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Traffic microsimulation scenario tests by the Taguchi method

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The usability of the Taguchi method in traffic simulation was investigated to demonstrate whether full factorial scenario testing is necessary on a small road network by changing certain links into one-way streets to ascertain the minimum total delay. A network with 52 links was constructed and four arbitrarily chosen links were made one-way streets, one by one in both directions. The best directions of traffic for each of these four links which gave minimum total delay time over the whole network were studied by means of Paramics microsimulation software. The simulation runs were designed using an orthogonal array technique in L_8 array with four factors (with two levels each) and three interactions. The total delay time was selected as the response variable. The response data were analysed using an analysis of variance technique by the Taguchi method. In addition, the Taguchi outcome was judged against the results of the full factorial design of the actual Paramics runs for the best and transparent comparison. Furthermore, in comparison with full factorial design, the results demonstrated that the use of the Taguchi method enabled the interactions between the factors to be seen, which cannot be achieved so simply by simulation trials.

1. Introduction

Simulation modelling has been widely used to measure various characteristics of roads and traffic. As there are many factors affecting the performance of a road network, usually one factor is varied while the other factors are kept constant. The optimum conditions achieved by this approach, however, may not be a true optimum if there are interactions between the factors. Literature on factorial experiments and response surface designs are available for further details (Li *et al.*, 2008; Montgomery *et al.*, 1972; Nathan, 1976; Ozturk and Kavak, 2008). In the case of a full factorial design, the number of scenarios required may be numerous, such that it becomes impractical to carry out all possible experiments. To overcome this, fractional factorial experiments using an orthogonal array was first investigated by Taguchi (1987). This approach substantially decreased the number of experiments and made it feasible to study the effects of the factors and their interactions. The objective of the Taguchi method was to obtain products (or processes) that were more robust under varying environmental conditions and to consider the variability in the products' components (sub-products). The Taguchi method showed that experimental designs could be used to minimise variability around the target value, and that the performance of a product (i.e. optimum working conditions) may be affected by (a) the environmental conditions in which it is going to be used, and (b) components used in its production (Celik and Burnak, 1998). Thus, when determining the optimum working and environmental conditions in which the product will be used, the details of its components should be taken into account. Parameters affecting the product may be divided into two groups: controllable and uncontrollable. Because of large time costs, instead of identifying and removing uncontrollable parameters, the values of controllable parameters which remove or reduce the negative effects of uncontrollable parameters were investigated. Controllable parameters were further divided into three groups with respect to their effects on the performance of the product as control parameters, adjustment parameters and ineffective parameters (Celik and Burnak, 1998).

When analysing experimental results, after applying this classification, the variability in the performance of the product around the target value was reduced by using control parameters, as well as considering ineffective parameters from the point of view of economical considerations and practicality (Kackar, 1985). For this process, Taguchi suggested the use of a new experimental

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design method that was different from the conventional ones such as orthogonal arrays, performance statistics (signal to noise ratio), loss functions, and so on (Celik and Burnak, 1998). Optimum working conditions determined by using the experimental data should always be able to provide the same or very close performance values (i.e. mechanical properties) at different times and in different working environments. According to Taguchi (1987), the optimisation criteria used to carry out this task should be able to address both whether the target value has been reached and whether the variability around the target is kept to a minimum. Kackar (1985) reported that Taguchi developed more than 60 performance statistics which can be used depending on the problem being investigated.

The performance characteristics are chosen as the optimisation criteria. There are three categories of performance characteristics: (*a*) the larger the better, (*b*) the smaller the better, and (*c*) the nominal value preferred. These performance characteristics are evaluated using Equations 1 to 3. For more details refer to Celik and Burnak (1998), Kackar (1985), Phadke (1989) and Hinislioglu and Bayrak (2004).

The larger the better

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i{}^2}\right) \quad (1)$$

The smaller the better

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}Y_i{}^2\right) \quad (2)$$

The nominal value preferred

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}(Y_i - Y_0)^2\right) \quad (3)$$

where the *S/N* values are the performance statistics, defined as the signal to noise ratio (*S/N* unit: dB); n is the number of repetitions for an experimental combination; Y_i is a performance value of the ith experiment; and Y_0 is the nominal value desired.

Celik and Burnak (1998) introduced a flow chart and grouped its functionality into 13 operational steps to achieve design optimisation: (i) determination of the problem and organisation of the team; (ii) determination of the performance characteristic(s) and measurement of the system; (iii) determination of the variables (parameters) affecting the performance characteristic(s); (iv) conducting the screening design; (v) determination of the number of levels and values of the controllable variables (parameters) and uncontrollable variables (parameters); (vi) determination of the interactions to be examined; (vii) selection of appropriate assignment of the variables to the suitable columns; (viii) determination of the loss function(s) and performance statistics; (ix) conducting experiments and recording results; (x) analysis of the data and selection of the optimum values of the controllable variables; (xi) testing the results; (xii) tolerance design; and (xiii) evaluation, implementation, and observation.

Using the Taguchi method, the experiment corresponding to the optimum working conditions might not be performed during the experiments. In such cases the performance value corresponding to optimum working conditions can be predicted by utilising the balanced characteristic of the orthogonal array using Equation 4 (Roy, 1990):

$$Y_i = \mu + X_i + e_i \quad (4)$$

where μ is the overall mean of the performance value; X_i is the fixed effect of the parameter level combination used in the ith experiment, and e_i is the random error in the ith experiment.

Because Equation 4 is a point estimation which is calculated using experimental data in order to determine whether the results of the confirmation experiments are meaningful or not, the confidence interval must be evaluated. The confidence interval at a chosen error level may be calculated by Equation 5:

$$CI = \mu + X_i \pm \sqrt{F(1,\, n_2) \times \frac{V_e}{N_e}} \quad (5)$$

where $F\ (1,\ n_2)$ is the F value from an F table given in statistics books at the required confidence level with degrees of freedom (DOF) 1 and error DOF n_2; V_e is the variance of the error term from analysis of variance (ANOVA); N_e is the effective number of replications, that is:

$$N_e = \frac{\text{The total number of results (or the number of } S/N \text{ ratios})}{\text{DOF of mean (always 1·0)} + \text{DOF of all factors included in the estimate of the mean}}$$

In order to demonstrate the application of the Taguchi approach to the context of traffic simulation, in this paper we will look at total delay time as a performance criterion for a subject network, as will be discussed in the next section. The minimisation of total delay time was also chosen by others as one of the objective functions in previous studies (Bentley and Lambe, 1980; Fouladvand *et al.*, 2004; Ma *et al.*, 2004; Papageorgiou, 1995; Tenekeci, 2007). It should be noted that the present study did not investigate one-way streets nor did it target certain modelling

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objectives, such as system optimum/user equilibrium approaches, optimisation, etc. The interim aim of the paper is to show a successful application of a statistical method on one of the typical traffic simulation problems.

2. An example problem

Introduction of one-way traffic (where appropriate) is a common technique to improve certain characteristics of a road network. It may be used as part of an area-wide scheme to break up a road into short sections, and by creating detours to discourage rat running (IHT, 1997). Higher speeds can also be achieved due to the absence of psychological lateral friction between the opposing lanes (Gunay, 2007). In high-density areas with many signalised interactions, 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 operation authorities is to determine which links should be made one-way and in which direction. Sometimes, the number of alternatives is limited due to other factors affecting the decision. In these circumstances, the authorities have less flexibility leading to easy decision making. When all possible links have a relatively equal chance of being made one-way streets, however, then the number of scenarios in a typical simulation of all possible alternatives becomes big, and hence time-consuming test runs become inevitable. In the present study the latter case was assumed. To demonstrate this argument a typical problem of introducing one-way streets in an artificially constructed and loaded sample network was considered. The problem assumes 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, it was assumed that the decision maker would use Paramics microsimulation to run all possible options in order to seek the minimum total delay time.

To allow other researchers to replicate the simulation results for further scrutiny, some of the key vehicle and network characteristics are provided. Table 1 shows the origin–destination movements (in number of vehicles) throughout a 1 h simulation period. These values are randomly generated figures within a moderate range to produce a slightly congested assignment so that the effects of direction changes to the links A, B, C and D can be seen. Light and heavy origin–destination assignments were excluded from the study.

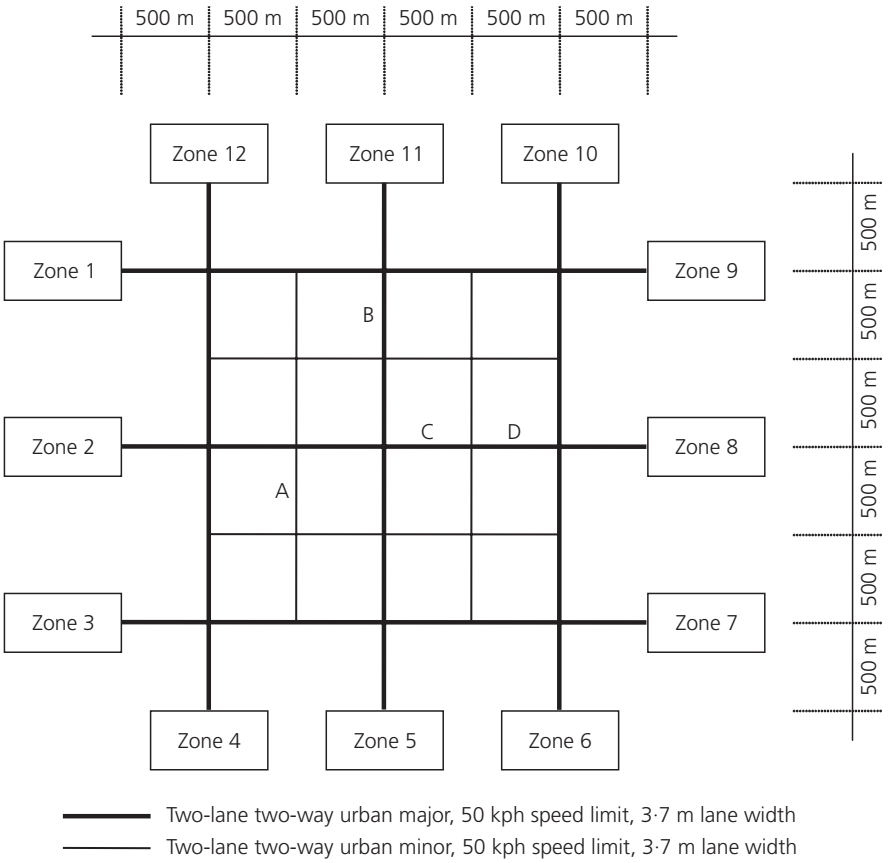

Figure 1. The sample network

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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

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

For the input of physical and kinematic attributes of all vehicle classes, the default parameters of Quadstone Paramics v6.3 were used as shown in Table 2. To minimise complexity, no signalised or roundabout intersections were used in the experiment. All junctions were give-way type junctions, the default of Paramics. Route choices for the origin–destination movements of each vehicle were determined by the selection of 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 origin–destination pair. Again, these values were arbitrarily chosen after a number of trial-and-error runs to produce reasonably dispersed traffic on the network by using the default perturbation algorithms of Paramics (Quadstone Paramics, 2007).

It was not within the scope of the present paper to mimic a real world network with real traffic data. Furthermore, it was not the intention to discuss applications of one-way street systems in terms of their advantages and disadvantages, etc. The sample network, the changeable four links, and the traffic data used may not represent a possible real-world situation. Rather the intention was to demonstrate the applicability of the Taguchi method to a traffic engineering problem. The fact that there are no signalised intersections (or roundabouts) may not be realistic for an urban setting, but it should be remembered that inclusion of signals complicates the problem because one also has to optimise the

	Car	LGV	OGV1	OGV2	Coach
Proportion: %	86·5	7·8	3·2	2·8	0·7
Length: m	4·0	6	8·0	11	10
Width: m	1·6	2·3	2·4	2·5	2·5
Acceleration: m/s^2	2·5	1·8	1·1	1·4	1·2
Deceleration: m/s^2	4·5	3·9	3·2	3·7	3·7
Top speed: km/h	160·0	130	105	120	130
Crawl speed: km/h	80·5	64·4	48·3	32·2	48·3
Mean age: years	2	2	2	2	2
Weight: t	0·8	2·5	15	38	12
Perturbation factor	40	40	40	40	40
Familiarity: %	85	85	85	85	85

LGV, light goods vehicles; OGV, other goods vehicles.

Table 2. Vehicle types and some of their characteristics

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signal timings to find the optimal solution, and this should not be linked to the effectiveness of the Taguchi approach.

3. Full factorial simulation approach

It is clear that there are 16 possible one-way movements for the four links identified in the example problem above. These 16 possibilities (referred to as 'scenarios' throughout the paper) are

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

The number of possibilities may be many more in practice with larger networks, a greater number of links that may be converted to one-way streets, or when the combinations include partial changes. For instance, the example network with four flexible links may well have $3^4 = 81$ combinations in practice (if two-way traffic options for these four links are included as some of the alternatives). Therefore full factorial experiments become infeasible, even in such a small network with only four flexible links, leading to very time-consuming scenario testing situations through simulation. To prove the effectiveness of the Taguchi method, however, a full factorial experimental design was performed for the four factors and two levels, each leading to 2^4 (i.e. 16) separate simulations (scenarios). Since two runs are made for each scenario (to smooth out random effects for the purpose of better statistical averaging), a total of 32 simulation runs were carried out. This was achieved by using random seed numbers generated by Paramics. 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. In practice more than two runs may be required for statistical reasons, making the full factorial design option even more time consuming. Note that each run and its output analysis usually take around 30 min for a small network such as the present example problem. This may lead to a number of days of simulation study for larger networks.

A summary of all simulation results is given in Table 3 where the smallest total delay time is achieved at the 10th scenario over both runs. This will be compared with the Taguchi results discussed in Section 5 to ascertain whether the Taguchi method can be used quickly and efficiently instead of the full factorial design in the simulation of traffic in the sample network investigated herein.

4. The Taguchi approach

The Taguchi method was employed here to see if the same particular scenario which gave the minimum total delay time can be identified in comparison with the full factorial experiment discussed in Section 3 (both implemented independently of each other). To improve any further analyses the systematic approach given by Celik and Burnak (1998) was adopted. The best direction of traffic for each changeable link (i.e. A, B, C and D) to minimise total delay times was studied through the Taguchi method and these links are labelled as factors A, B, C and D, respectively (Table 4), for consistency with the terminology of the Taguchi literature. Additionally, the corresponding total delay time simulation results for each run, together with the factor names and level numbers, are given in Table 5.

Scenario No.	Run 1: min	Run 2: min
1	137·65	128·92
2	127·50	229·53
3	175·97	176·13
4	148·17	144·38
5	322·05	276·45
6	331·88	339·72
7	223·83	249·97
8	254·88	223·80
9	144·47	123·55
10	100·00	97·33
11	257·05	201·30
12	106·62	143·65
13	348·00	346·28
14	325·47	333·20
15	197·38	167·80
16	287·67	300·40

Table 3. Total delay time results of the full factorial simulation runs

In Table 4, link A, for instance, can take two levels: (1) one-way north, and (2) one-way south. Similarly, link C, as another example, can be (1) one-way east, and (2) one-way west, and so on. According to Table 5, in the first scenario the links A, B, C and D become one-way towards the north, north, east, and east, respectively.

It was within the scope of this paper to study the effects of the three interactions A × B, B × D, and A × D, based on the preliminary design. In the orthogonal array technique, the mini-

Link No.	Factors	Levels	
Link A	A	1 (↑)	2 (↓)
Link B	B	1 (↑)	2 (↓)
Link C	C	1 (→)	2 (←)
Link D	D	1 (→)	2 (←)
All other links		←→	

Table 4. Factors and their levels studied in the simulations

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Scenario No.	Factor A	Factor B	Factor C	Factor D	Run 1: min	Run 2: min
1	1	1	1	1	137·7	128·9
2	1	1	1	2	127·5	229·5
3	1	1	2	1	176·0	176·1
4	1	1	2	2	148·2	144·4
5	1	2	1	1	322·1	276·5
6	1	2	1	2	331·9	339·7
7	1	2	2	1	223·8	250·0
8	1	2	2	2	254·9	223·8
9	2	1	1	1	144·5	123·6
10	2	1	1	2	100·0	97·3
11	2	1	2	1	257·1	201·3
12	2	1	2	2	106·6	143·7
13	2	2	1	1	348·0	346·3
14	2	2	1	2	325·5	333·2
15	2	2	2	1	197·4	167·8
16	2	2	2	2	287·7	300·4

Table 5. Level numbers for each scenario and factor together with the simulation total delay time results

mum number of required simulations for four factors (with two levels and three interactions) was eight. It was therefore designed as $L_8(2^7)$ as shown in Table 6. A linear graph (Figure 2) was used to assign the interactions to the correct columns in Table 6, as it appeared likely that there were some interactions between the factors studied. According to the experimental plan, the first seven columns are assigned to A, B, A × B, C, A × D, B × D and D, respectively. This is explained in detail below. Whereas the numbers on the nodes in a linear graph show the column numbers assigned to the factors, the numbers on the lines show the column numbers assigned to the interactions between these factors. The present authors thought that there might be some interactions between factors A and B, factors A and D, and factors B and D. Figure 2 shows the two alternative linear graphs for the possible different interactions. The linear graph in Figure 2(a) was used for the above-mentioned interactions, which are columns 1 and 2 for A × B, columns 1 and 4 for B × D, and columns 2 and 4 for A × D. The interaction between factor A in column 1 and factor B in column 2 is assigned to column 3 using the linear graph in Figure 2(a). The other interactions considered,

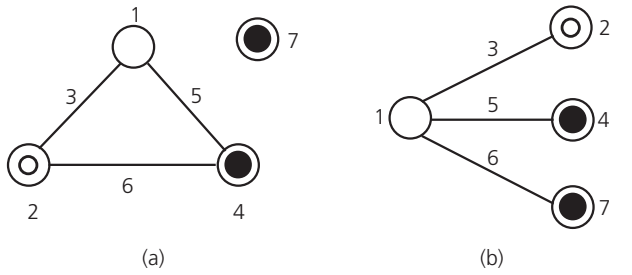

Figure 2. Linear graph for L_8 orthogonal array

Simulation No.	1 A	2 B	3 A × B	4 C	5 A × D	6 B × D	7 D	Run 1: min	Run 2: min	*S/N*
1	1	1	1	1	1	1	1	137·7	128·9	−78·064
2	1	1	1	2	2	2	2	148·2	144·4	−78·868
3	1	2	2	1	1	2	2	331·9	339·7	−86·086
4	1	2	2	2	2	1	1	223·8	250·0	−83·068
5	2	1	2	1	2	1	2	100·0	97·3	−75·448
6	2	1	2	2	1	2	1	257·1	201·3	−82·831
7	2	2	1	1	2	2	1	348·0	346·3	−86·374
8	2	2	1	2	1	1	2	287·7	300·4	−84·933
									Average *S/N* =	−81·959

Table 6. $L_8(2^7)$ run plan used in the study

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namely A × D and B × D, were assigned to columns 5 and 6 using the same linear graph, respectively.

Since the purpose of the study was to minimise the total delay time in the network, *S*/*N* values were calculated based on the quality characteristics of 'the smaller the better' using Equation 2. For convenience in further calculations, total delay time values are presented in their original units, namely seconds. The average *S*/*N* effects of the factors and interactions are shown in Figures 3 and 5, and in Table 7.

When evaluating the negative *S*/*N* values it should be noted that the minus signs in front of the numbers do not have the commonly understood effect (e.g. −56 is bigger than −38). The levels of factors that minimise the *S*/*N*s are optimum. ANOVA was implemented to determine the relative effects of the factors and interactions (Table 8).

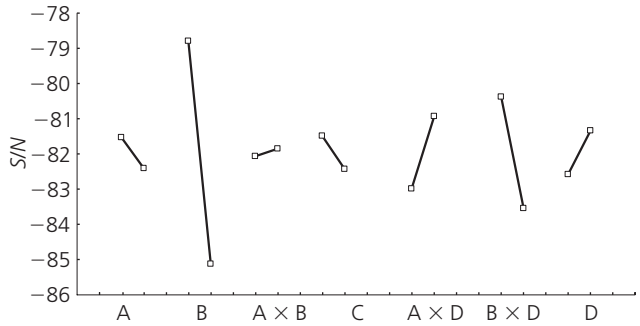

Figure 3. The average *S*/*N* effects of each factor and interaction on the delay time

5. Results and discussion

The average effects of all the factors and the interactions considered are given in Table 3 and Figure 2. The interactions of A × D and B × D are shown in Table 9. An ANOVA of the factors and interactions included indicates the relative influences (the rightmost column in Table 8) on the variations in total delay times. When ANOVA reveals that one of the factors is of little significance, it is a common practice to revise the ANOVA by pooling insignificant factors. The revised ANOVA after pooling the one insignificant factor interaction between A and B is shown in Table 10. It was also observed in Table 8 that the interaction between A and B could be neglected since it had the weakest effect on the total delay time. It is evident from Table 10 that B was the most significant factor. Hence, B × D and A × D can be treated as significant, whereas factors A, C and D are less significant in minimising total delay times.

The optimum condition is determined from the average effects given in Table 7. Before determining the recommended levels for all factors, the interactions between the factors were analysed. The optimum factor levels seem to be: factor A1 (level 1), factor B (level 1), factor C (level 1), and factor D (level 2). Because there are significant interactions, the levels of interacting factors are adjusted

A	B	A × B	C	A × D	B × D	D
−81·52	−78·80	−82·06	−81·49	−82·98	−80·38	−82·58
−82·40	−85·12	−81·86	−82·43	−80·94	−83·54	−81·33

Table 7. The average *S*/*N* effects of each link and interaction on total delay time

	Degrees of freedom	Sum of squares	Variance	Pure sum of squares	Percentage contribution
A	1	1·536	1·536	1·536	1·342
B	1	79·702	79·702	79·702	69·619
A × B	1	0·081	0·081	0·081	0·071
C	1	1·743	1·743	1·743	1·522
A × D	1	8·311	8·311	8·311	7·259
B × D	1	19·981	19·981	19·981	17·453
D	1	3·126	3·126	3·126	2·731
Error	0				
Total	7	114·483			100

Table 8. Results of ANOVA before pooling

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A × D				B × D			
A1D1	A2D1	A1D2	A2D2	B1D1	B2D1	B1D2	B2D2
−80·57	−84·61	−82·48	−80·20	−80·45	−84·73	−77·16	−85·51

Table 9. Interactions between A and D and between B and D

	Degree of freedom	Sum of squares	Variance	*F*-ratio	Pure sum of squares	Percentage contribution
A	1	1·536	1·536	18·902	1·455	1·271
B	1	79·702	79·702	980·468	79·621	69·548
A × B			(1) (0·081) pooled			
C	1	1·743	1·743	21·443	1·661	1·451
A × D	1	8·311	8·311	102·238	8·229	7·188
B × D	1	19·981	19·981	245·8	19·9	17·382
D	1	3·126	3·126	38·464	3·045	2·66
Error	1	0·081	0·081			0·5
Total	7	114·483				100

Table 10. Results of ANOVA after pooling

by examining the test of the presence of interaction plots (Figure 4). From Table 8, the interaction A × B has almost no influence on the total delay time and it is not necessary to evaluate this interaction. The review of the plots of interactions between factors A and D shown in Figure 4 reveals that the smallest value is obtained at level 2 of factor A (A2D2 = −80·20). This means that the level of factor A needs to be set to level 2. Similarly, the review of the plots of interaction between factors B and D shows that B1D2 has the smallest *S*/*N* value (−77·16), which is the same as the value originally selected from the main effects as shown in Figure 5.

After evaluating the interactions between the factors, the optimum

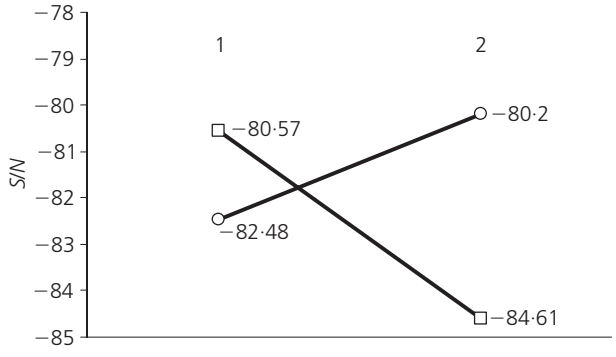

Figure 4. Interaction between factors A and D (A × D)

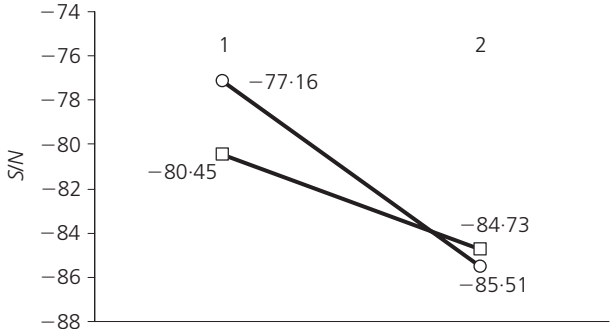

Figure 5. Interaction between factors B and D (B × D)

condition for 'the smaller the better' is found to be A2B1C1D2. The average *S*/*N* values for each factor were given in Table 7. The graph in Figure 3 is drawn according to the values in Table 7. The numerical value of the minimum point of each graph marks the best value of that particular factor. The minimum values for each parameter were given in Table 8. In addition, when the experimental plan (Table 6) is studied carefully, it can be seen that an experiment corresponding to the optimum conditions A2B1C1D2 was performed during the simulation work. Thus, the expected performance for the optimum condition A2B1C1D2 is calculated using the average values for each factor of A2, B1, C1 and D2, as shown below:

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$$\begin{aligned} EP = & -81{\cdot}959 + [-81{\cdot}52 - (-81{\cdot}959)] \\ & + [-78{\cdot}80 - (-81{\cdot}959)] \\ & + [-81{\cdot}493 - (-81{\cdot}959)] \\ & + [-80{\cdot}939 - (-81{\cdot}959)] \\ & + [80{\cdot}378 - (-81{\cdot}959)] \\ & + [-81{\cdot}334 - (-81{\cdot}959)] \\ = & -74{\cdot}676 \end{aligned}$$

There is no need to recalculate the expected performance at the optimum level as it already includes the effect of the significant interactions as shown in the calculation of the expected performance above.

The confidence interval at the 95% level was calculated as $-74{\cdot}676 \pm 2{\cdot}86$ by using Equation 5:

$$\mu = -81{\cdot}959$$

$$\begin{aligned} X_i = & [-81{\cdot}52 - (-81{\cdot}959)] \\ & + [-78{\cdot}80 - (-81{\cdot}959)] \\ & + [-81{\cdot}493 - (-81{\cdot}959)] \\ & + [-80{\cdot}939 - (-81{\cdot}959)] \\ & + [80{\cdot}378 - (-81{\cdot}959)] \\ & + [-81{\cdot}334 - (-81{\cdot}959)] \\ = & \ 7{\cdot}283 \end{aligned}$$

and

$$\sqrt{F(1,\ n_2) \times \frac{V_e}{N_e}} = \sqrt{F(1,\ 1) \times \frac{0{\cdot}081}{8/(1+4)}} = 2{\cdot}86$$

Thus, the lower and upper *S*/*N* limits for the expected performance are $-71{\cdot}816$ and $-77{\cdot}536$, respectively. In this study, there is no need to perform a confirmation run for the optimum condition because the fifth simulation in Table 6 gives the optimum condition. It is seen that the runs for the optimum condition A2B1C1D2 are 100 min and 97·3 min. These values are well within the calculated confidence interval.

6. Concluding remarks

In practice, traffic managers and decision-makers face difficulties in tackling the high number of alternatives in scenario tests through simulation. This is usually due to the large number of factors affecting the performance of road networks. To overcome this, in the traditional simulation approach one factor is varied while the other factors are kept constant. The optimum conditions achieved in this conventional approach may therefore not be a true optimum if there are interactions between the factors. To address this issue, the Taguchi method was used, which substantially decreased the required number of experiments and proved to be a feasible way of studying the effects of the factors and their interactions. In the study an example problem of introducing one-way streets in a sample network was demonstrated. The problem assumed that four arbitrarily chosen links in this network can be made one-way streets for potential improvements in delay times. In deciding the best combination of the directions of these four links, it was assumed that the decision maker would use the Paramics microsimulation tool to run all possible options in order to seek the minimum total delay time. The simulation runs were designed using an orthogonal array technique in an L_8 array system. For a proof and a complete comparison, both the full factorial design and the Taguchi method were used to find the best scenario (among 16 possibilities) and the response data were analysed using an analysis of variance technique. As discussed in detail in Section 5, the Taguchi method proved to be successful so that, even in a small network, by using the approach identified in the present study the number of runs could safely be reduced from 16 (or 32 if each run is repeated twice with two different seed numbers for more confidence in averaging) to 8 (or 16 if each run is repeated twice for the same reason). Furthermore, the use of the Taguchi method enabled the interactions between the factors to be seen, which cannot be achieved so easily in pure simulation trials. The paper is quite theoretical but the proposed use of the Taguchi method to reduce the number of runs would appear to be of significant benefit to practitioners. Ongoing work will develop the method further and apply to a 'real life' network so that transport modellers can be shown its potential practical use.

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REFERENCES

Bentley RW and Lambe TA (1980) Assignment of traffic to a network of signalized city streets. *Transportation Research Part A – Policy and Practice* **14(1)**: 57–65.

Celik C and Burnak N (1998) A systematic approach to the solution of design optimization problem. *Total Quality Management* **9(1)**: 101–108.

Fouladvand ME, Shaebani MR and Sadjadi Z (2004) Intelligent controlling simulation of traffic flow in a small city network. *Journal of the Physical Society of Japan* **73(11)**: 3209–3214.

Gunay B (2007) Car following theory with lateral discomfort. *Transportation Research Part B: Methodologic*al **41(7)**; 722–735.

Hinislioglu S and Bayrak UO (2004) Optimization of early flexural strength of pavement concrete with silica fume and fly ash by Taguchi method. *Civil Engineering and Environmental Systems* **21(2)**: 79–90.

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IHT (1997) *Transport in the Urban Environment*. IHT, London, UK.

Jones B (1986) One way to neighbourhood deterioration? *Journal of Planning Education and Research* **5(154)**: 154–163.

Kackar RN (1985) Off-line quality control, parameter design and Taguchi method. *Journal of Quality Engineering* **17(4)**: 176–209.

Karmeier D (1982) *Traffic Regulations. Traffic and Transportation Engineering Handbook*. Institute of Transportation Engineers, Washington, DC, USA.

Li X, Xu T, Ma X, Guo K, Kai L, Zhao Y, Jia X and Ma Y (2008) Optimization of culture conditions for production of cis-epoxysuccinic acid hydrolase using response surface methodology. *Bioresource Technology* **99(13)**: 5391–5396.

Ma WT, Cheu RL and Lee DH (2004) Scheduling of lane closures using genetic algorithms with traffic assignments and distributed simulations. *Journal of Transportation Engineering, ASCE* **130(3)**: 322–329.

Montgomery DC, Talavage JJ and Mullen CJ (1972) A response surface approach to improving traffic signal settings in a street network. *Transportation Research* **6(1)**: 69–80.

Nathan HG (1976) On the application of a response surface methodology to traffic signal settings. *Transportation Research* **10(1)**: 59–60.

Ozturk N and Kavak D (2008) Boron removal from aqueous solutions by batch adsorption onto cerium oxide using full factorial design. *Desalination* **223(1–3)**: 106–112.

Papageorgiou M (1995) An integrated control approach for traffic corridors. *Transportation Research Part C – Emerging Technologies* **3(1)**: 19–30.

Phadke MS (1989) *Quality Engineering Using Robust Design*. Prentice-Hall, Eaglewood Cliffs, NJ, USA.

Quadstone Paramics (2007) *Paramics User Manual, Version 6*. Quadstone Paramics, Edinburgh.

Roess RP, Prassas ES and McShane WR (2004) *Traffic Engineering*, 4th edn. Prentice Hall, Upper Saddle River, NJ, USA.

Roy RK (1990) *A Primer on the Taguchi Method*, Competitive Manufacturing Series. Van Norstrand Reinhold, New York, NY, USA.

Taguchi G (1987) *Systems of Experimental Design 1–2*. Quality Resources, New York, NY, USA.

Tenekeci G (2007) A modelling technique for assessing linked MOVA. *Proceedings of the Institution of Civil Engineers – Transport* **160(3)**: 125–138.

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