overset{\leftarrow}{D}$	16.	$\overset{\downarrow}{A}\overset{\downarrow}{B}\overset{\leftarrow}{C}\overset{\leftarrow}{D}$

Table 2: The Scenarios

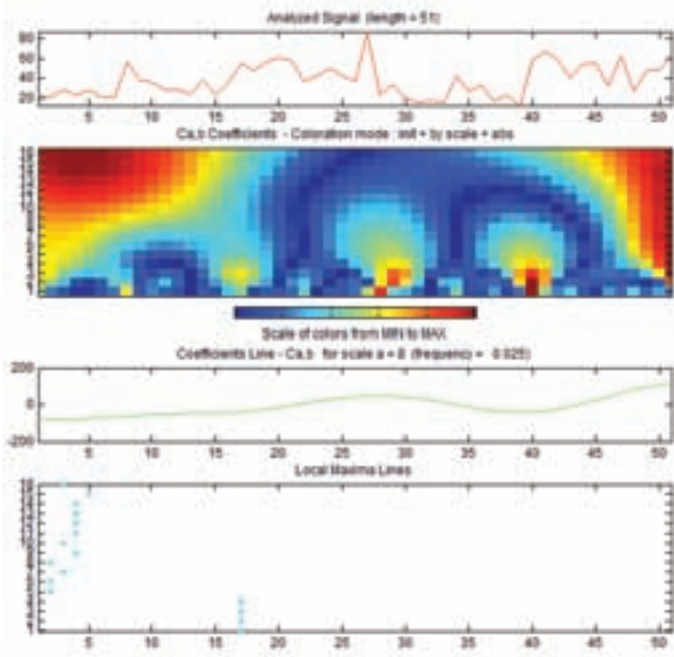


Figure 2: Average delay (s).

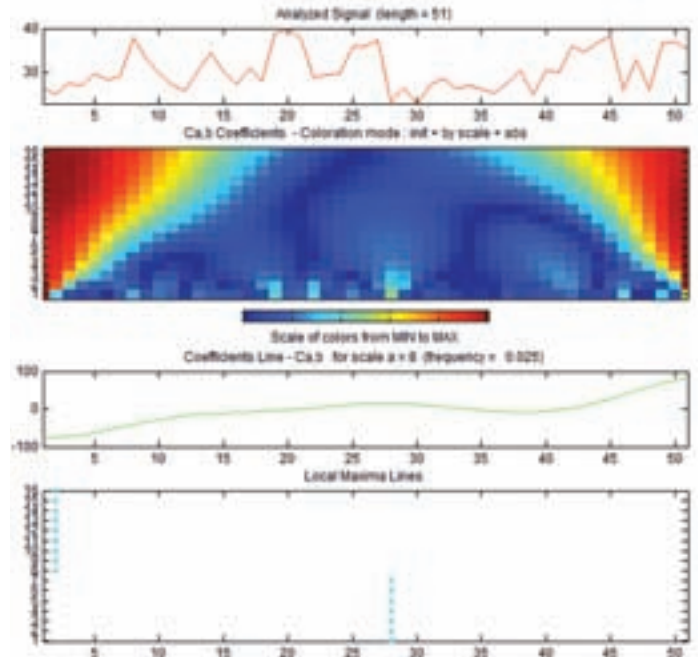


Figure 3: Average link density (pcu/km).

on the average delay.

Figure 3 shows the CWT analysis of average link density in that the Scenarios 9 and 10 (ie $\overline{A\overline{B\overline{C\overline{D}}}}$, $\overline{A\overline{B\overline{C\overline{D}}}}$) are more effective than the other scenarios with respect to average link density. In both scenarios, the Links A, B and C were kept unchanged. As a result, changing the direction of Link D increased average link density.

Figures 4 and 5 show CWT analysis of average link flows and average link speeds respectively. None of the 16 scenarios had an effect on the average link flows and speeds.

Figure 6 shows the CWT analysis of average stoppage time. This figure has shown that the Scenarios 2 and 6 (ie $\overline{A\overline{B\overline{C\overline{D}}}}$, $\overline{A\overline{B\overline{C\overline{D}}}}$) are more effective than the other scenarios in relation to the average stoppage time. In both sce-

narios, the Links A, C and D were not changed. We therefore can conclude that changing the direction of Link B increased the average stoppage time.

CONCLUDING REMARKS

In this paper, the CWT-based feature extraction provided a simple and computational efficient way to uncover unobvious behaviour of traffic flow. Especially in detailed interpretations of traffic simulation results, usually it is very difficult, if not impossible, to predict certain features by conventional means. As we discussed above, the effectiveness of some of the scenarios on certain criteria would not be detected by crude (visual) inspection of the simulation results. The choice of wavelet coefficients is flexible

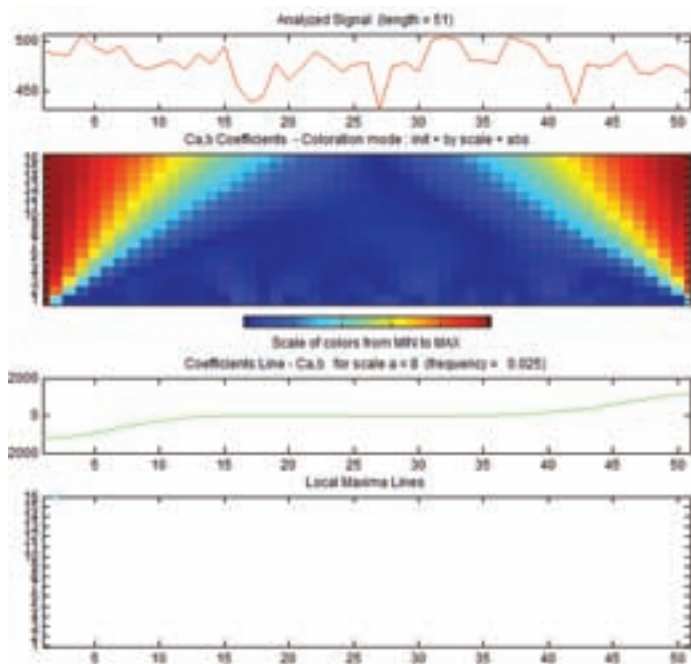


Figure 4: Average link flow (pcu/h)

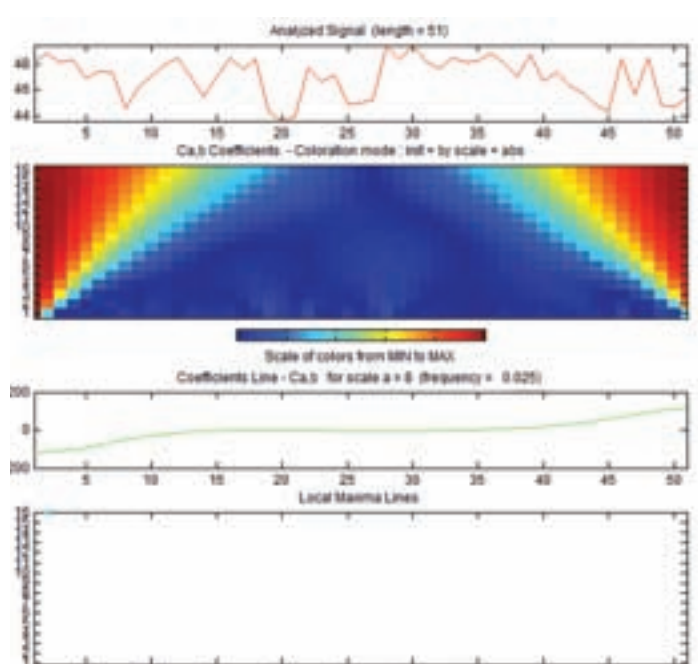


Figure 5: Average link speed (km/h).

and application-dependent, and by selecting different levels of CWT coefficient, traffic flow characteristics at different resolution can be located. The proposed methods have proven to be useful in real applications and may outperform conventional methods in flexibility, accuracy and effectiveness.

Simulation is usually performed to evaluate instant cases. CWT, however, gives not only the instant cases but also the strong actual data for their following stages. Moreover, the similarities uncovered can be used to improve accuracy of outlier detection and the traffic flow prediction.

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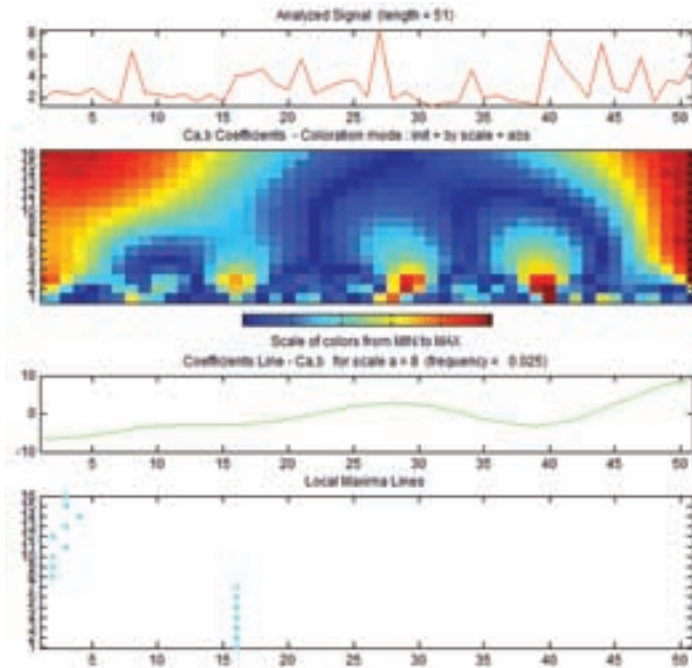


Figure 6:
Average
stoppage
time (s).

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