

Cite this article

Hussain RS, Quddus MA, Enoch MP *et al.*
Time series analysis of local authority policy interventions on highway works durations.
Proceedings of the Institution of Civil Engineers – Transport,
<https://doi.org/10.1680/jtran.18.00013>

Research Article

Paper 1800013
Received 29/01/2018;
Accepted 18/10/2018

Keywords: roads & highways/public
policy/traffic engineering

Published with permission by the ICE under the CC-BY 4.0 license.
(<http://creativecommons.org/licenses/by/4.0/>)

Transport**ICE** Publishing

Time series analysis of local authority policy interventions on highway works durations

Rizwana Shaheen Hussain MSc, EngD, Cert Eng
Traffic and Transportation Engineer, Communities and Place, Derby City Council, Derby, UK

Mohammed A. Quddus BSc, MEng PhD
Professor of Intelligent Transport Systems, Centre for Innovative and Collaborative Construction Engineering, School of Architecture, Building and Civil Engineering, Loughborough University, Loughborough, UK

Marcus P. Enoch BEng (Hons), MSc (Eng), PhD, CMILT, FHEA, FRGS
Professor of Transport Strategy, Centre for Innovative and Collaborative Construction Engineering, School of Architecture, Building and Civil Engineering, Loughborough University, Loughborough, UK
(corresponding author: m.p.enoch@lboro.ac.uk)

Kirti D. Ruikar BArch, MSc, EngD, FHEA
Senior Lecturer in Architectural Engineering, Centre for Innovative and Collaborative Construction Engineering, School of Architecture, Building and Civil Engineering, Loughborough University, Loughborough, UK

Nigel Brien LLB
Head of Traffic and Transportation, Communities and Place, Derby City Council, Derby, UK

David Gartside
Former Director, Strategic Partnership, Planning and Streetpride, Communities and Place, Derby City Council, Derby, UK

Highway works are highly inconvenient and disruptive for society. Accordingly, four highway policy interventions were investigated in Derby, UK, for potential corresponding reductions in highway works durations. Time series analysis was used to test the durational impacts on works led by Highway Authorities (HAs) and utility industries. The modelling results demonstrated that a highway works management permit scheme (chargeable) reduced utility works durations by 5.4% (727 work days annually). Conversely, three conflated interventions – namely, the permit scheme (cost-free to HAs), JCB Pothole Master deployment and construction direct labour organisation – did not make any statistically significant difference to HA works durations; however, introducing an automated works order management system (Woms) reduced HA works duration by 34% (6519 work days annually). The key finding of this study is that chargeable permit schemes can create the impetus for change, as demonstrated by the utility industry. Furthermore, the Woms revealed that back-office efficiency can lead to on-site efficiency in works execution.

Notation

B	backward shift operator
d	order of non-seasonal difference
$f(l, X)$	function of deterministic part of model
I_t	intervention variable
N_t	stochastic or noise component
p	order of non-seasonal autoregressive process
q	order of non-seasonal moving average process
t	discrete time
t'	implementation date
u_t	uncorrelated random error term with zero mean and constant variance
X	independent control variable
Y_t	dependent variable (i.e. the mean duration of each highway work activity) for a particular time t
y_t	appropriate Box–Cox transformation of Y_t
β	beta coefficients
θ	regular moving average operator
ϕ	regular autoregressive operator

1. Introduction

Growing urbanisation and the escalation of internet dependence has created an increased need for utility infrastructure to match commercial and residential needs, notwithstanding the need to maintain and replace ageing Victorian utility infrastructure. Underground, a complex network of utility apparatus enables the delivery of essential services to properties for day-to-day domestic and commercial use, with at least seven

main utilities underground (i.e. water, sewers, gas, electricity, telecommunications, street lighting and traffic cabling) owned by different organisations that manage, install, operate and repair their private networks independently of each other (e.g. Rogers *et al.*, 2012). Problems can (and often do) arise when utility companies, known as statutory undertakers (SUs), need to install/access/maintain utility assets (known as street works) or when a Highway Authority (HA) needs to repair the fabric or structure of its highway (known as road works); these practices can disturb and clash with society's above-ground expectations for expeditious transportation.

Unsurprisingly, road works and street works are considered disruptive and inconvenient to society (Hussain *et al.*, 2016). An estimated 1.5 million street works with a direct construction cost of around £1.5 billion occur in the UK annually (McMahon *et al.*, 2005), which can substantially decrease lane flow capacity and cause major congestion (e.g. Walker and Calvert, 2015). Furthermore, repeated utility cuts seriously deteriorate road life and significant damage to infrastructure has been reported in Toronto, Vancouver, San Francisco (California), Phoenix (Arizona) and several UK cities (e.g. Amec, 2002; Jordan *et al.*, 2009; Mouaket and Capano, 2013). Other negative impacts of road works and street works include, among others, loss of trade for local businesses, increased accidents, increased vehicle operating costs, increased air pollution, frustration for drivers and aesthetic depreciation (Brady *et al.*, 2001; Hussain *et al.*, 2016; Lepert and Brillet, 2009; Matthews *et al.*, 2015; TRL,

2012; UK Parliament, 2014; Walker and Calvert, 2015; Wilde *et al.*, 2018). Annual societal costs of street works in the UK are estimated at £5.6 billion, of which £5.1 billion is attributable to lost driver time alone, indicating that the cost of delay is actually higher than the cost of construction itself (Halcrow, 2004; McMahon *et al.*, 2005). Therefore, there is a compelling need to minimise highway works activities and their impacts in order to minimise disruption and inconvenience and maximise transportation movement above-ground.

The literature indicates that, traditionally and primarily, highway works in England were managed through either noticing schemes, permit schemes or lane rental schemes, briefly described as follows.

- Noticing schemes are the traditional highway works management schemes that enable work promoters to submit prescribed notifications to the street authority (SA) to 'notify' of their intention to work (UK Parliament, 2014). Noticing schemes afford the least control to local authorities (LAs) and therefore their effectiveness in works management is anecdotally limited.
- Permit schemes supersede noticing, whereby all work promoters are required to submit permit applications to seek authorisation to execute highway works, and thus are gaining popularity in England. Similar schemes also operate in Singapore and New York (LTA, 2014; TRL, 2012). Permit schemes seek to control and coordinate highway works; this can be helpful in minimising utility cuts, which are recognised as damaging to highway structures and reduce pavement life (Jordan *et al.*, 2009). UK permit schemes give SAs increased powers to manage and control works compared to the noticing regime; failure to comply with any conditions set can attract financial penalties (UK Parliament, 2014).
- Lane rental schemes, as operated in London and Sydney, advance permit schemes, enabling LAs to rent out highway lanes for specified durations for works execution, with rental costs higher during busier traffic times (CoS, 2014; DfT, 2012a; TRL, 2012). Unlike the noticing and permit schemes, lane rental schemes are focused on expeditious works completion in the least disruptive manner, which is advantageous to the travelling public.

Looking at the performance of permit schemes in practice, government regulations require that SAs evaluate permit schemes after 12 months, then subsequently after 36 months to monitor their effectiveness (DfT, 2014). An analysis of permit scheme performance reports from around the UK reveals the following reductions.

- London permit scheme – 2% reduction in average duration in the first year (LPSOC, 2014).
- Kent County Council – 18% reduction in 'impact of road works' over 4 years (KCC, 2014).

- Yorkshire common permit scheme – 21% reduction in duration over 2 years (YCPS, 2015).

Overall, these reports are detailed, identify data limitations and report on pre-agreed performance indicators agreed with the Department for Transport (DfT), but lack robustness due to limited information about study methods, data analysis techniques, and lack appropriate statistical sensitivity testing of results. Moreover, the results are not subject to independent peer review or DfT feedback, which can undermine confidence in the results given. In addition, the National Joint Utilities Group (NJUG, 2012) found that SUs feel that such evaluations are not comprehensive as they fail to reflect the true costs borne by them.

Looking more broadly, research into the performance and impacts of specific policy interventions or on how they affect an area or population is limited and, so far, there is only one academic study, which analysed the Kent permit scheme using fuzzy logic (Shrivastava, 2010), that has looked at how these schemes have performed. This absence of robust permit policy analysis in the literature is therefore a concern when one considers the degree of change caused by the adoption of permit schemes in the English highways management industry (Hussain *et al.*, 2016). It was this concern that led to this study on the impacts of introducing a package of highway works management interventions in Derby.

This paper is important because it contributes to knowledge in an under-researched area of policy, and innovative because it uses time series analysis to measure the impact of introducing key policy changes. The remainder of the paper is structured in sections covering information about the study area (Derby), study data, method, results, followed by a discussion and conclusion with important policy implications.

2. Derby

Derby is a fairly typical English regional city of around 250 000 people and is located approximately 200 km north of London. Derby City Council (DCC) has competing statutory functions in respect of highway management: the SA is statutorily responsible for the above-ground management of traffic movement on the highway network, which includes the legal network management function and regulation of the permit scheme, while the HA is statutorily responsible for maintaining the fabric and structure of the highway – both functions are independent of each other.

Traditionally and primarily, highway works in Derby have been managed by the SA through a noticing system. The Derby permit scheme commenced in October 2013, replacing noticing on key city streets (DCC, 2013). Permit costs can range from £60 to £231 per application, and £45 per variation. Permit applications and their variations incur costs for SUs; the HA undertakes the same application processes, but permits

are free. The overall financial impact of the permit scheme on SUs is unclear, but includes permit fees and likely increased back-office costs through greater pre-planning and the production of supporting permit application information such as site information, plans, methods, techniques and so on. Similarly, HA operational costs are also likely to have increased. The permit scheme only operates on 'traffic-sensitive' streets, which comprise around 20% of Derby's roads. Traffic-sensitive streets are formally designated subject to legislation and are essentially those streets where works would be especially disruptive to road users (DfT, 2012b). Noticing applies on the remaining streets. SAs must exercise parity of treatment between the HA and the SUs (DfT, 2008).

In addition to the permit scheme, the HA has also been actively working towards making highways maintenance more efficient and cost-effective through the introduction of the following practices.

- Works order management system (Woms) (October 2011) – this technological change involved replacing the paper-based system of recording works information with an app-based electronic system. Highways inspectors were given devices to use remotely, interactively and in real time, reducing delays caused by a manual system.
- Purchase of a JCB Pothole Master (3CX) (August 2013) – this purchase was made to assist in-house construction by a direct labour organisation (DLO).
- In-house construction activity (September 2013) – this policy change meant that, after 16 years of contracting construction works to an external company, the HA brought most services in-house, employing a DLO.

A time series statistical analysis model was employed to evaluate whether the introduction of these interventions had any impact on the reduction of the mean duration of excavation activity while controlling for other factors that influence work durations.

3. Data

Time series analysis was used on two separate data sets to investigate the duration of HA and SU highway works to compare performance. The study period lasted 6.5 years, commencing in October 2009, on permit-applicable streets only. During this period, 56 235 valid individual works registered with the SA were downloaded. The mean volume of works was 8651 per annum overall, with the HA and SUs executing 4902 (57%) and 3748 (43%) works on average respectively (Table 1). Data were collated using the SA's central database used to receive permit applications, and uploaded to IBM SPSS Statistics 22 (SPSS). The mean duration of highway works per month was calculated by dividing the total applications received by the total days spent occupying the highway.

Figure 1 shows time series plots of mean work durations on a monthly basis for both data sets. The graph shows that SU works remained relatively smooth over the study period, but seemed to decrease around October 2013, coinciding with the introduction of the permit scheme. This is an indication that the permit scheme potentially reduced the duration of SU works. The impact of the permit scheme is less distinct for HA works, although a dramatic drop in works duration in October 2011 coincides with the introduction of the Woms, indicating a positive impact by Woms on works durations. A surge in HA works is evident in August 2013 – this is considered to tie in with the changeover period of the HA moving from a term maintenance contractor to employing a DLO. Overall, it is hypothesised that the permit scheme reduced the duration of highway works for the SUs, but not the HA. Furthermore, the data indicate that the Woms reduced HA works durations.

In order to determine how external factors could affect works duration, a range of control variables was also collated to account for external factors (Table 2). Examination of the control data revealed that the gross domestic product (GDP) showed an uneven trajectory until June 2012, after which it consistently increased. Construction infrastructure output

Table 1. Volumes, means and intervention data for time series analysis

Year (commencing October)	Intervention	Works volume		
		HA	SU	Total
Year 1: 2009–2010	—	4819	3693	8512
Year 2: 2010–2011	—	3783	4418	8201
Year 3: 2011–2012	Woms (October)	4466	4160	8626
Year 4: 2012–2013	JCB Pothole Master (August), in-house maintenance (September)	3708	3970	7678
Year 5: 2013–2014	Permit scheme (October)	5771	3383	9154
Year 6: 2014–2015	—	5662	3149	8811
Year 7: 2015–2016 (6 months only)	—	3658	1595	5253
Total works		31 867	24 368	56 235
Mean volume/year		4902	3748	8651
Mean duration of works prior to permit intervention		2.8 d	3.6 d	—
Mean duration of works prior to Woms intervention		3.9 d	—	—

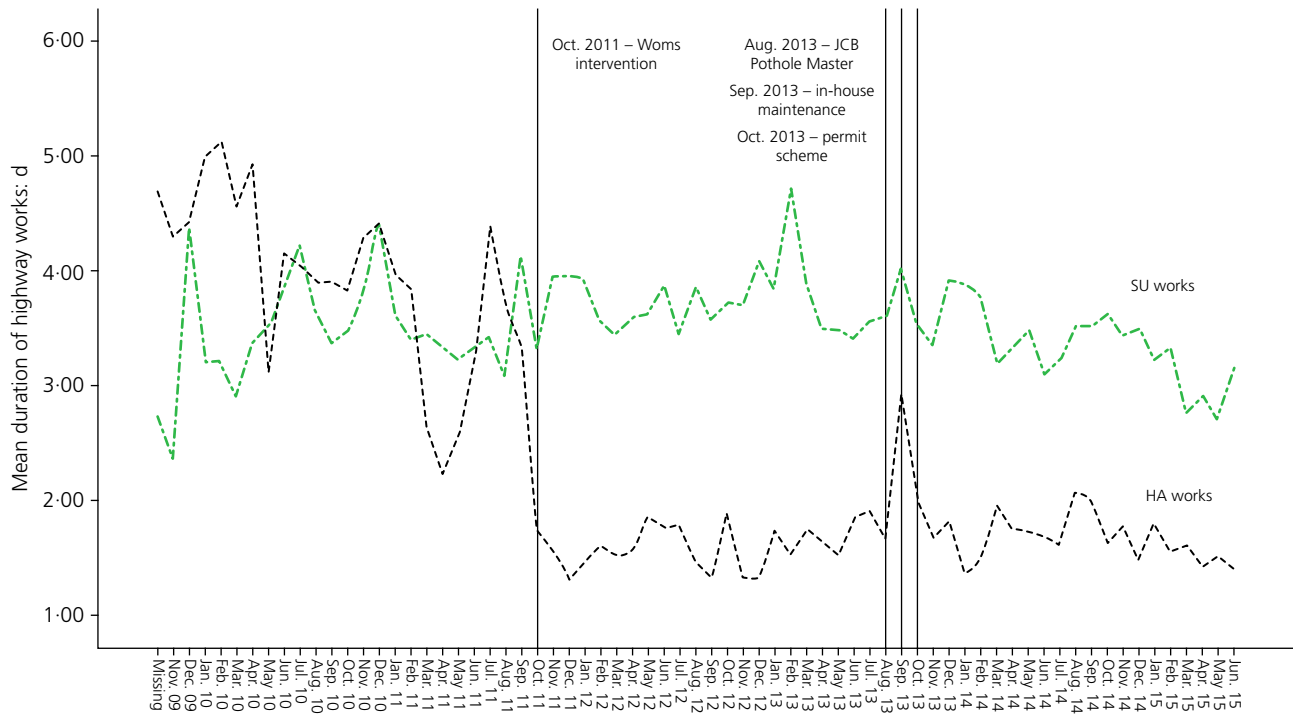


Figure 1. Sequence of mean highway works activities (October 2009 to March 2016)

showed a small and steady increase, while housing demand almost doubled. As expected, vehicle miles travelled (VMT) showed regular seasonal peaks (July–September) and dips (January–March), but this parameter was relatively static over the 5-year period. The Christmas restrictive period is a period when the SA heavily restricts works on traffic-sensitive streets between mid-November and early January (except for emergencies).

4. Method

This study sought to evaluate the impact of various policy-relevant interventions on the duration of excavation activity using statistical analysis, for which an autoregressive integrated moving average (Arima) time series model was employed. This section provides further information on time series analysis, the role of Arima and intervention functions.

4.1 Time series model

Time series analysis can be used to measure the impact of one or more interventions on a dependent variable. A time series model repeatedly measures a single variable (i.e. dependent variable) over a regular and consistent time period and can thus be employed to understand patterns and trends historically and also to extrapolate these trends to make future predictions. Accordingly, a time series model was used to evaluate the impact of policy-relevant interventions on highway works duration, while controlling for other factors such as GDP, weather and other incidental and cyclic events. Since all the variables were time-variant (as opposed to

time-invariant for the case of a cross-sectional study), a time series regression model was preferred. An important criterion of employing time series regression models is that a minimum of 50 observations are used for more reliable results (Chatfield, 2004); accordingly, this study aimed to use 78 monthly observations (no future predictions were sought).

The time series model can be defined as

$$1. \quad y_t = f(X_t, I_t) + N_t$$

in which t is the discrete time (month in this case); y_t is the appropriate Box–Cox transformation of Y_t , say in $\log Y_t$, Y_t^2 or Y_t itself (Box and Cox, 1964); Y_t is the dependent variable (i.e. the mean duration of each highway work activity) for a particular time t ; $f(l, X)$ is the deterministic part of the model, which contains the intervention component (I) and the deterministic effects of independent control variables (X); and N_t is the stochastic or noise component.

The random component (N_t) follows an Arima model that is normally denoted as Arima (p, d, q), in which p is the order of the non-seasonal autoregressive process, d is the order of the non-seasonal difference and q is the order of the non-seasonal moving average process. The Arima model can be expressed as (Box and Cox, 1964)

$$2. \quad \phi(B)(1 - B)^d N_t = \theta(B)u_t$$

Table 2. Variables used in the analysis and descriptive statistics

Variable type	Variable	Variable description	Variable format (unit)	Source	Mean value
Dependent variable	Mean duration of work per month	Total number of works/total duration	Count (d)	DCC reports	3.05
Intervention variable	Regime	Type of management regime – noticing or permit scheme	Binary – 0 or 1	DCC	–
Intervention variable (HA model only)	Woms	Manual or real-time electronic system	Binary – 0 or 1	DCC	–
Independent variable	GDP	Indicator of economic activity based on household final consumption expenditure – ‘current price’ per month (£ million)	Ratio (£)	ONS (2015a)	105.31
Independent variable	Construction industry output (overall)	Indicator of economic activity: money spent on construction of new housing, infrastructure and ‘other’ works – commercial and private per month in UK (£ million)	Ratio (£)	ONS (2015b)	18.011
Independent variable	Construction housing output	Indicator of economic activity: money spent on new public and private housing per month across UK (£ million)	Ratio (£)		5218
Independent variable	Construction infrastructure output	Indicator of economic activity: money spent on public and private (industrial and commercial) infrastructure per month across UK (£ million)	Ratio (£)		3359
Independent variable	Daylight	Indicator of working conditions: number of hours of daylight per day (h:min)	Count (h)	Weather Channel (2015)	12:38
Independent variable	Air temperature	Indicator of working conditions: mean air temperature over a month	Ratio (°C)	Met Office (2015a)	10
Independent variable	Precipitation	Indicator of working conditions: based on amount of rainfall	Count (mm)	Met Office (2015b)	56.23
Independent variable	VMT	Distance travelled on all roads in UK by all classes of vehicles per year (billion miles)	Count (miles)	DfT (2015)	76.2
Independent variable	School holidays	Indicator of road activity based on the proportion of school holidays over week days per month	Count (%)	DCC	25
Independent variable	Christmas restrictive period	Indicator of a period of typically low excavation activity and high traffic volumes between mid-November and early January over Christmas period	Binary – 0 or 1	DCC	–

in which ϕ is the regular autoregressive operator, θ is the regular moving average operator, B is the backward shift operator and u_t is an uncorrelated random error term with zero mean and constant variance (σ^2). Seasonal versions of the model and details can be found elsewhere (Box and Cox, 1964).

4.2 Arima modelling

The process of the Arima model analysis entails the identification, estimation and diagnosis of data (e.g. Tabachnick and Fidell, 2007). Analysis firstly requires identification of stationarity in the time series; a stationary time series or applying, for example, ‘differencing’ to achieve stationarity is critical for the Arima process (Box *et al.*, 2016). Stationarity removes any linear/quadratic or other trends to provide a series where means, variance and autocorrelations remain constant over time (Tabachnick and Fidell, 2007). Stationarity can be identified using autocorrelation function and partial autocorrelation function correlograms. The second step is to run the model to test whether the lingering autoregressive or moving average effect is more appropriate. This may include

incorporating control variables (as detailed in Table 2). The final step is diagnosis of the model to determine its accuracy – this incorporates examination of the significance of parameter estimates, goodness-of-fit statistics and testing white-noise residuals for all systematic variances (Box *et al.*, 2016).

4.3 The intervention function $f(I_t)$

Time series analysis can include intervention variables, which examine the effect of events or occurrences in the data set (Box and Tiao, 1975). This research sought to analyse the effect of various interventions. Both models (SU and HA) were subject to the permit scheme (commencing October 2013) and the SU model was singularly tested against this intervention. The HA model was, however, affected by three further interventions: the introduction of the Woms (October 2011), the purchase of a JCB Pothole Master (August 2013) and the employment of a DLO (September 2013). As the permit scheme, JCB purchase and DLO employment occurred over three consecutive months, their potential impacts were conflated; therefore the Arima model is a test of the set of interventions.

The intervention variables are characterised by a step function. This means that, prior to their onset, the value of the function (f) of the intervention (I) was 0 but, at onset, the value changed to 1 (Yaffee, 2000).

The intervention function is defined as

$$3. \quad f(I_t) = \theta_0 I_t$$

where θ_0 is a constant and I_t is the intervention variable, which takes a value of 0 for every month before the implementation date (i.e. t') of the policy intervention and a value of 1 for every month thereafter; that is

$$I_t = \begin{cases} 1 & \text{for } t \geq t' \\ 0 & \text{otherwise} \end{cases}$$

Therefore, the full Arima model can be presented as

$$4. \quad y_t = \theta_0 I_t + \beta X + \frac{\theta(B)u_t}{\phi(B)(1-B)^d}$$

The parameters of this model can be estimated by employing a maximum likelihood estimation.

5. Results and discussion

Analysis of the autocorrelation functions (Figure 2) revealed numerous lags where the autocorrelation coefficients fell outside the 95% confidence limits, thus exhibiting serial correlation in both data models; however, the HA model was significantly more non-stationary than the SU model.

A log transformation was applied to stationarise the series, but this failed. Instead, 'differencing' was found to stationarise the series more effectively. As the data required first-order differencing, this is indicated in the Arima (p, d, q) model by the $1(d)$, where $d=1$, as opposed to $d=0$ where no differencing is required (Yaffee, 2000). Different variations of Arima models were tested to find the best-fit models for the data sets. In the models, the mean duration of works respective to the SU and HA models was the dependent variable, the permit scheme was the single intervention variable in the SU model and the permit scheme/JCB/DLO package and Woms were the two separate intervention variables tested in the HA model. In addition, the control variables (as shown in Table 1) that were not found to be statistically significant or relevant to a model were disposed of.

Model diagnosis to determine accuracy was judged by a number of goodness-of-fit measures, including

- root mean squared error (RMSE), which compares a predicted value with an observed value

- mean absolute percentage error (MAPE), which measures the absolute percentage error across the series
- maximum absolute percentage error (MaxAPE), which suggests the maximum percentage of variation not explained at some point in the series
- Ljung–Box Q -value, which must be over 0.05 to demonstrate that the model is correctly specified (Yaffee, 2000).

5.1 Model 1: SU works only (1,1,0)

Optimum results for the SU data set were found in the Arima (1,1,0) model (Table 3).

The model is a non-seasonal autoregressive model with no indication of any lingering effect of works from previous months (statistically significant at the 95% confidence level). The model shows that the permit scheme intervention variable reduced works duration by 0.194 d per activity on average (all other factors being constant); this was statistically significant at the 99% confidence level. Based on the average volume of 3748 works (Table 1) and multiplying this by the mean duration of highway works of 3.6 d prior to the permit scheme, the typical number of utility work days per annum was around 13 492 d in Derby. The model estimated that the permit scheme reduced works duration by -0.194 d per highway works activity, which is equivalent to 727 work days or 5.4% reduction per annum.

Goodness-of-fit indicators provided a low RMSE of 0.384, which suggests a low mean squared error. The MAPE of 7.537 showed an average 6.2% predicted error margin across the series. The MaxAPE value of 36.2 suggests that, at worst, 36% of the variation was not explained at some point in the series. The Ljung–Box Q -value of 0.285 demonstrates that the model was correctly specified (Yaffee, 2000).

Daylight hours and VMT were found to be statistically significant. Firstly, should VMT increase by a billion miles, street works duration is likely to increase simultaneously by 0.051 d per job on average (significant at the 95% confidence level). In terms of daylight hours, a 1 h increase in daylight led to works durations decreasing by 0.037 d per activity (significant at the 100% confidence level).

5.2 Model 2: HA works only (4,1,0)

A visual examination indicated that the Woms had a significant and sustained impact on works duration, while the conflated impact of the permit scheme/JCB/DLO interventions was less clear (see Figure 1). To test this, a number of different variations of Arima models were run; however, the model results were weak and the impact of the combined interventions seemed exaggerated given the visual examination. It was considered that the inclusion of two intervention variables was disturbing the model and therefore the models were re-run examining the interventions separately. The permit

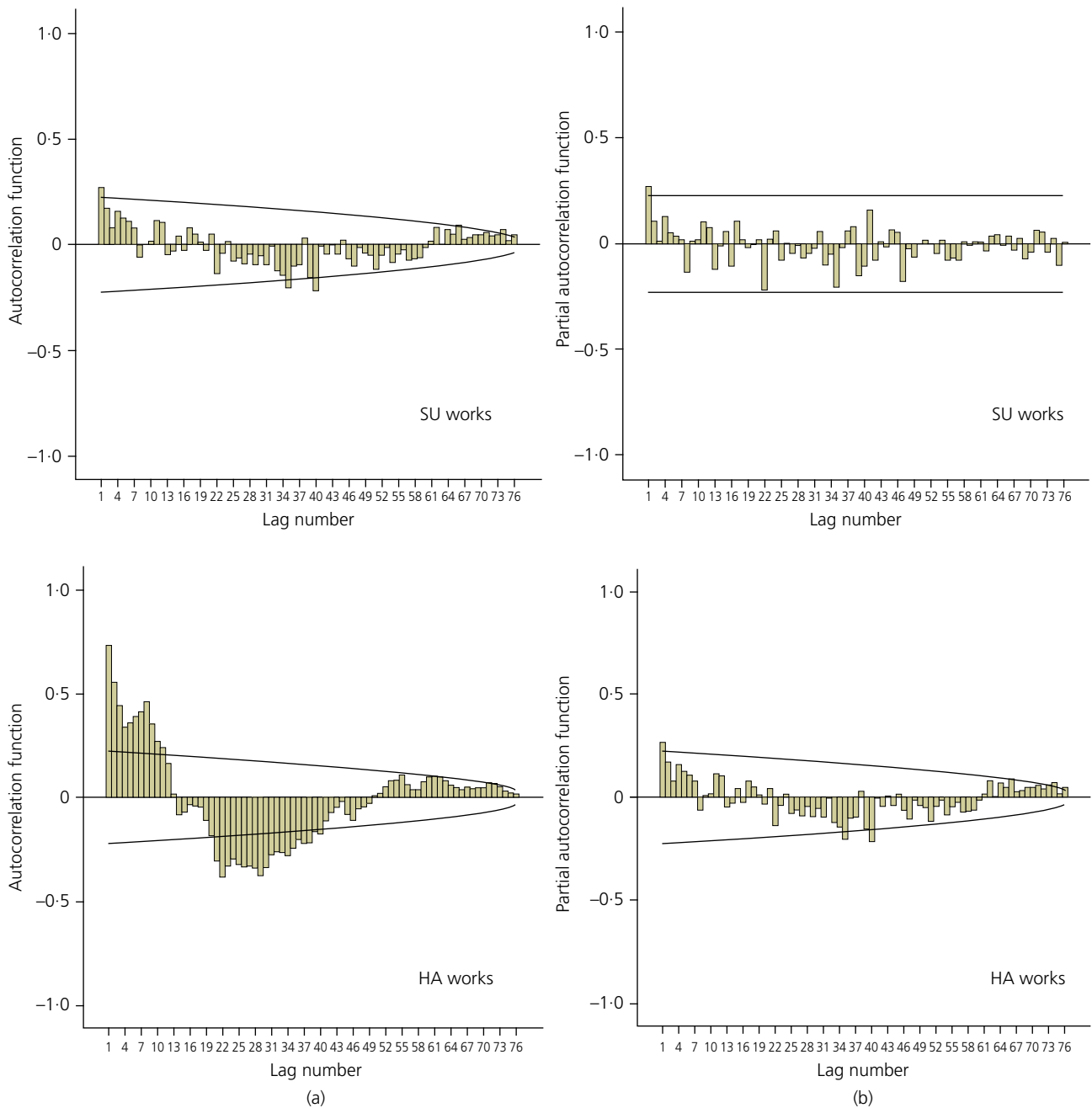


Figure 2. Sample autocorrelation functions: (a) and partial autocorrelation functions; (b) with associated 95% confidence limits of monthly highway works durations showing non-stationary time series for SU works and HA works

scheme/JCB/DLO was first tested using a 52-observation model that removed the observations prior to the Woms intervention to ensure model consistency. Despite trying a number of varying Arima models it was not possible to find a statistically significant model showing the impact of the combined interventions. Using SPSS, a simple mean comparison of work durations was run before and after the permit scheme/JCB/DLO. The mean comparison showed that works duration prior to the combined interventions was 1.68 d, marginally

improving to 1.67 d with the onset of the interventions. As the change was so slight, it corroborated the reasons why a suitable Arima model could not be found from the outset. Works duration is not the only proxy to measure success and therefore volumes of works were also examined. It is evident from Figure 3 that the overall works volume had increased since the combined intervention, with minor works substantially increasing, along with urgent/emergency works (Figure 4), which again demonstrates that the schemes did not have an impact.

Table 3. Results from the time series intervention models

Intervention model	Model: SU works only		Model: HA works only	
	Arima (1,1,0)		Arima (4,1,0)	
Noise component	Coefficient	t-statistic	Coefficient	t-statistic
Autoregressive 1	-0.486	-4.723	-0.277	-2.65
Autoregressive 1	—	—	-0.339	-3.16
Intervention variable				
Woms (October 2011)	—	—	-1.33	-3.34
Permit scheme (October 2013)	-0.194	-0.2.55	—	—
Control parameter				
VMT	0.051	3.117	—	—
Daylight hours	-0.037	-2.34	—	—
Descriptive statistics				
RMSE	0.384		0.420	
MAPE	7.537		12.96	
MaxAPE	36.169		48.47	
Ljung–Box Q	0.285		0.085	

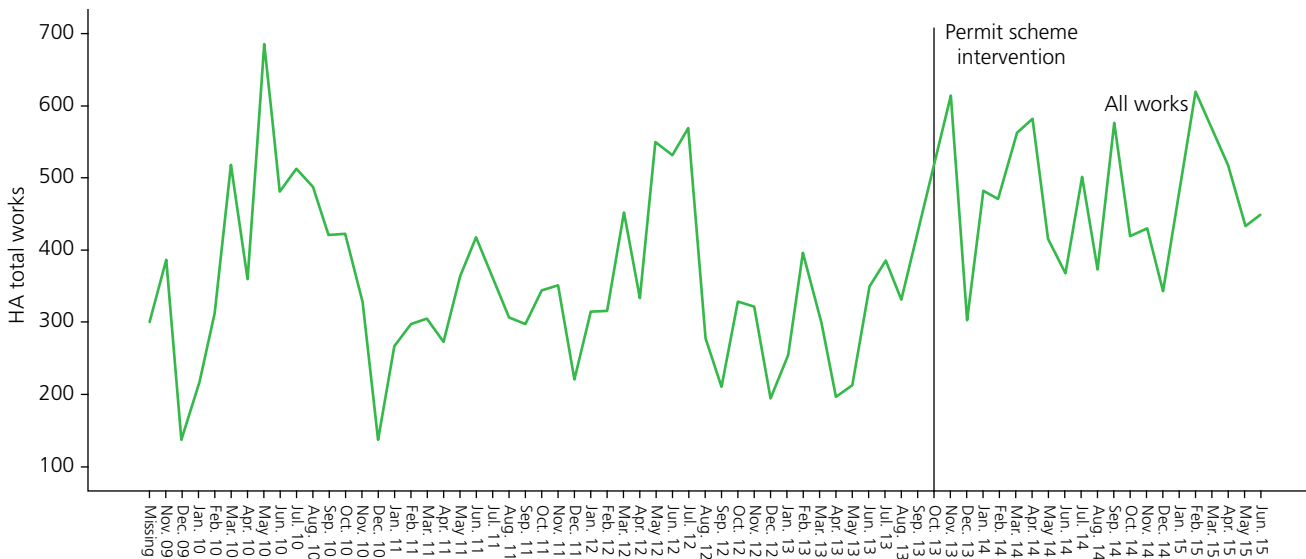


Figure 3. Overall volume of HA works

The second model exclusively examined the Woms impact using 78 observations. Optimum results for the HA data set were found in the Arima (4,1,0) model (see Table 3). This model is a non-seasonal moving average model with a lingering effect from the previous month four (statistically significant at the 95% confidence level). The Woms intervention was found to reduce works duration by 1.33 d per activity (significant to 99% confidence) (all other factors remaining constant).

Based on the average volume of 4902 works and multiplying this by the mean duration of highway works of 3.9 d prior to the Woms intervention (see Table 1), the typical highway work

days volume per annum was approximately 19 117 d in Derby. The model estimated that the Woms introduction reduced works by -1.33 d on average per works activity – equivalent to 6519 work days or 34% reduction per annum.

The goodness-of-fit indicators provide an RMSE of 0.420, which suggests low mean squared error. The MAPE value of 12.96 means that, across the series, the predicted value had an average 13% error margin. The MaxAPE value of 48.47 means that, at worst, 48% of the variation was unexplained at some point in the series. The Ljung–Box Q-value of 0.085 demonstrates that the model was correctly specified (Yaffee, 2000).

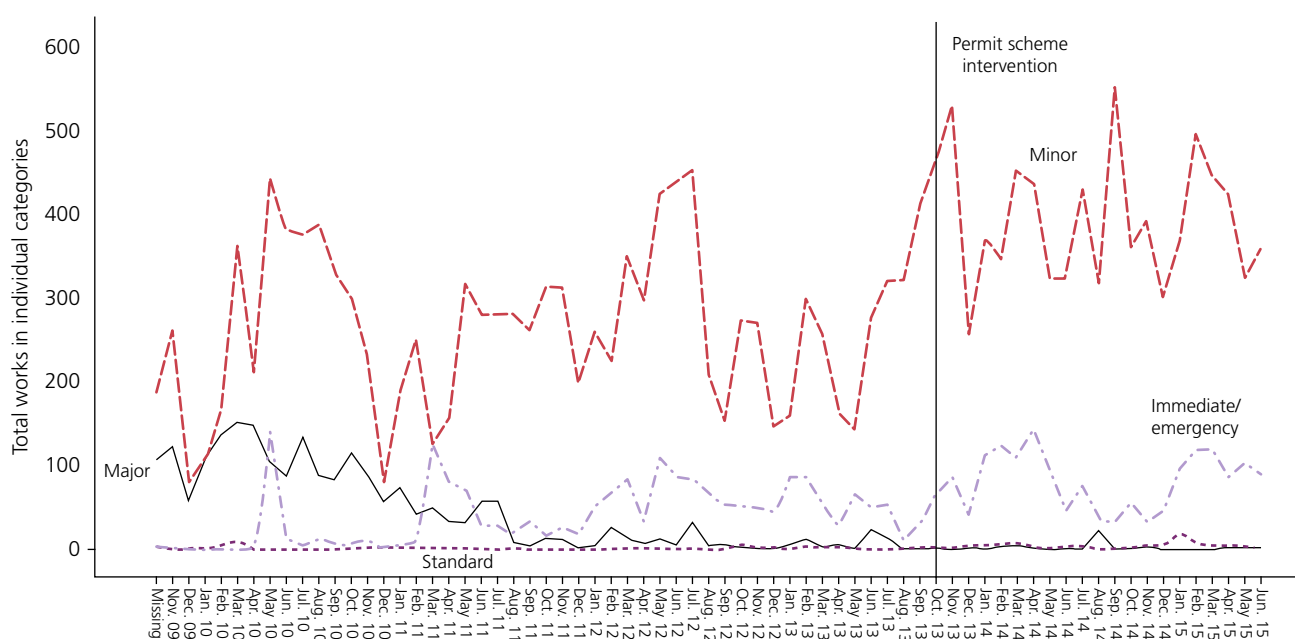


Figure 4. Volume of HA works among different categories

6. Discussion and conclusion

The permit scheme was found to reduce SU works durations by around -0.194 d per highway works activity, which is equivalent to 727 work days or 5.4% reduction per annum. In rationalising why the permit scheme had this effect for SUs, a key explanation could lie with the greater pre-planning that the scheme demands for application approval. Permit applications, resubmissions and variations all attract fees for utility companies. Rejected applications waste time and create uncertainty; this is likely to be significantly more inconvenient and expensive than the permit costs themselves, especially if it involves re-programming works, plant and equipment, the labour supply chain, as well as informing stakeholders. Greater pre-planning involves submitting robust site information, plans, methods, techniques and detailed traffic management information, which can lead to greater collaboration with SAs. This study demonstrates that permit schemes can be successful in reducing works durations.

Additionally, VMT and daylight hours were statistically significant in SU works durations – both may be rooted in health and safety as road construction workers are disproportionately more affected by injury and fatality than their counterparts (Harb *et al.*, 2008). Firstly, should VMT increase by a billion miles, street works durations are likely to increase simultaneously by 0.051 d per job on average (significant at the 95% confidence level). Increased VMT could be correlated with greater traffic volumes, which are known to increase safety risks to on-site personnel (Walker and Calvert, 2015) and increase the risks of crashes and fatalities on highway work zones (Debnath *et al.*, 2013). Increased works duration could be reflective of work sites being managed more carefully to

prevent accidents, thus inadvertently increasing works durations. In terms of daylight hours, a 1 h increase in daylight led to works durations decreasing by 0.037 d per activity (significant at the 100% confidence level). This may be because daylight naturally creates a more productive working environment and therefore it is unsurprising that longer daylight hours reduce works duration. Conversely, a disproportionate number and severity of accidents occur in darkness (Harb *et al.*, 2008), with fatalities five times more likely during night-time construction compared with construction during the day (Arditi *et al.*, 2007). Night-time working can increase project costs due to increased personnel and traffic management costs, as well as compromising aesthetic considerations and affecting workforce productivity (McMahon *et al.*, 2005; Rebholz *et al.*, 2004).

In terms of HA works, the combined permit scheme/DLO/JCB interventions were not found to have any statistically significant impact on reducing works durations. It is considered that the absence of permit scheme charges fails to incentivise change in the same manner that it would for SUs, who pay for permits and also have to suffer greater impact when re-scheduling customer works. Hypothetically, if HAs were subject to permit costs, it is unlikely that Derby's road works would have increased as rapidly given the associated cost implications. Furthermore, it is speculated that the accessibility of the DLO and the JCB could have increased works volumes because the HA can now be more reactive with works. While this is positive for the HA because they are now executing more works in financially austere times and positive for the public because they are experiencing improved road conditions, conversely, for the SA, it suggests that more highway works are taking place than ever before and thus the

societal impact of these works is increasing. A caveat to this, however, is that works are calculated by the day; therefore, even though a straightforward pothole repair can take around 30 min from start to site clearance, it will be recorded as 1 d work, which can misrepresent works durations. Recording of this information is governed by statutory legislation and is thus not easy to overcome in the short term. However, in its regulatory role, the SA could seek to minimise works impacts by conditioning permits so that minor works executions take place outside peak travel hours. Additionally, it is recommended that investigations are made into reducing ad hoc and minor highway repair works to minimise highway impacts.

In examining the Woms impact on HA works, this was found to have the greatest impact on reducing works duration. It is considered that the Woms enables the works manager to allocate and control works information sent to highways inspectors, which reduces duplications arising from a manual system. It can be deduced that efficient planning from the outset can lead to efficient execution of works on-site, culminating in an overall reduction in on-site works duration. The adoption of Woms also fits in with the wider transformation government strategy of using information technology to transform government operations and processes (Weerakkody *et al.*, 2011). This result, however, should be treated cautiously because Woms is not a direct construction tool and therefore it is more likely that the Woms has in fact improved reporting, and is thus reflecting actual works durations, which can be undermined due to delays prevalent in paper-based systems. Notwithstanding this, it is recognised that better planned road works and street works lead to better executed works on-site, therefore its impact should not be underestimated.

In moving forward, this study has found that permit schemes can reduce SU works durations in an urban authority; however, the absence of permit costs to HAs can nullify an important behavioural change incentive. Accordingly, further investigations are required to identify appropriate interventions for HAs. Furthermore, the introduction of a Woms was also found to improve works durations significantly, which suggests that back-office process efficiency can lead to improved works on-site. The purchase of a JCB Pothole Master to expedite certain works and the DLO nature of the HA's construction workforce was not found to reduce work durations.

The limitation of this study is that it was based on a single LA and therefore the results are not necessarily transferable to other authorities, particularly rural authorities. However, this is important and novel research because highway works management policies and particularly intervention impacts are under-researched. This research is valuable to policymakers, practitioners and the utility industry because it provides evidence that the permit scheme, as a policy intervention, can be a successful scheme for SUs but may not provide enough impetus for HAs to change their working practices significantly.

The study has also identified that back-office policy changes such as business process improvements can have a key effect on improving on-site works execution. The Arima studies in this paper are comparative models (e.g. noticing compared with permit schemes, paper-based systems compared with Woms etc.) and therefore cost calculations are not necessary to prove the effectiveness of policy measures. However, this study could be enhanced by more current research into road works and street works costs, which are critically under-researched (Brady *et al.*, 2001; McMahan *et al.*, 2005); this would aid greater understanding of the financial impacts of the reductions. This research could also be strengthened by qualitative research examining the running costs of permit schemes.

Acknowledgements

This research was conducted at the Centre for Innovative and Collaborative Construction Engineering of Loughborough University. This work was supported by the Engineering and Physical Science Research Council (grant number EP/G037272/1) and Derby City Council. Special thanks go to Dr David Coates of Loughborough University for his assistance. Access to the underlying data will be made available through the Loughborough University Data Repository.

REFERENCES

- Amec (International Association for the Measurement and Evaluation of Communication) (2002) *Evaluation of Pavement Cut Impacts*. Amec, London, UK.
- Arditi D, Lee DE and Polat G (2007) Fatal accidents in nighttime vs. daytime highway construction work zones. *Journal of Safety Research* **38**(4): 39–405.
- Brady K, Burtwell M and Thomson J (2001) *Mitigating the Disruption Caused by Utility Street Works*. Transport Research Laboratory, Crowthorne, UK, TRL report 516.
- Box G and Cox D (1964) An analysis of transformation. *Journal of the Royal Statistical Society* **26**(2): 211–252.
- Box G and Tiao G (1975) Intervention analysis with applications to economic and environmental problems. *Journal of the American Statistical Association* **70**(3): 70–79.
- Box GEP, Jenkins GM, Reinsel GC and Ljung GM (2016) *Time Series Analysis: Forecasting and Control*, 5th edn. Wiley, Hoboken, NJ, USA.
- Chatfield C (2004) *The Analysis of Time Series – An Introduction*, 6th edn. Chapman & Hall/CRC Press, Boca Raton, FL, USA.
- CoS (City of Sydney) (2014) *Traffic Management*. CoS, Sydney, Australia. See <http://www.cityofsydney.nsw.gov.au/business/business-responsibilities/traffic-management> (accessed 01/08/2014).
- DCC (Derby City Council) (2013) *Derby City Council Permit Scheme for Road Works and Street Works Appendix 1 Additional Information*. DCC, Derby, UK. See <http://www.derby.gov.uk/media/derbycitycouncil/contentassets/documents/transport/derbycitycouncil-permit-scheme-roadworks-and-street-works-additional-info-app1-june-2013.pdf> (accessed 10/10/2015).
- Debnath AK, Blackman RA and Haworth N (2013) Understanding worker perceptions of common incidents at roadworks in Queensland. *Proceedings of the 2013 Australasian Road Safety Research, Policing & Education Conference, Brisbane, Australia*, pp. 1–13.
- DfT (Department for Transport) (2008) *Traffic Management Act 2004 Code of Practice for Permits*. DfT, London, UK.

- DfT (2012a) *New Roads and Street Works Act 1991 Lane Rental Schemes: Guidance to English Highway Authorities*. DfT, London, UK.
- DfT (2012b) *New Roads and Street Works Act 1991 Code of Practice for the Co-ordination of Street Works and Works for Road Purposed and Related Matters*, 4th edn. The Stationery Office, London, UK.
- DfT (2014) *Traffic Management Act 2004 Part 3: Local Highway Authority Permit Schemes: Consultation on the Amendments to the 2007 Permit Scheme Regulations*. DfT, London, UK.
- DfT (2015) *Road Traffic (Vehicle Miles) by Road Class in Great Britain from 1993*. DfT, London, UK. See <https://www.gov.uk/government/statistical-data-sets/tra25-quarterly-estimates> (accessed 25/03/2015).
- Halcrow (2004) *Assessing the Extents of Street Works and Monitoring the Effectiveness of Section 74 in Reducing Disruption Third Annual Report Volume 3 – Estimation of the Cost of the Delay From Utilities' Street Works*. Department for Transport, London, UK.
- Harb RC, Radwan E and Yan X (2008) Environmental, driver and vehicle risk analysis for freeway work zone crashes. *ITE Journal* **78**(1): 26–30.
- Hussain RS, Brien N, Gartside D, Enoch M and Ruikar K (2016) Street works policy in England, UK: insights from stakeholders in England. *Infrastructure Asset Management* **3**(2): 61–70.
- Jordan RW, Ferne BW, McMahon W and Rahman M (2009) *A Charge Structure for Trenching in the Highway – Published Project*. Transport Research Laboratory, London, UK, Report PPR 386.
- KCC (Kent County Council) (2014) *Measuring the Success of the Kent Permit Scheme*. KCC, Maidstone, UK. See http://www.kent.gov.uk/_data/assets/pdf_file/0020/31763/Kent-Permit-Scheme-annual-report.pdf (accessed 01/06/2015).
- Lepert P and Brillet F (2009) The overall effects of road works on global warming gas emissions. *Transportation Research Part D: Transport and Environment* **14**(8): 576–584.
- LPSOC (London Permit Scheme Operational Committee) (2014) *London Permit Scheme for Road Works and Street Works – First Year Evaluation Report*. LPSOC, London, UK. See <http://www.londoncouncils.gov.uk/node/5944> (accessed 24/11/2018).
- LTA (Land Transport Authority) (2014) *Road Works*. LTA, Singapore. See http://www.onemotoring.com.sg/publish/content/onemotoring/en/on_the_roads/road_maintenance/road_works.print.html (accessed 03/12/2014).
- Matthews JC, Allouche EN and Sterling RL (2015) Social cost impact assessment of pipeline infrastructure projects. *Environmental Impact Assessment Review* **50**: 196–202.
- McMahon W, Burtwell MH and Evans M (2005) *Minimising Street Works Disruption: the Real Costs of Street Works to the Utility Industry and Society*. UK Water Industry Research, London, UK.
- Met Office (2015a) *Climate Summaries*. Met Office, Exeter, UK. See <http://www.metoffice.gov.uk/climate/uk/summaries> (accessed 10/03/2015).
- Met Office (2015b) *Weekly Precipitation Figures – Central England (CEP)*. Met Office, Exeter, UK. See http://www.metoffice.gov.uk/hadobs/hadukp/data/daily/HadCEP_daily_qc.txt (accessed 13/01/2015).
- Mouaket A and Capano N (2013) Development of a pavement degradation fee structure for the city of Toronto, Urban Pavements: Better, Faster, Safer Session of the 2013. *Proceedings of the Conference of the Transportation Association of Canada, Winnipeg, Manitoba, Canada*, pp. 1–18.
- NJUG (National Joint Utilities Group) (2012) *Consultation Response Proforma – For the Consultation on Revising the Permit Scheme Approval Process (for Local Highway Authorities in England) – Amending the Traffic Management Act (TMA) 2004*. NJUG, London, UK. See <http://www.njug.org.uk/wp-content/uploads/1204-NJUG-permit-devolution-response-proforma-final.pdf> (accessed 19/07/2012).
- ONS (Office for National Statistics) (2015a) *Quarterly National Accounts*. ONS, Newport, UK. See <http://www.ons.gov.uk/ons/re/naa2/quarterly-national-accounts/index.html> (accessed 15/03/2015).
- ONS (2015b) *Output in the Construction Industry, December and Q4, 2014*. ONS, Newport, UK. See http://www.ons.gov.uk/ons/dcp171778_395092.pdf (accessed 20/03/2015).
- Rebholz FE, Al-Kaisy A, Nasser K *et al.* (2004) *Night-Time Construction: Evaluation of Construction Operations*. Illinois Transportation Research Center, Edwardsville, IL, USA, Report number ITRC FR 00/01-5.
- Rogers C, Hao T, Costello S *et al.* (2012) Condition assessment of the surface and buried infrastructure – a proposal for integration. *Tunnelling and Underground Space Technology* **28**: 202–211.
- Shrivastava S (2010) Kent Permit Scheme: benefits assessment and monitoring. *Proceedings of the European Transport Conference 2010, Glasgow, UK*, pp. 1–14.
- Tabachnick BG and Fidell LS (2007) *Using Multivariate Statistics*, 5th edn. Allyn and Bacon, Boston, MA, USA.
- TRL (Transport Research Laboratory) (2012) *Interim Report – Reducing Congestion on the Road Network: Plating, Temporary Backfill and Permanent Rapid-Cure Reinstatement Solutions*. Transport Research Laboratory, London, UK.
- UK Parliament (2014) *Roads: Public Utilities and Street Works, Standard Note SN739*. UK Parliament, London, UK.
- Walker G and Calvert M (2015) Driver behaviour at road works. *Applied Ergonomics* **51**: 18–29.
- Weather Channel (2015) *Climatology: Sunrisetosunset for London, United Kingdom*. See <http://uk.weather.com/climate/sunRiseSunSet/London+GLA+United+Kingdom+UKXX0085:1:UK?month=10> (accessed 27/03/2015).
- Weerakkody V, Janssen M and Dwivedi Y (2011) Transformational change and business process reengineering (BPR): lessons from the British and Dutch public sector. *Government Information Quarterly* **23**(3): 320–328.
- Wilde WJ, Grant CA and Nelson PK (2018) *Manual for Controlling and Reducing the Frequency of Pavement Utility Cuts*. Federal Highway Administration, Washington, DC, USA, Final report. See <https://www.fhwa.dot.gov/utilities/utilitycuts/manual.pdf> (accessed 24/11/2018).
- Yaffee R (2000) *Introduction to Time Series Analysis and Forecasting with Applications of SAS and SPSS*. Academic Press, London, UK, Final report – Internal report.
- YCPS (Yorkshire Common Permit Scheme) (2015) *Yorkshire Common Permit Scheme Annual Report (2013–14)*. YCPS, York, UK. See <https://www.kirklees.gov.uk/beta/transport-roads-and-parking/pdf/annual-report-year2.pdf> (accessed 24/11/2018).

How can you contribute?

To discuss this paper, please email up to 500 words to the editor at journals@ice.org.uk. Your contribution will be forwarded to the author(s) for a reply and, if considered appropriate by the editorial board, it will be published as discussion in a future issue of the journal.

Proceedings journals rely entirely on contributions from the civil engineering profession (and allied disciplines). Information about how to submit your paper online is available at www.icevirtuallibrary.com/page/authors, where you will also find detailed author guidelines.