Effectiveness of Speed Control Measures on Nighttime Construction and Maintenance Projects

Lindsay Miller[1]; Fred Mannering[2]; and Dulcy M. Abraham[3]

Abstract: Nighttime work-zone safety has become a concern among state transportation agencies due to an increasing number of work-zone fatalities and the high percentage of roadwork performed at night. Speed control has been determined by numerous researchers to be one of the best ways to improve safety on nighttime work zones. This paper presents an empirical analysis of speed-control strategies for nighttime interstate construction and maintenance projects in Indiana. The analysis considers the effect of various speed-control measures on the mean speed and the standard deviation of speed through nighttime work zones. Using a seemingly unrelated regression modeling approach, the present analysis revealed that the presence of police enforcement, a high percentage of semitrucks in the traffic stream, and a high traffic flow significantly reduced mean work-zone speeds. Factors found to significantly increase mean work-zone speeds included an increase in the number of open lanes, an original speed limit of the road section greater than 100 km/h (62 mi/h) an increase in the distance between the work-zone speed-limit signs and the first cone/barrel in the construction zone taper, and the progression of time through the night. The standard deviation of vehicle speeds was found to be significantly lower before midnight and as the number of vehicles queued increased. It was found to be significantly higher with an increase in the number of open lanes through the work zone, an increase in the number of worksite speed-limit signs, a high percentage of personal vehicles in the traffic, and an increase in total traffic flow. The results from this research demonstrate a useful analysis methodology (seemingly unrelated regression estimation) and provide some empirical results that can provide guidance for transportation agencies and contractors to improve speed-control strategies in nighttime work zones.

DOI: 10.1061/(ASCE)CO.1943-7862.0000018

CE Database subject headings: Nighttime construction; Safety; Traffic speed; Estimation.

Introduction

In the last two decades, state transportation agencies have shifted their focus from new construction to the rehabilitation and improvement of current highway infrastructure as new-project costs have risen and funding has declined. With rehabilitation and improvement projects, state agencies are often faced with the prospect of working at night. A survey of state departments of transportation and the Illinois Department of Transportation district offices found that the most important advantage of nighttime construction/maintenance is the significant reduction in congestion and delay for the traveling public due to lower nighttime traffic volumes (Al-Kaisy and Nassar 2003). Delays and congestion caused by lane closures are minimized at night because traffic volumes are at their lowest. This advantage is considered an overriding factor in selecting night work over day work (Hinze and Carlisle 1990; Elrahman and Perry 1998; Rebholz et al. 2004). However, the safety of nighttime work zones has become a major concern in recent years. In 2005, there were 1,074 work-zone fatalities in the United States (National Work Zone Safety Information Clearinghouse 2006) and approximately one-half of these fatalities occurred at night (FHwA 2007).

There have been numerous studies that have analyzed safety concerns in nighttime work zones (Al-Kaisy and Nassar 2003; Cottrell 1999; Burgess et al. 2007). The consensus of previous work is that poor visibility, driver inattention, and speed are primary contributors to compromised work-zone safety at night. Of these factors, speed control has received the most attention from state transportation agencies in their efforts to improve work-zone safety. A review of the extant literature shows that there are a multitude of techniques that have been used to control work-zone speeds, including regulatory speed limits, recommended speed limits, work-zone speed limits, police enforcement, speed-display monitors (giving a display of a vehicle's speed to their driver), changeable message signs, variable speed advisory systems, rumble strips, increased fines, citizens band radio alert systems, and narrowed lane widths. Recently, Miller (2007) conducted an extensive review of currently used speed-control strategies for work zones. She found that of the available speed-control methods, regulatory speed limits, increased fines, and police enforcement were the most popular. In her survey of state-highway personnel, she found that speed control was considered most critical in the active work area and that police enforcement was thought to be the single most effective speed-control method, followed by regulatory speed limits, work-zone speed limits, speed display monitors, increased fines, changeable message signs, and narrowed lane widths.

Although much has been done in the past, the profession still

[1]Installation Engineer, EXXON Mobil, 17001 Northchase Dr., GP5-756, Houston, TX 77060. E-mail: lindsay.m.baretto@exxonmobil.com

[2]Professor, School of Civil Engineering, Purdue Univ., 550 Stadium Mall Dr., West Lafayette, IN 47907-2051. E-mail: flm@purdue.edu

[3]Professor, School of Civil Engineering, Purdue Univ., 550 Stadium Mall Dr., West Lafayette, IN 47907-2051. E-mail: dulcy@purdue.edu

Note. This manuscript was submitted on June 27, 2008; approved on November 11, 2008; published online on June 15, 2009. Discussion period open until December 1, 2009; separate discussions must be submitted for individual papers. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 135, No. 7, July 1, 2009. ©ASCE, ISSN 0733-9364/2009/7-614–619/$25.00.

does not fully understand how traffic flows, police presence, initial speed limits, number of lanes open, and work-zone setup affect work-zone speeds. The intent of this study is to add to the growing body of literature on this subject by applying a new methodological approach that will enable new insights to be drawn. Specifically, the present work will simultaneously consider the mean and standard deviation of speed—the first time this has been done, to the writers' knowledge, in the study of work-zone speeds. Consideration of the standard deviation of speeds has important implications because speed variations are known to increase accident risk (Lave 1985; Garber and Gadiraju 1989).

The empirical analysis will be undertaken using speed data from active nighttime work zones in Indiana, and will seek to identify the factors (including observed speed-control efforts) that significantly affect the mean and standard deviation of vehicle speeds in work zones. Our study will focus on interstate projects due to their high speed limits and frequent use of speed control.

Methodological Approach

Understanding the relationship between the mean of vehicle spot speeds and their variance is important as both mean speed and speed variance can affect the likelihood of an accident. Previous research by Boyle and Mannering (2004) studied the mean and the standard deviation of individual driver speeds over 1 km sections of highway. They estimated mean speed and the standard deviation of speed as a simultaneous equations system using three-stage least squares. Their findings showed that, for individual drivers (in addition to a multitude of other explanatory variables relating to roadway geometrics, driver socioeconomics, and so on), increases in the standard deviation of speed tended to decrease mean speed and that increases in mean speed tended to decrease the standard deviation of speed. However, because the present data will be composed of the spot speeds of numerous drivers as opposed to the continuous collection of speeds for individual drivers (as was the case in Boyle and Mannering's work), the present paper develops a model structure that will not have mean speed and the standard deviation of speed directly related to one another (with mean speed appearing in the equation for the standard deviation of speed and the standard deviation of speed appearing in the equation for mean speed). Instead the model presented will have mean speed and standard deviation of speed indirectly related to each other through disturbance–term correlation (unobserved factors that affect mean speed will also affect speed deviation). Thus, the proposed model system takes the following form:

$$\text{MS}_i = \boldsymbol{\beta}_i\mathbf{Z} + \boldsymbol{\alpha}_i\mathbf{X} + \varepsilon_i \tag{1}$$

$$\text{SD}_i = \boldsymbol{\lambda}_i\mathbf{Z} + \boldsymbol{\omega}_i\mathbf{X} + \upsilon_i \tag{2}$$

where MS_i=mean speed (km/h) for time interval i; SD_i =measured standard deviation of spot speeds in time interval i (km/h); $\mathbf{Z}$=vector of site-specific characteristics; $\mathbf{X}$=vector of vehicle-specific characteristics; β_i, α_i, $\lambda_{i,}$, and ω_i=vectors of estimable parameters; and ε_i and υ_i=disturbance terms capturing unobserved characteristics.

Ordinary least squares (OLS) may be thought of as one approach to estimating Eqs. (1) and (2). However, because both mean speed and the standard deviation of speed are calculated for the same 10-min interval within a particular nighttime work zone, they are likely to share unobserved characteristics. Although OLS estimation will yield unbiased and consistent estimates for these equations when estimated separately, because the correlation of the disturbances (resulting from shared unobserved characteristics) would not be considered, the parameter estimates will not be efficient. Efficient parameter estimates can be obtained by considering the contemporaneous correlation of disturbances ε_i and υ_i and viewing the equations as seemingly unrelated [Washington et al. 2003; Mannering 2007) as first proposed by Zellner (1962)]. The seemingly unrelated estimation approach allows for additional information to be captured from the correlation of disturbance terms in Eqs. (1) and (2). This can lead to tighter confidence intervals (higher t-statistics of estimated parameters) and subsequently different inferences can be draw relative to using OLS. Estimation of seemingly unrelated equations is accomplished using generalized least squares (GLS). OLS assumes that disturbances have equal variance and are not correlated—so when using seemingly unrelated regression, GLS is used to relax these OLS assumptions (Washington et al. 2003). Recall that under OLS assumptions the resulting parameters are estimated as

$$\hat{\boldsymbol{\beta}} = (\mathbf{X}^T\mathbf{X})^{-1}\mathbf{X}^T\mathbf{Y} \tag{3}$$

where $\hat{\beta}$ $=p\times 1$ column vector (where p=number of coefficients); $\mathbf{X}=n\times p$ matrix of data (where n=number of observations); X^T=transpose of $\mathbf{X}$; and $\mathbf{Y}=n\times 1$ column vector. GLS generalizes this expression by using a matrix that considers the correlation among equation error terms (Ω), so Eq. (3) is rewritten as

$$\hat{\boldsymbol{\beta}} = (\mathbf{X}^T\Omega^{-1}\mathbf{X})^{-1}\mathbf{X}^T\Omega^{-1}\mathbf{Y} \tag{4}$$

In seemingly unrelated regression estimation, Ω is estimated from initial OLS estimates of individual equations (Washington et al. 2003).

Although seemingly unrelated regression is an important statistical method for capturing the interrelationships among equations it is, as with OLS, still limited by the overall quality of the data and the number of variables available to explain the process being modeled.

Data

Data from seven site visits to nighttime work zones on Indiana interstates were used in this study. Of these seven sites visited, three different speed-control strategies were deployed: worksite speed-limit signs, changeable message signs, and police enforcement. Summary information on the seven sites is presented in Table 1.

Site visits were made between July and November of 2006. Upon arrival to the project site, the research team drove through the length of the work zone, marking down the locations of signs, changeable message signs, and police enforcement. The researcher's vehicle was then parked behind the construction equipment so as to appear as part of the work zone and not interfering with construction activity. The vehicle was equipped with a flashing light to comply with safety regulations, which also aided in blending in with contractor vehicles within the work zone, which were also equipped with flashing lights.

Speeds and distances were collected using a handheld laser gun. Speeds were collected on vehicles that had at least 4 s headways behind the vehicle that they were trailing to ensure that their choice of speed was not being hindered by a slower-moving lead vehicle. In total, 2,797 vehicle speeds were collected at the seven

Table 1. Construction and Maintenance Site Visits

Site number	1	2	3	4	5	6	7
Interstate	I-69	I-465	I-70	I-70	I-465	I-65	I-65
Total directional lanes	2	3	3	2	3	2	3
Directional lanes open	1	1	2	1	2	1	1
Original speed limit [km/h (mi/h)]	113 (70)	89 (55)	105 (65)	105 (65)	89 (55)	113 (70)	80 (50)
Work-zone speed limit [km/h (mi/h)]	72 (45)	72 (45)	72 (45)	72 (45)	72 (45)	72 (45)	80 (50)
Number of worksite speed-limit signs	4	2	3	4	2	3	0
Number of changeable message signs	0	2	1	1	1	0	1
Police enforcement	Yes	No	No	No	Yes	No	No
Rumble strips	No	No	No	No	No	No	No
Number of individual vehicle speeds collected	377	436	175	375	589	196	649

site visits. An example of the spot-speed distribution for one of the work-zone sites is presented in Fig. 1. For each vehicle, the speed and vehicle type (car/van/SUV/pickup, single-unit truck, semitruck, other) were recorded. For purposes of the analysis of mean speed and the standard deviation of speed, speeds were grouped into 10-min intervals. The following were recorded for each 10-min interval: time period, flow rate (vehicle/h/lane), distance between data collection point and nearest construction vehicle (ft), distance between data collection point and police enforcement (ft), and the number of vehicles queued (the number of vehicles trailing a slower lead vehicle).

The original data of 2,797 individual vehicle speeds were reduced to 69 10-min intervals for statistical modeling of mean speeds and speed standard deviations. Table 2 presents some summary statistics for these data which, when viewed in conjunction with Table 1, gives a good overview of the data available.

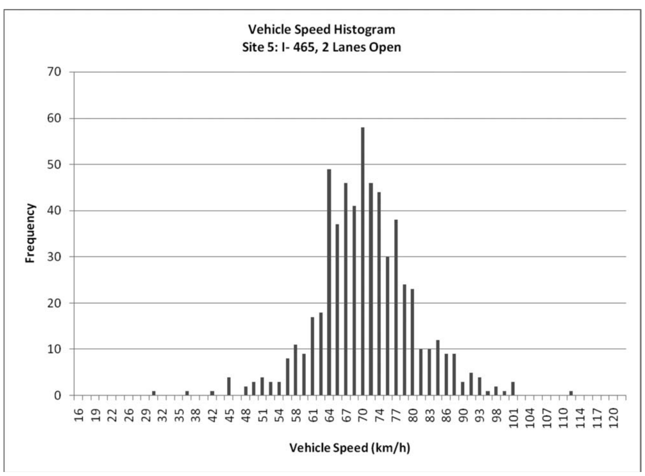

Fig. 1. Sample histogram of spot speeds at Site 2 (see Table 1 for a site description

Table 2. Some Sample Statistics for the 69 10-min Time Intervals (Standard Deviations in Parentheses)

Variable	Values
Range of time periods	9:30 p.m.–3:30 a.m.
Average speed (km/h)	66.28 (9.70)
Average standard deviation speed (km/h)	8.84 (2.25)
Percent car–pickup–van–SUV/single-unit truck/semitruck/other	42/3.2/54/0.8
Average total traffic flow (vehicles/h/lane)	506 (292)
Average number of vehicles queued	49 (47)
Average distance from work-zone speed-limit sign to the first cone or barrel in taper (km)	0.72 (0.69)

Model Estimation Results

Seemingly unrelated regression estimation was used to estimate the model system presented previously in Eqs. (1) and (2). Table 3 gives the parameter estimates and model goodness-of-fit measures for the mean speed [Eq. (1) of the equation system]. Table 3 shows that the included variables are of plausible sign and statistically significant (all parameters estimated in the model are significantly different from zero with over 99% confidence). The adjusted R^2 value is 0.78.

Turning to specific estimation results, it is found that, with all other variables constant, work zones that had two lanes opened (as opposed to one) had mean speeds that were 13.42 km/h (8.34 mi/h) faster (recall that five of our seven work zones had just one lane open and the other two had two lanes open, see Table 1). This means that drivers were less likely to slow down when mul-

Table 3. Seemingly Unrelated Regression Estimation Results for Mean Speed in km/h

Variable	Estimated parameter	t-statistic
Constant	74.43	11.38
Lanes open indicator (1 if two lanes are open, 0 if one lane is open)	13.42	5.39
Speed-limit indicator [1 if the original speed limit of the roadway is greater than 100 km/h (62 mi/h), 0 otherwise]	6.97	3.61
Police presence indicator (1 if police enforcement is present, 0 otherwise)	−8.46	−4.14
Distance from work-zone speed-limit sign to first cone or barrel in taper (km)	4.61	5.37
Percent of semitrucks in the traffic stream	−0.180	−4.74
Total traffic flow (vehicles/h/lane)	−0.0119	−3.50
Before/after midnight time-period indicator Example: −2 for time periods beginning at 11:40 p.m.; −1 for 11:50 p.m.; 0 for midnight; 1 for 12:10 a.m.; 2 for 12:20 a.m., etc.	0.574	3.42
Number of observations		69
Adjusted R^2		0.78
Log-likelihood at zero		−221.34
Log-likelihood at convergence		−161.53

tiple lanes were open through the work zone, presumably due to the additional maneuvering freedom afforded by the additional lane.

With all other variables constant, work zones where the original speed limit was greater than 100 km/h (62 mi/h) were found to have mean speeds that were 6.97 km/h (4.33 mi/h) faster than works zones with original speed limits below 100 km/h (62 mi/h). Recall from Table 1 that site visits were made to work zones with original speed limits of 80, 89, 105 and 113 km/h (50, 55, 65, and 70 mi/h). This shows that the magnitude of the difference between the original speed limit and work-zone speed limit [set to 72 km/h (45 mi/h) for all work zones except one which retained its initial 80 km/h (50 mi/h) speed limit] is an important consideration.

As shown in Table 3, police enforcement was found to decrease the mean speed through the work zone by 8.46 km/h (5.26 mi/h). This value is consistent with prior research on the effectiveness of police enforcement. For example, Noel et al. (1988) found that police enforcement in work zones decreased average speeds by 8.2 km/h (5.1 mi/h), and Benekohal et al. (1992) found that the mean speeds of passenger cars and trucks were reduced by roughly 6.4 and 8 km/h (4 and 5 mi/h), respectively, in the presence of police enforcement.

The longer the distance in kilometers from the work-zone speed-limit sign to the first cone or barrel in the taper, the higher the mean work-zone speed. For each kilometer of distance between the work-zone speed-limit sign and the beginning of the taper the mean speed through the work zone increased by 7.4 km/h (4.61 mi/h) (with all other factors constant). This means that each additional tenth of a mile of distance between the work-zone speed-limit signs and the taper caused an increase in average speed through the work zone of almost 0.8 km/h (0.5 mi/h). This is very important to consider when creating a traffic-control plan for a work zone. It is important to note that this distance between the signs and the taper varied between 0 and 2.1 km (1.3 mi) among the seven sites considered. Because the longest distance observed was 2.1 km (1.3 mi), extreme caution should be exercised when using the results presented herein on work zones with a distance greater than 2.1 km (1.3 mi).

With all other factors constant, higher percentages of semitrucks in the traffic flow were found to result in lower mean work-zone speeds as expected. The parameter estimate for this variable suggests that a 100% composition of semitrucks would result in an average speed 18 km/h (11.2 mi/h) slower than if there were no semitrucks in the traffic flow, and each 1% increase in the composition of semitrucks would result in a decrease in the mean speed of 0.16 km/h (0.1 mi/h). This shows that semitrucks generally drive at lower speeds through work zones and may also be having a speed-calming effect on other vehicles. One might expect this calming effect to vary by truck density which would provide a measure of the mean distance between trucks. However, with the range of volume data considered, the percentage of trucks was found to produce a better statistical fit than the volume. A more extensive data set would allow one to explore this relationship further.

Total traffic flow was also found to significantly decrease mean speeds. The parameter estimate shows that for each additional 100 vehicles/lane/h that pass through the work zone (other factors constant), the average speed decreases by 1.19 km/h (0.74 mi/h).

Finally, the indicator variable for the 10-min time interval in which the data were collected (centered around midnight where its value is equal to 0) was also found to have a statistically significant impact on mean vehicle speeds. The model shows that for each 10-min interval after midnight there is an increase in average speed of 0.58 km/h (0.36 mi/h). For example, data collected at 12:30 a.m. will have an average speed 1.74 km/h (1.08 mi/h) faster than data collected at midnight [three times 0.58 km/h (0.36 mi/h)]. Data collected at 11:40 p.m. will have an average speed of 1.16 km/h (0.72 mi/h) slower than data collected at midnight [two times 0.58 km/h (0.36 mi/h)]. This shows traffic speeds gradually increase with time during nighttime projects. This finding must be viewed in light of the present data, which is limited to collection between 9:30 p.m. and 3:30 a.m., so extensions to times beyond this interval would be problematic.

Table 4. Seemingly Unrelated Regression Estimation Results for Standard Deviation of Speed in km/h

Variable	Estimated parameter	t-statistic
Constant	5.23	1.50
Lanes open indicator (1 if two lanes are open, 0 if one lane is open)	1.80	1.40
Number of worksite speed-limit signs	0.43	1.59
Percent of car–pickup–van–SUV in the traffic stream	0.021	1.21
Before midnight indicator (1 if data collected before midnight, 0 otherwise)	−2.33	−2.23
Number of vehicles queued	−0.31	−1.37
Total traffic flow (vehicles/h/lane)	0.00729	1.95
Number of observations		69
Adjusted R^2		0.062
Log-likelihood at zero		−120.77
Log-likelihood at convergence		−111.70

Many variables were found insignificant in the mean-speed model. For example, it was speculated that the average speed would increase with the distance away from the active workspace. Because most of the work zones visited were paving operations, this distance often changed from one time interval to the next throughout the site visit as equipment moved forward. However, this distance was not statistically significant. Also, the number of work-zone speed-limit signs and the number of changeable message signs were found to be statistically insignificant in reducing the mean speed through the work zone. These findings may be related to the limited data—with only seven work zones visited, the amount of variance in the speed-control measures across sites is limited.

The seemingly unrelated regression estimation results for the standard deviation of speed [Eq. (2)] are presented in Table 4. Table 4 shows that most of the variables are significant at the 80% confidence level and above (only one variable is less than the 80% confidence level using a two-tailed t-test). Due to the large amount of variance in the speed deviation data, a lower confidence level was used for this model. The idea was that a larger data set would improve the t-statistics further (because seemingly unrelated regression estimates are consistent) and the writers wanted to provide some preliminary idea as to which variables might be significant in a larger database. The only downside of leaving parameters of lower significance in the model is that the standard errors of the other parameters will be slightly larger (resulting in slightly lower t-statistics) and the writers felt that the additional information provided was worth this trade-off. The adjusted R^2 value is only 0.062 which again reflects the rather large amount of variance in the speed standard deviation data Despite the low adjusted R^2 value, it will be shown later that inclusion of this equation as part of the joint estimation of mean-speed and speed standard deviation significantly improves the parameter estimates of the mean-speed equation.

Looking at the results in Table 4, work zones that had two lanes opened (as opposed to one) had speed standard deviations that were 1.80 km/h (1.12 mi/h) faster. As was the case for the mean-speed parameter estimate, the additional lane allows greater speed-choice flexibility and this seems to increase the mean speed and spread of vehicle speeds.

Holding other factors in the model constant, the number of work-zone speed-limit signs was significant with each additional work-zone speed-limit sign increasing the standard deviation of speed by 0.43 km/h (0.27 mi/h). This increase in standard deviation may be caused by having only a portion of the driver population reacting to the signs and others do not.

The higher the percentage of personal vehicles (cars, pickup trucks, vans, and SUVs) in the traffic flow, the higher the standard deviation of speed. The parameter estimate indicates that, with all else constant, a 100% composition of personal vehicles would result in a speed variance 2.12 km/h (1.32 mi/h) higher than if there were no personal vehicles in the traffic flow. The diversity in vehicle types and drivers in the personal-vehicle category are the likely source of this finding.

Parameter estimates show that time intervals before midnight had a 2.33 km/h (1.45 mi/h) lower standard deviation than those after midnight. This reflects the higher standard deviation in speed after midnight. It is also interesting that this simple indicator variable fit the speed standard deviation data better than the more involved time-period indicator variable used in the mean-speed model.

The number of vehicles queued during the 10-min interval was found, as expected, to reduce the standard deviation of speed. Recall that the writers define a queued vehicle as one that trails a lead vehicle by less than 4 s—the idea being that the driver's choice of speed in a queued vehicle is potentially restricted by the lead vehicle. The parameter estimate shows that, with other factors held constant, for each additional 100 vehicles queued during the time interval, the speed variance decreased by 3.2 km/h (2 mi/h). As one would expect, as the number of queued vehicles increases, vehicles were less able to drive much above or below the average speed of traffic. With slower vehicles causing queues, the standard deviation of vehicle speed is reduced.

Finally, total traffic flow was found to increase the standard deviation of speed [for each additional 100 vehicles per lane the standard deviation of speed increases by 0.72 km/h (0.45 mi/h), with other factors held constant]. This might seem counterintuitive at first because one would expect that as the roadway becomes more congested the standard deviations of spot speeds would decline. But with the present data in nighttime work zones, total traffic flows do not exceed 1,000 vehicles/h/lane and are often well below this value. Thus the flows per lane per hour are well below congested conditions. It appears this variable is capturing greater diversity in the driver population as flow increases and, because queued vehicles are already taken into account in another variable, this diversity leads to greater standard deviation.

To provide some evidence that seemingly unrelated regression estimation is improving parameter estimates relative to OLS estimation of Eq. (1), a likelihood ratio test was conducted. The test statistic is $X^2 = -2[\mathrm{LL}(\beta_{\mathrm{OLS}}) - \mathrm{LL}(\beta_{\mathrm{SURE}})]$, where $\mathrm{LL}(\beta_{\mathrm{OLS}})$ = log likelihood at convergence of Eq. (1) estimated by OLS and $\mathrm{LL}(\beta_{\mathrm{SURE}})$ = log likelihood at convergence of Eq. (1) estimated by seemingly unrelated regression estimation (sure). This test statistic is χ^2 distributed and, with $\mathrm{LL}(\beta_{\mathrm{OLS}}) = -165.79$ and $\mathrm{LL}(\beta_{\mathrm{SURE}}) = -161.53$, the estimates used show that the writers can reject the hypothesis that OLS and SURE estimates are the same with over 99.5% confidence, suggesting seemingly unrelated regression is significantly improving model estimates.

Conclusions and Contributions to Research and Practice

The goals of this research were to demonstrate a methodology and provide some additional insight into the nighttime speed-control strategies that may help to improve safety for workers and the traveling public. Data were collected from July to November 2006 on work-zone characteristics and vehicle speeds on seven Indiana nighttime work zones that deployed a variety of speed-control methods. SURE was used to simultaneously model mean speed and speed standard deviation. The model estimation results show that the number of open lanes, original speed limit of the road section, distance from the work-zone speed-limit signs to the beginning of the work-zone taper, and the passing of time through the night, all resulted in higher mean speeds through the work zone. In contrast, police enforcement, percentage of semitrucks, and flow rate all decreased the mean speed. The estimation results for the model of the standard deviation of speed indicated that the number of open lanes, number of worksite speed-limit signs, percentage of personal vehicles and traffic flow all increased the standard deviation of spot speeds through the work zone. Observing speeds before midnight and a higher number of queued vehicles decreased the standard deviation of speed.

These findings have some important implications for determining how work-zone safety can be managed. With regard to mean speeds, the placement of the work-zone speed signs to the cone/barrel taper is critical and this distance should be kept to a minimum. Also, works zones with high volumes and higher percentages of semitrucks (both of which reduce mean speeds) may require less police enforcement and thus these findings can be used to more efficiently allocate police resources. In contrast, work zones with more lanes open and higher original speeds may be candidates for higher police enforcement. In terms of the standard deviation of speeds, care should be taken with regard to the number of worksite speed-limit signs used as well as in situations where there is a high percentage of passenger vehicles and during the early morning hours.

In assessing the findings of this work it is important to note that the number of worksites visited limited our ability to uncover potentially important variables such as the effect of median types, lane widths, and channelization methods on speeds because there simply was not enough variance in these values in the sample [for example, all lane widths were 3.66 m (12 ft)]. Moreover, in terms of the writers' ability to assess possible speed-control strategies in nighttime work zones, the fact that some of the work-zone projects employed multiple speed-control methods made it statistically difficult to distinguish the individual effect of each speed-control method on mean speed and speed standard deviation due to multicollinearity. However, even with the limited data used, the writers were able to statistically quantify the effectiveness of police enforcement and the distance between speed-control signs and the active work zone in terms of reducing work-zone speeds. Gathering additional data and applying the SURE approach would be a fruitful direction for future research and lead to additional insights on work-zone speed-control effectiveness. Specifically, additional data could allow assessing various flashing light options on construction speed-limit signs, the effect of varying the location and number of the speed-limit signs based on the length of the work zone, the effect of varying the placement of the signs based on the location of the active workspace within the work zone, and a multitude of other factors aimed at reducing speeds in nighttime work zones.

Acknowledgments

The writers would like to express their sincere appreciation to the Indiana Department of Transportation (INDOT) personnel, Indiana contractors, and the Indiana Local Technical Assistance Program (LTAP). Their time and interest during data collection provided for a more complete analysis. The writers were supported by the National Institute for Occupational Safety and Health (NIOSH) Grant No. 1 R01 0H07553-02 and the Indiana Department of Transportation/Joint Transportation Research Program (JTRP) Project—SPR 2987. The contents of this paper reflect the views of the writers, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessary reflect the official views or policies of the NIOSH or the Federal Highway Administration and the Indiana Department of Transportation, nor do the contents constitute a standard, specification, or regulation.

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