Use of Box and Jenkins Time-Series Analysis to Isolate the Impact of a Pavement Improvement Policy

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The impact of a freeway pavement improvement policy, in terms of its actual effects on freeway volumes and the duration of those effects as well as the effect of this intervention on the accuracy of model forecasts, is analyzed. Univariate and multivariate time-series models are used for the impact analysis. Both types of models exhibit accurate volume forecasts. Two approaches to isolating the impact effect are used. One approach is to fit a univariate time series model to predict trends prior to the intervention. A second approach fits a time-series model with intervention variables to the entire series. Both models yield similar results in terms of measured volume impacts.

This paper addresses two major issues concerning the use of time-series analysis in traffic planning. First, this study and a previous one by Nihan and Holmesland (1) indicate that time-series models can yield accurate short-term forecasts of traffic volumes for operational planning. The fact that such models appear to be quite accurate and are also inexpensive and easy to run suggests the need for further development in this area of traffic forecasting.

Time-series techniques can also be used to isolate the impact of certain policy interventions on traffic volumes. By using such techniques, we can statistically determine not only the impact itself but its duration as well. This second issue is of considerable importance to those involved in the day-to-day decisions that affect traffic operations. This paper shows how time-series analysis can be used to study the impact of one such decision. The policy to be studied is a three-month, 24-h pavement improvement program for a freeway bridge crossing that occurred during the months of July, August, and September 1975 in Seattle, Washington.

STATE OF THE ART

Time-series models have proved to be accurate forecasters in modeling socioeconomic phenomena in other disciplines. They have been very successful, for example, in economics, a field that is related to transportation in many respects since economic activity creates many of the conditions that encourage transportation. Economic time-series models have been shown to forecast quite accurately (2-6). Given the positive results in this related area, it stands to reason that this approach would be useful to traffic engineers. Yet little time-series modeling has occurred in traffic planning. This is somewhat puzzling, since traffic-volume data provide an excellent basis for time-series analysis. A few traffic studies have been performed by using the widely accepted Box and Jenkins time-series technique (7, p. 44) used in the current study. From these preliminary studies, the use of the Box and Jenkins technique for forecasting and determining the effects of external interventions (8) appears promising. The current study expands on this set of traffic studies.

Among the studies observed in transportation is one by Holmesland (9) that showed that traffic data are time-dependent and that dynamic models are needed in this area. Another study was conducted by Hammatuck (10) in Madison, Wisconsin, to determine the impact of a one-month transit strike on total transit revenue. The results demonstrated clearly that the method is applicable. There have also been three studies of the impact of interventions on traffic accidents. Atkins (11) looked at the effect of a speed-limit change on fatalities on freeways in British Columbia. Another study by Bhattacharyya and Layton (12) analyzed the effect on accidents of the safety-belt law introduced in the state of Queensland, Australia. A third study by Wiorkowski and Heckard (13) dealt with the impact of alcohol legislation on accidents in Texas. Finally, Box and Jenkins models have also been used in estimating aggregate transit demand in Montreal (14).

An important factor in the above-mentioned transportation studies is the fact that they show time dependency of data series exists in such different areas as traffic volumes, transit ridership and revenues, and traffic accidents.

RESEARCH DESIGN

Notation

Before a discussion of the actual experiments, the notation to be used throughout the remainder of this paper is defined. The symbols for the variables used in the model equations are as follows:

a_t = random noise term (residual) associated with month t,

$\mu_{1t} = \begin{Bmatrix} 0 \text{ if } t \neq \text{July 1975} \\ 1 \text{ if } t = \text{July 1975} \end{Bmatrix}$ = dummy intervention variable for July 1975,

$\mu_{2t} = \begin{Bmatrix} 0 \text{ if } t \neq \text{August 1975} \\ 1 \text{ if } t = \text{August 1975} \end{Bmatrix}$ = dummy intervention variable for August 1975,

$\mu_{3t} = \begin{Bmatrix} 0 \text{ if } t \neq \text{September 1975} \\ 1 \text{ if } t = \text{September 1975} \end{Bmatrix}$ = dummy intervention variable for September 1975, and

z_t = average weekday volume for month t.

The symbols for the operators used in the model equations are as follows:

B = backward shift operator,

$Bz_t = z_{t-1}$,

$B^n z_t = z_{t-n}$,

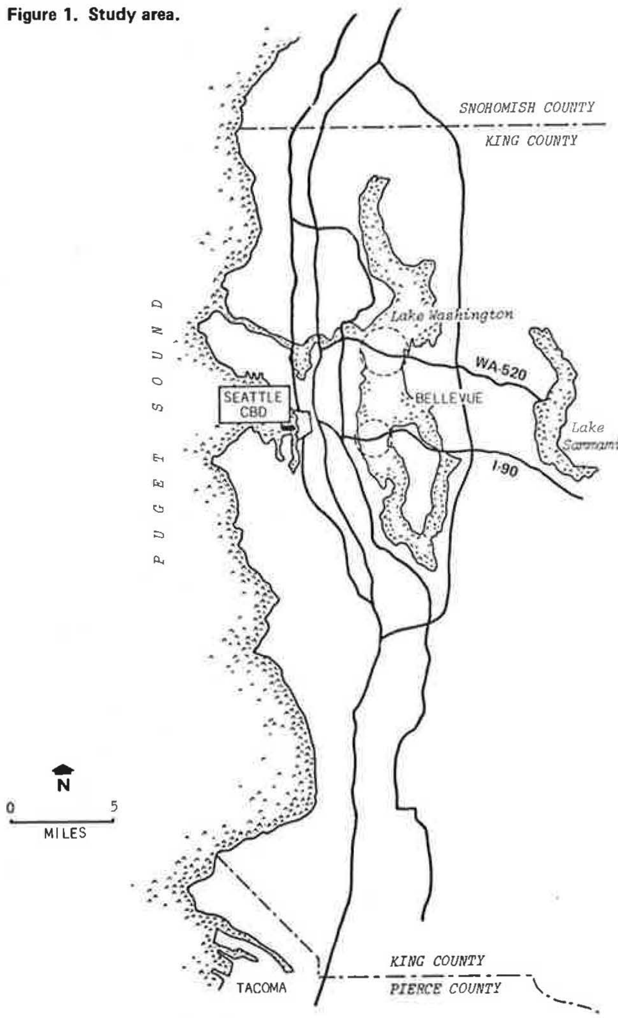
$\nabla\nabla_{12}$ = double difference operator with season of 12 months = $(1 - B)(1 - B^{12})$, and

$\nabla\nabla_n = (1 - B)(1 - B^n)$, where the first difference term is nonseasonal (single difference) and the second difference term is seasonal and represents a seasonal lag of n months.

Study Area

The focus of the study was on traffic volumes on two freeway bridge crossings that serve the Puget Sound metropolitan region (see Figure 1). The two bridges, which cross Lake Washington on I-90 and WA-520, are the only major transportation connectors between the suburban Eastside and the city of Seattle. During July, August, and the first half of September 1975, the I-90 bridge was under repair and severe capacity restrictions were imposed on it. The chosen policy of pavement improvement was a 24-h operation. During the off-peak hours, the bridge was in operation with two lanes (one in each direction) rather than the normal four lanes. During the

Figure 1. Study area.



rush hours, one lane was added for the main direction (since I-90 used reversible lanes during rush hours, this meant two plus one compared with the normal three plus one). In addition to the reduction in the number of lanes, there was also a reduction in the width of lanes, which further restricted capacity per lane.

The purpose of the modeling experiments that follow was to determine whether such a policy had a measurably detrimental effect on traffic volumes between Seattle and the Eastside and whether this effect was of long or short duration.

Data and Models

The two data series used for specification and diagnostic checking for WA-520 and I-90 were average weekday (AWD) traffic volumes per month from January 1968 to March 1980. Of interest were the impact of pavement improvements on I-90 during July, August, and September 1975 on traffic volumes and also the effect this intervention had on the use of the I-90 data base for future volume predictions.

Four types of models were specified for the two data series. These are summarized below:

1. Model A (I-90) was a univariate model fitted to the time series of monthly AWD volumes from January 1968 through December 1977. This model was used to forecast volumes for the months of January 1978 through March 1980 for diagnostic checking. No special treatment for the I-90 pavement improvement was included in this model.
2. Model B (I-90) was a multivariate model fitted to the same time series as model A, but binary policy variables were added to represent the months when pavement improvement was taking place.
3. Model C (I-90) was a univariate model fitted to the time series of monthly AWD volumes from January 1968 to June 1975--i.e., prior to the pavement improvement period. This model was used to forecast volumes from July 1975 to June 1978 to represent the expected volumes if no pavement improvement had occurred.
4. Model D (I-90) was a multivariate model fitted to the time series of monthly AWD volumes from January 1968 to December 1977. Binary variables were added to represent the months when pavement improvement on I-90 was taking place.

Thus, models A and C are univariate models for the I-90 data series fitted to different subsets of the data. Both models A and C ignore the effects of outside intervention (such as pavement improvements) on forecast volumes. Models B and D are multivariate models fitted to the time-series data for the same period months but policy variables were added. Model B is specified for I-90 data, and model D is specified for the WA-520 series. Both models B and D include binary variables to represent the months of the policy intervention of pavement improvement on I-90 (i.e., July, August, and September 1975).

The fitted models A, B, C, and D (Equations 1-4) are given in order below (the standard deviations of the individual coefficients are given below the line):

$$\nabla\nabla_{12} Z_t = (1 - \underset{0.081}{0.228}B - \underset{0.081}{0.562}B^2)(1 - \underset{0.031}{0.93}B^{12})\, a_t \quad (1)$$

where chi-square = 20.5 on 23 df;

$$(1 + \underset{0.11}{0.15}B - \underset{0.11}{0.27}B^2)(1 + \underset{0.08}{0.73}B^{12})\nabla\nabla_{12} z_t = -\underset{1445}{12\,366}\,\nabla\nabla_{12}\mu_{1t} - \underset{1691}{16\,391}\,\nabla\nabla_{12}\mu_{2t} - \underset{1452}{6041}\,\nabla\nabla_{12}\mu_{3t} + a_t \quad (2)$$

where chi-square = 13.8 on 23 df;

$$(1 + \underset{0.107}{0.3972}B + \underset{0.108}{0.3275}B^2)\nabla\nabla_{12} z_t = (1 - \underset{0.039}{0.8955}B^{12})\, a_t \quad (3)$$

where chi-square = 20.6 on 23 df; and

$$\nabla\nabla_{12} z_t = (1 - \underset{0.095}{0.37}B - \underset{0.095}{0.166}B^2)(1 - \underset{0.036}{0.88}B^{12})\, a_t + \underset{1527}{5239}\,\mu_{1t} + \underset{1521}{1461}B^2\mu_{3t} \quad (4)$$

where chi-square = 12.1 on 23 df. [In order for the model to be accepted, the residuals must be random according to the chi-square test. Due to the nature of time-series data, df is chosen differently than it is with ordinary data samples. A rule of thumb is that df is at least two seasons plus one or two observations less than one-third of the series, whichever is smallest (7). For all four models, the mean of residuals is not significantly different from zero.]

Experiments

The models given above were used for the following experiments, which were designed to investigate the

Table 1. Forecast results for I-90: model A.

Year	Month	Traffic Volume (no. of vehicles) Actual	Forecast	Forecast Error (%)
1978	January	56 892	52 754	7.27
	February	57 963	54 541	5.90
	March	60 324	56 800	5.84
	April	60 398	57 725	4.43
	May	60 494	57 425	5.07
	June	63 289	60 146	4.96
	July	61 555	57 348	6.83
	August	64 648	58 193	9.98
	September	60 731	56 198	7.46
	October	62 582	56 452	9.79
	November	58 664	55 253	5.81
	December	58 924	54 709	7.15
1979	January	56 434	51 535	8.68
	February	57 770	53 902	6.69
	March	59 645	56 161	5.84
	April	61 521	57 086	7.21
	May	59 636	56 786	4.78
	June	61 074	59 508	2.56
	July	57 342	56 709	1.10
	August	58 260	57 555	1.21
	September	56 141	55 560	1.03
	October	55 959	55 814	0.26
	November	53 924	54 614	-1.28
	December	52 519	54 070	-2.95
1980	January	47 511	50 897	-7.13
	February	52 122	53 264	-2.19
	March	54 478	55 523	-1.92

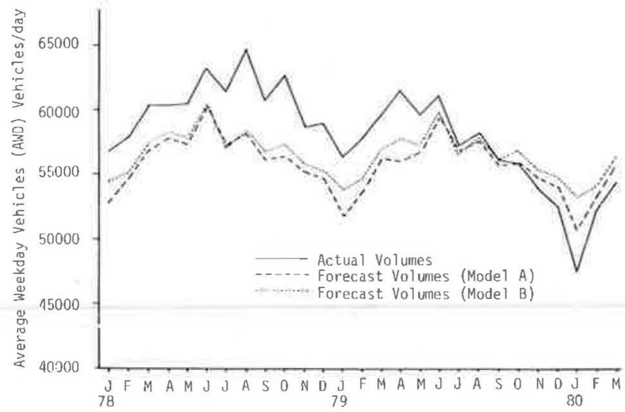
Table 2. Forecast results for I-90: model B.

Year	Month	Traffic Volume (no. of vehicles) Actual	Forecast	Forecast Error (%)
1978	January	56 892	54 454	4.28
	February	57 963	55 068	5.00
	March	60 324	57 456	4.75
	April	60 398	58 286	3.50
	May	60 494	57 814	4.43
	June	63 289	60 428	4.52
	July	61 555	57 151	7.16
	August	64 648	58 446	9.59
	September	60 731	56 633	6.75
	October	62 582	57 373	8.32
	November	58 664	55 987	4.56
	December	58 924	55 398	5.98
1979	January	56 434	53 760	4.74
	February	57 700	54 591	5.50
	March	59 645	56 914	4.58
	April	61 521	57 698	6.21
	May	59 636	57 266	3.97
	June	61 074	59 879	1.96
	July	57 342	56 589	1.31
	August	58 260	57 890	0.63
	September	56 141	56 079	0.11
	October	55 959	56 817	-1.53
	November	53 924	55 431	-2.79
	December	52 519	54 843	-4.42
1980	January	47 511	53 204	-11.98
	February	52 122	54 035	-3.67
	March	54 478	56 358	-3.45

I-90 pavement improvement and its impact on volumes for the two bridges and on model forecasts.

1. Experiment 1 was designed to compare the forecasts of models A and B with what actually happened during the months from January 1978 through March 1980. This is designed to determine (a) whether a 2.5-month, 24-h/day pavement improvement program in the summer of 1975 must be considered in forecasting a period three years later and (b) whether either model gives an acceptably accurate forecast.

Figure 2. Forecast volumes versus actual volumes for I-90: models A and B.



2. Experiment 2 was designed to compare the forecast of model C, which represents expected volumes if there were no pavement improvement, with the actual volumes. This is designed to determine what the impact of the pavement improvement on volumes was and how long this impact lasted.

3. Experiment 3 was designed to compare the coefficients of the binary policy variables in model B to the outcome of experiment 2 (these coefficients are another means of assessing the impact of the pavement improvements). The two results should be comparable, given adjustment for an expected error term.

4. Experiment 4 was designed to compare models B and D to assess the mutual effects of the I-90 improvement on both I-90 and WA-520.

RESULTS

The results of the forecasting experiment for models A and B for a 27-month time horizon are given in Tables 1 and 2. Model B performs slightly better than model A for most months. The average absolute percentage error for model A is 5.08 versus 4.66 for model B. Given the likelihood that traffic counters have an expected error within the range of ±5 percent, both models appear sufficiently accurate for forecasting purposes. Figure 2 further illustrates this comparison.

Thus, for purposes of attaining the required accuracy, it appears that a short-term policy intervention will not have a marked effect on the forecasting potential of the data base three years hence. However, one must examine the residuals of the first-pass model before determining the need for introducing binary policy variables. If the residuals for model A that correspond to the months of July, August, and September were significant, then model B would be chosen as the more accurate model. In fact, residuals for $t = 91$ and $t = 92$ that corresponded to the months of July and August 1975 were significant (the fact that the pavement improvement continued for only half the month of September may explain the fact that the residual for $t = 93$ was not identified as significant by the program). This, coupled with the fact that the estimated standard deviation of the residuals and the chi-square value for both models indicate a preference for model B, shows that the use of intervention variables increases the expected accuracy of the model

Thus, in time-series modeling it is important to take care of significant residuals. The process therefore becomes, in many instances, a two-stage estimation: First, a gross univariate estimation is made (no intervention variables); then the model is inspected for significant residuals (outliers) and reestimated by using dummy binary variables (intervention variables) corresponding to events that create explainable outliers. The coefficients of these dummy variables plus the type of forecast in experiment 2 give us information on the probable impact of the intervention in question.

The results of experiment 2 are given in Table 3. The comparison between actual and forecast volumes is also shown in Figure 3. We are assuming that model C represents the trends prior to the 1975 pavement improvement operation. Thus, the forecast volumes should represent what would have happened without the intervention plus an error term. Given the forecast errors in the previous example and in other time-series studies mentioned previously, a 5 percent error term appears to be reasonable expected error. Thus, the impacts on volumes indicated for July, August, and September 1975 are -27.16 ± 5 percent, -36.45 ± 5 percent, and -14.71 ± 5 percent, respectively. This represents the impact of the improvement on volumes during those months (note that the impact in the month of September is lower because the improvements were being made during the first half of September only). This impact dies off right after the project ceases. Judging from the residuals for 1976, the improvement may have a one-year lagged impact on volumes. However, since the residuals are not statistically significant, any lagged effect (i.e., reduced volumes due to memory of the previous year's experience) is probably minor.

Table 3. Forecast results for I-90: model C.

Year	Month	Traffic Volume (no. of vehicles) Actual	Forecast	Forecast Difference (%)
1975	July	45 717	58 135	-27.16
	August	43 709	59 641	-36.45
	September	49 765	57 088	-14.71
	October	54 774	56 519	-3.19
	November	54 144	56 005	-3.44
	December	53 610	55 794	-4.07
1976	January	52 845	53 122	-0.52
	February	53 713	54 967	-2.33
	March	54 347	57 355	-5.53
	April	55 117	58 069	-5.36
	May	55 885	58 094	-3.95
	June	57 532	61 320	-6.58
	July	56 538	59 762	5.70
	August	54 238	61 422	-13.25
	September	49 488	58 866	-18.95
	October	49 663	58 248	-17.29
	November	52 754	57 755	-9.48
	December	54 997	57 552	-4.65
1977	January	54 455	54 870	-0.76
	February	55 008	56 716	-3.10
	March	57 229	59 107	-3.28
	April	59 134	59 820	-1.16
	May	57 001	59 844	-4.99
	June	61 727	63 070	-2.18
	July	60 181	61 513	-2.21
	August	61 108	63 173	-3.38
	September	58 616	60 617	-3.41
	October	58 321	59 998	-2.88
	November	56 030	59 505	-6.20
	December	56 030	59 302	-5.84
1978	January	56 892	56 620	0.48
	February	57 963	58 466	-0.87
	March	60 324	60 857	-0.88
	April	60 398	61 570	-1.94
	May	60 494	61 594	-1.82
	June	63 289	64 821	-2.42

Comparison of models A and B provides another way of examining the impact of the I-90 pavement improvement on both I-90 and WA-520. The results of this comparison are given below:

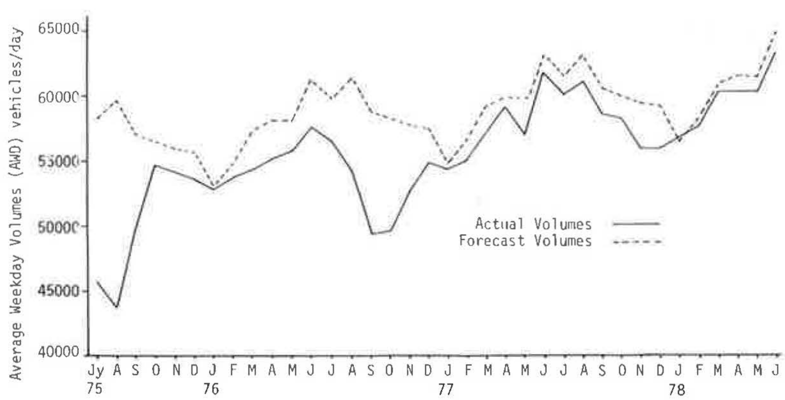
Bridge Affected	Month	Absolute Value	Change (%)
I-90	July	-12 366	-27.0
	August	-16 391	-37.5
	September	-6 041	-12.1
WA-520	July	+5 239	+8.9
	August	+5 035	+8.8
	September	+1 461	+2.8
Both	July	-7 217	-6.9
	August	-11 356	-11.3
	September	-4 580	-4.5

The coefficients of the policy variables for model A should be comparable to the results for July, August, and September 1975 obtained in the previous experiment for model C. If one takes an error term into account, the resulting reductions in I-90 volumes of 27.0, 37.5, and 12.8 percent correspond favorably to those obtained by using model C to forecast existing trends prior to 1975 and comparing with actual values. The results of a comparison of these impact measurements for I-90 made by using the two different approaches are summarized below:

Model	Month	Absolute Value	Change (%)
B	July	-12 366	-27.0
	August	-16 391	-37.5
	September	-6 041	-12.1
C	July	-12 418	-27.2
	August	-15 932	-36.5
	September	-7 323	-14.7

As the first table above further illustrates, the resurfacing of I-90 (a job that created severe traffic restrictions) had a twofold effect with regard

Figure 3. Forecast volumes versus actual volumes for I-90: model C.



to this study. First, the total traffic across Lake Washington decreased during the summer months of 1975, and these outliers (significant residuals) affected the model structure and the final estimate of the models. Second, although it was expected that traffic across Lake Washington would merely shift from I-90 to WA-520, the results show that there was a net decrease in across-the-lake traffic during this period. The traffic on I-90 decreased 20-30 percent, but WA-520 did not compensate for even half of this decrease in corresponding traffic increases. It must be concluded, therefore, that many of the trips crossing Lake Washington are a matter of convenience and are "noncaptive" trips.

SUMMARY

The experiments described in this paper indicate a promising potential for using the Box and Jenkins technique to assess the impact of short-term policy effects, such as pavement improvements on traffic volumes in the corridor in question and on parallel facilities. They also reemphasize the accuracy of short-term time-series forecasts (given the expected accuracy of existing traffic counters).

The experiments also indicate that models that introduce intervention variables corresponding to explainable outliers (significant residuals) are preferred over simple univariate models, although the impact of such outliers may be lessened over time. In other words, the impact of a short-run policy in 1975 may not significantly affect a forecast period three years hence [providing, of course, that all subsequent data (1975-1978) are included in the model specification].

The experiments also illustrated a high correlation between the two approaches to impact analysis. The first approach, in which a model was fitted to data prior to the intervention (model C) and then used to forecast what would have happened with no intervention, gave results that were very close to the results obtained with the multivariate model (model B). The reductions in volumes indicated by a comparison of actual and forecast volumes made by using model C were very close to the reductions indicated by the coefficients of the policy variables introduced in model B.

Finally, it appears that a pavement improvement policy such as the one analyzed here can have a significant and statistically measurable impact on traffic volumes for both the facility in question and the parallel facility. Such a policy also affects the absolute volumes of crossings regardless of route. The impact appears to die out almost immediately after the improvement is finished and to have no significant long-term effects.

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