A Procedure to Determine When Safety Performance Functions Should Be Recalibrated

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ABSTRACT

Crash prediction models or Safety Performance Functions can be used for estimating the number of crashes and evaluating roadway safety. Developing a new model can be a difficult task and requires a significant amount of time and energy. To simplify the process, the Highway Safety Manual provides Safety Performance Functions for conducting different types of safety analyses for several facilities. However, since data collected from a few selected states for a specific period of time were considered for fitting and validating these models, they are required to be calibrated to the conditions of the new jurisdiction, and as well need to be revisited for recalibration over time. Therefore, the analyst may need to know when or how often the models are recommended to be recalibrated. This paper addresses this question and documents recommendations that are based on the general characteristics of data. The proposed procedure only require (1) the total number of crashes (2) the average traffic flow and (3) the total segment length (or number of interactions) in the network. The method was validated with different empirical datasets collected in Texas and Michigan. The results show that the proposed procedure provides useful information about when recalibration is recommended.

1. INTRODUCTION

Crash prediction models can be used to estimate the number of crashes, screen the effects of variables on crashes, identify hotspots and in general evaluate roadway safety. Developing a new model can demand a great deal of time, energy and resources. In order to simplify the process, the Highway Safety Manual (HSM) (AASHTO, 2010) provides crash prediction models (CPMs) or Safety Performance Functions (SPFs) for conducting different types of safety analyses for several categories of facilities. These SPFs were fitted and validated with data collected from a limited number of states. Therefore, for a new jurisdiction, the safety analyst needs to either develop a jurisdiction-specific model (see Lu et al., 2014; Young and Park, 2013) or calibrate the HSM SPFs to the jurisdiction conditions. For the later approach, the HSM provides a calibration procedure to account for both the randomness of crash data and the effect of the factors that were not or could not be considered in predictive models, such as the weather conditions or driver behavior.

The HSM recommends collecting crash and site characteristics data from a randomly selected sample that includes 30-50 sites with total of at least 100 crashes per year. [note: several researchers have raised issues about the HSM one-size-fits-all sample size recommendation (see
Banihashemi, 2012; Alluri et al., 2016; Lord et al., 2016). For better guidelines on the required sample size, interested readers are referred to Bahar (2014) and Shirazi et al. (2016). Then, the calibration factor (C-factor) is estimated by taking the ratio of the number of observed crashes to the number of unadjusted predicted crashes as follows:

\[
C = \frac{\sum_i N_{\text{obs}, i}}{\sum_i N_{\text{pre}, i}} = \frac{\frac{\sum_i N_{\text{obs}}}{\sum_i N_{\text{base}, i} \times \text{CMF}_{1i} \times \cdots \times \text{CMF}_{Ni}}}{1}
\]

where,

- \( C \) = calibration factor;
- \( N_{\text{obs}} \) = the observed number of crashes at site \( i \);
- \( N_{\text{pre}} \) = the unadjusted predicted number of crashes at site \( i \);
- \( N_{\text{base}, i} \) = the predicted number of crashes at site \( i \) at the base conditions; and,
- \( \text{CMF}_{ji} \) = the \( j \)-th crash modification factor at site \( i \).

The C-factor is multiplied as a scalar term to the SPF from the HSM for the type of facility being analyzed.

Since the release of the HSM, several states such as Oregon (Xie et al., 2011), Utah (Brimley et al., 2012), Illinois (Williamson and Zhou, 2012), Alabama (Mehta and Lou, 2013), and Maryland (Shin et al., 2014), among others, calibrated the HSM models to local conditions. It was widely reported in these studies that the calibration procedure is a time consuming task due to limitations which are mostly pertained to the data collection, readiness and completeness. Moreover, the procedure is not a one-time task. Since the characteristics of crash data (associated with continuous change in roadway, vehicle and driver characteristics) are likely to change as time goes on, prediction models should also be recalibrated (or updated) over time (see Wood et al, 2013; Connor et al, 2013).

On the one hand, recalibrating the predictive models is inevitable as the characteristics of crash data are likely to change over time or temporarily. On the other hand, although more efficient than fitting a new model, recalibrating the predictive models can still be a challenging task. Furthermore, the effort put into recalibrating models could be wasted if it was found that a recalibration had not been required at that point of time. Consequently, the analyst or an agency may need to know when or how often SPFs should be recalibrated to avoid unnecessary calibration.
efforts or expenses. The HSM recommends calibrating the models every 2 or 3 years, regardless of the crash data characteristics and their variation over time. However, this recommendation should be reviewed as crash data are random and their characteristics can vary substantially from one period of time to the next and this randomness can influence the recalibration decision.

The objective of this study is therefore to provide a simple and convenient procedure (or recommendations) to determine when the analyst is advised to recalibrate the predictive models. The proposed procedure is based on general characteristics of data that will be used for recalibration of the predictive models. In order to use the recommendations, the analyst needs to secure only three sources of information for the period of data that will be used for recalibration. These sources are: 1) the total number of crashes 2) the traffic flow average and 3) the total segment length (or the total number of intersections). Once the information is secured, the recommendations can simply be used to make the recalibration decision.

2. RECALIBRATION RECOMMENDATIONS

This section is divided into two parts. The first part describes the characteristics of the proposed method. The second part covers the procedure to use the recommendations for segment and intersection models.

2.1 Methodology

As discussed above, the characteristics of crash data vary over time. This variation can influence the recalibration decision. Based on Equation (1), the value of the C-factor is a function of the observed number of crashes. Therefore, it may initially seem that a substantial change in total observed number of crashes is an indicator for recalibrating a model. However, this may not necessarily be the case, as sometimes the change in the number of crashes can simply be attributed to a comparable change in network traffic flow. An increase (or decrease) in number of crashes can be caused by one of these two factors: (1) a fluctuation in traffic flow, or (2) a change in crash risk (or a decrease or increase in safety). It can be argued that if the change in the number of crashes is pertained to comparable traffic flow fluctuation on the network, the analyst does not need to recalibrate the predictive models. On the other hand, if the increase (or decrease) in the number of
crashes is attributed to a particular change that induce a safety issue (or safety improvement) ceteris paribus, the model should be recalibrated.

We use the HSM base models [Note: the flow only models with all other variables at the base conditions are referred to as base models] to account for the effect the traffic flow on time-to-time variation of the crash data and estimate the number of crashes caused by changing the mean value of the traffic flow, either Average Daily Traffic (ADT) or Annual Average Daily Traffic (AADT). The typical HSM base model to estimate the number of crashes on roadway segments is as follows:

\[ N_{\text{base},i} = e^{b_0 + b_1 \times \ln(F_i) + \ln(L_i)} \]  

where \( F_i \) and \( L_i \) respectively denote the traffic flow (AADT or ADT) and the segment length at the site “i”. The parameters \( b_0 \) and \( b_1 \) denote the intercept and the traffic flow coefficient, respectively. The functional form shown in Equation (2) is kept the same. However, instead of using the Flow value at each individual site, the mean value of the traffic flow in the network (\( \overline{F} \)) is considered in the model to approximately estimate the overall number of crashes as a function of variable \( F \). This is shown in Equation (3):

\[ \sum_i N_{\text{base},i} \approx \sum_i e^{b_0 + b_1 \times \ln(F)} + \ln(L_i)} \]

The parameter \( \tilde{C} \) (which is referred to as the C-proxy in this study) is calculated as follows:

\[ \tilde{C} = \frac{\sum_i N_{i,\text{obs}}}{\sum_i e^{b_0 + b_1 \times \ln(F) + \ln(L_i)}} \]

In other words,

\[ \tilde{C} = \frac{\sum_i N_{i,\text{obs}}}{\sum_i e^{b_0 + b_1 \times \ln(F)} \times L_i} \]

Therefore,

\[ \tilde{C} = \frac{\sum_i N_{i,\text{obs}}}{e^{b_0 + b_1 \times \ln(\overline{F})} \times \sum_i L_i} \]
Hence,

\[
\tilde{C} = \frac{N_{\text{obs}}^T}{e^{b_0+b_1 \times \ln(\bar{F})} \times L^T}
\]  

(7)

where,

\begin{align*}
\tilde{C} &= \text{C-proxy}; \\
N_{\text{obs}}^T &= \text{the total number of crashes on the network}; \\
\bar{F} &= \text{the mean value of the traffic flow (AADT or ADT) on the network}; \text{ and,} \\
L^T &= \text{the total combined length of all sites}.
\end{align*}

As shown in Equation (7), only three sources of information at the network level are required to calculate the C-proxy: (1) the total number of crashes, (2) the mean value of the traffic flow, and (3) the total segment length.

Recall that it was argued that if the number of crashes increases or decreases due to comparable traffic flow fluctuations, the analyst does not require to put effort on recalibration of the predictive model (i.e., find a new calibration factor). This can adequately be addressed by calculating the C-proxy periodically. In this case, if the C-proxy does not change significantly from one recalibration period to the next, the analyst will not be required to recalibrate the predictive model. On the other hand, a significant change in C-proxy indicates a variation in crash data that has not just been pertained to comparable traffic flow fluctuation. Hence, recalibration is advised.

In order to use the procedure, the analyst is required to calculate the C-proxy periodically and compare it with the C-proxy that was estimated in the reference year [Note: the latest year that the predictive model was recalibrated is referred to as the reference year]. If the relative difference between the current C-proxy (\(\tilde{C}\)) and reference-year C-proxy (\(\tilde{C}_{\text{REF}}\)) is less than a certain threshold, the analyst can ignore the recalibration and keep the current model; otherwise, the analyst is recommended to recalibrate the predictive model. In this study, we set the threshold to 10 percent. However, it should be pointed out that the procedure works for any threshold. The threshold is in fact a function of or a balance between the accuracy sought and the effort undertaken by the analyst (i.e., how often does the analyst want to recalibrate the model). Further discussion about the threshold is provided below.
2.2. Instructions to Use the Procedure

This section summarizes the instructions for using the proposed procedure for roadway segment and intersection models. Before presenting the instructions, it is worth pointing out that the proposed method serves only as an approximation process. Some other factors can also influence the recalibration decision. For example, if significant system-wide safety improvements happened in the analyzed jurisdiction, the analyst would be required to update the models regardless of what the method states. Besides, the analyst is advised to recalibrate the models whenever it is possible and adequate resources are available.

2.2.1 Segment Models

The general steps to calculate the C-proxy and use the procedure for roadway segment models are as follows:

Step 1. Find the total number of crashes ($N_{\text{obs}}^T$) and the total segment length ($L^T$) on the network facility.

Step 2. Find the mean value of the traffic flow [the mean value of ADT or AADT ($\bar{\text{ADT}}$, or $\bar{\text{AADT}}$)] on the facility.

Note that if the mean value of the ADT or AADT is not available to the analyst, it is advised to calculate the mean value by randomly collecting ADT from a limited number of sites that provide the overall representation of the network.

Step 3. Consider the roadway segment base SPF (i.e., the model with all CMFs at the base condition) from the HSM. Let $b_0$ and $b_1$ denote the intercept and the coefficient of traffic flow respectively. Find $\bar{N}_F$ as:

$$\bar{N}_F = e^{b_0 + b_1 \times \ln(P)}$$  \hfill (8)

Step 4. Find the $\bar{C}$ using the following equation:
\[
\bar{c} = \frac{N_{obs}^T}{N_F \times L^T}
\]  

(9)

**Step 5.** Find the variable \( \bar{e} \) as follows:

\[
\bar{e} = \frac{|\bar{c} - \bar{c}_{REF}|}{\bar{c}_{REF}} \times 100
\]  

(10)

where \( \bar{c}_{REF} \) denote the \( \bar{c} \) that was calculated in the reference year.

**Step 6.** If \( \bar{e} \geq 10\% \), the model needs to be recalibrated; hence, calibrate the model and set the current \( \bar{c} \) as the new \( \bar{c}_{REF} \). Otherwise, keep the current \( \bar{c}_{REF} \) and use the calibration factor that was estimated in the reference year.

### 2.2.2 Intersection models

A similar procedure with small modifications can be proposed to investigate if the intersection models are required to be recalibrated. The general steps to calculate the C-proxy and use the recalibration procedure for intersection models are as follows:

**Step 1.** Find the total number of crashes (\( N_{obs}^T \)) and the total number of intersections (\( N \)) on the network facility.

**Step 2.** Find the average traffic flow on the major road (\( \bar{F}_{\text{major}} \)) and minor road (\( \bar{F}_{\text{minor}} \)).

Note: If the mean value of traffic flows is not available, it is advised to find the mean value by randomly collecting the traffic flows for a limited number of intersections that provide the overall representation of the intersection type.

**Step 3.** Consider the intersection base SPF from the HSM. Let \( b_0, b_1 \) and \( b_2 \) denote the intercept, the coefficient of the traffic flow on the major road, and the coefficient of the traffic flow on the minor road respectively. Find the variable \( \bar{N}_F \) as:
\[ \bar{N}_{P} = e^{b_0 + b_1 \times \ln(P_{\text{major}}) + b_2 \times \ln(P_{\text{minor}})} \]  

**Step 4.** Find the \( \bar{C} \) using the Equation (9). Note: for this case, in Equation (9), the total length variable \( (L^T) \) should be replaced with the total number of intersections \( (N) \).

**Step 5.** Find \( \bar{e} \) using the Equation (10).

**Step 6.** If \( \bar{e} \geq 10\% \), the model needs to be recalibrated; hence, calibrate the model and set the current \( \bar{C} \) as the new \( \bar{C}_{\text{REF}} \). Otherwise, keep the current \( \bar{C}_{\text{REF}} \) and use the calibration factor that was estimated in the reference year.

### 3. VALIDATING THE PROCEDURE WITH OBSERVED DATASETS

In this section, the proposed procedure is evaluated for several facilities in Texas and Michigan. For each example, the C-proxy is calculated and the procedure is applied to determine when recalibration is needed. Then, the procedure is validated by calculating the change in C-factor over time and comparing the results with the recommended outcome of the procedure. Recall that the C-proxy is computed given three sources of information at the network level as shown in Equation (7); on the other hand, the C-factor is estimated by collecting detailed data at individual sites as shown in Equation (1). First, the procedure is validated for the Texas urban four-lane divided arterials. The crash data for this facility were collected in three-year frequency from 2007 to 2014. This means, for example, if the traffic and geometric data in 2009 are considered then the crash data in this dataset will include crashes occurred in a three year period from 2007 to 2009. All variables in the dataset met the base conditions except the median width. Thus, the model includes one CMF for the median width. Next, the same procedure is examined for Texas rural multilane divided segments. The crash data were collected in three-year frequency from 2007 to 2014. For this dataset, the SPF included three CMF modifications: lane width, right shoulder width and the median width. Finally, the recommendations are evaluated for four-legged signalized intersections in Michigan. The crash data were collected in one-year frequency from 2008 to 2012. For this dataset, the SPF included four CMF modifications: left turn lane, right turn lane, right turn on red and lighting.
3.1 Texas Urban Four-Lane Divided Arterials

For this facility, crash data were collected in three-year frequency. Except the median width, all other variables met the base conditions. For the purpose of analysis, it is assumed that the agency calibrated the model in 2009 using data that were collected from 2007 to 2009. Although the calibration will be conducted after year 2009 is completed, for convenience purpose, the calibration year is referred to as 2009. This year is set as the reference year and it’s C-proxy as the reference C-proxy (i.e., $\tilde{C}_{\text{REF}} = 1.055$). Table 1 shows the results of applying the proposed procedure to this dataset.

<TABLE 1 here>

In 2010, the analyst needs to use data from 2008 to 2010 and find the C-proxy ($\tilde{C}_{2010}$). The relative difference between $\tilde{C}_{2010}$ and $\tilde{C}_{\text{REF}}$ is equal to 5.0 percent, which is less than 10 percent, so the method does not recommend the recalibration. To verify the decision, the calibration factor (Equation 1) in 2010 is also calculated and shown in the table. As it is shown, the difference between the calibration factor in 2010 and the one in the reference year is equal to 3.5 percent which is relatively small; hence, the decision based on the proposed procedure is confirmed by checking the change in C-factor.

In 2011, the analyst needs to use the three-year data from 2009 to 2011 to calculate the C-proxy in 2011 ($\tilde{C}_{2011}$). Recall that recalibration was not recommended in 2010. Therefore, 2009 is still the reference year. The C-proxy in 2011 is compared to the $\tilde{C}_{\text{REF}}$. Since the C-proxy is changed by more than 10 percent, the model is recommended for recalibration. Therefore, the model is recalibrated and the reference year and $\tilde{C}_{\text{REF}}$ are modified accordingly. This decision is also supported by calculations based on the change in C-factor between those years.

In 2012, the data from 2010 to 2012 is used to find the C-proxy. The C-proxy is changed by 10 percent; hence, recalibration is recommended. To verify the procedure outcome, the calibration factor is also calculated. As shown in Table 1, in this year, the calibration factor is also increased by about 10 percent compared to the reference year; therefore, the outcome of the procedure is verified. The model is recalibrated and the reference year is set to 2011 and $\tilde{C}_{\text{REF}}$ is modified accordingly.
The same procedure is repeated for subsequent years. As indicated in Table 1, the model, again, is needed for recalibration in 2014 once the analyst observes an 18 percent change in C-proxy. Figure 1 shows the value of the C-proxy in different periods for the analyzed data. In this figure, points are marked in red if recalibration is recommended, and in green otherwise.

<FIGURE 1 here>

As discussed above, we used a threshold of 10 percent for our analysis. In cases when the safety analyst would prefer to have a more accurate C-factor, a lower threshold, such as 5 percent, could be used. However, the model would then need to be calibrated more frequently. On the other hand, by choosing a higher threshold, such as 15 percent, a less accurate C-factor will be used, but the analyst will place less effort on calibrating models over time. In the end, the analyst needs to balance the recalibration process between accuracy and the effort or resources needed for recalibrating the models.

3.2 Texas Multi-Lane Divided Rural Segments

Texas multi-lane divided rural segments data were collected from 2007 to 2014 in three-year frequency. This dataset represents a scenario where multiple variables do not meet base conditions. The SPF included three CMFs: lane width, right shoulder width and median width. Table 2 shows the recalibration decisions made for this dataset. For the purpose of analysis, it is assumed that the model was calibrated in 2009 using data from 2007 to 2009. Table 2 shows the results of applying the method to this dataset.

<TABLE 2 here>

As it is indicated in Table 2, until 2013, no significant change in C-proxy is observed and values remain below the 10 percent threshold; hence, for four years, recalibration is not recommended. The small change in calibration factors verifies this decision. In 2013, however, the C-proxy is increased by 10.0 percent compared to the reference C-proxy; therefore, recalibration is recommended. The significant increase (10.1 percent) in the calibration factor verifies the decision based on the proposed recommendations. In 2014, since the change in C-proxy is more than 10 percent, the model again is recommended for recalibration, even though the SPF was recalibrated in the previous year. Figure 2 shows the value of the C-proxy in different periods for
the analyzed data. Similar to the Figure 1, points marked in red indicate a recalibration decision, and green otherwise.

<FIGURE 2 here>

3.3 Michigan Four-Legged Signalized Intersections

To validate the proposed procedure for intersections, the crash data collected at four-legged signalized intersections in Michigan are used. The data were collected from 2008 to 2012 in one-year frequency. For this dataset, the SPF included four CMF modifications: left turn lane, right turn lane, right turn on red and lighting. For the purpose of analysis, it was assumed that the predictive model was calibrated in 2008. Therefore, the reference year was set to 2008, and the C-proxy in 2008 was set as the reference C-proxy ($\bar{C}_{REF} = 1.346$). Next, the recalibration need was investigated for subsequent years from 2009 to 2012 in one-year time periods. Table 3 presents the results of applying the proposed procedure to this dataset. For each year, the C-proxy was calculated and reported in Table 3. The new C-proxy was compared to the C-proxy in reference year.

<TABLE 3 here>

As shown in the table, since the C-proxy change is less than 10 percent for all periods of data, no recalibration is required for any of the subsequent years until 2012. To validate the results, the C-factors were also calculated and reported in the table. As indicated in Table 3, the change in C-factors in subsequent years is also negligible. This verifies the decision based on the proposed recommendations.

4. SUMMARY AND CONCLUSIONS

Although less taxing than creating new models, the calibration of predictive models can still be a time-consuming and expensive task. Therefore, the analyst needs to know when or how often the models should be recalibrated to avoid unnecessary efforts and expenses. The HSM recommends deriving calibration factors at least every two or three years. However, there is no research to support this recommendation. In this research, we have documented a procedure to determine when the predictive models are advised to be recalibrated. The proposed procedure was successfully validated by applying them to several observed datasets in Texas and Michigan. The
procedure is straightforward and can be used for recalibrating any predictive models, irrespective of the type of facility, such as intersections and roadway segments. The only sources of information needed for segment models are: (1) the total number of crashes, (2) the mean value of ADT or AADT and (3) the total segment length. For intersection models, the only needed information are (1) the total number of crash data, (2) the average traffic flow on major and minor roads and (3) the number of intersections. The agency is required to secure these values periodically and follow the steps stated in the recommendations to make a decision on recalibration of the predictive models. Although the study recommendations are applicable to any threshold, further research is needed to determine the appropriate or statistically-oriented threshold for each facility being analyzed. In that context, although beyond the scope of this project, the uncertainty associated with the product of models and CMFs should be examined for determining the threshold for deciding when a model needs to be recalibrated (Lord, 2008; Bahar, 2014).

ACKNOWLEDGMENTS

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REFERENCES


Table 1. Recalibration for Texas Urban Four-Lane Divided Arterials.

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007-2009</td>
<td>8,573</td>
<td>8,140</td>
<td>7,613</td>
<td>8,613</td>
<td>9,114</td>
<td>10,072</td>
</tr>
<tr>
<td>2008-2010</td>
<td>17,508</td>
<td>17,375</td>
<td>17,355</td>
<td>17,452</td>
<td>17,286</td>
<td>17,346</td>
</tr>
<tr>
<td>2009-2011</td>
<td>1,050.3</td>
<td>1,060.2</td>
<td>1,083.2</td>
<td>1,105.9</td>
<td>1,105.9</td>
<td>1,105.2</td>
</tr>
<tr>
<td>2010-2012</td>
<td>1.055</td>
<td>1.002</td>
<td>0.919</td>
<td>1.011</td>
<td>1.011</td>
<td>1.011</td>
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<tr>
<td>2012-2014</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Total Crashes**

**Avg. Traffic Flow**

**Total Length (Mile)**

**C-proxy**

**Reference C-proxy**

| Change in C-proxy (%) | - | 5.0 | 12.9 | 10.0 | 7.2 | 18.0 |
| Recalibration Needed? | - | No | Yes | Yes | No | Yes |
| C-factor | 1.011 | 0.976 | 0.887 | 0.978 | 1.039 | 1.116 |
| Change in C-factor (%) | - | 3.5 | 12.3 | 10.2 | 6.3 | 14.1 |

*a* The number in parenthesis indicates the reference year (the time that the model was recalibrated).

*b* The time that the reference year was changed for the first time is marked in bold.

*c* The underlined numbers show the cases when recalibration was recommended.
Table 2. Recalibration for the Texas Multi-Lane Divided Rural Segments.

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>Total Crashes</td>
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<td>1,993</td>
<td>1,988</td>
<td>2,175</td>
<td>2,118</td>
<td>2,511</td>
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<tr>
<td>Avg. Traffic Flow</td>
<td>8,065</td>
<td>7,763</td>
<td>7,706</td>
<td>7,888</td>
<td>7,516</td>
<td>7,555</td>
</tr>
<tr>
<td>Total Length (Mile)</td>
<td>489.6</td>
<td>511.1</td>
<td>518.5</td>
<td>539.2</td>
<td>514.1</td>
<td>535.8</td>
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<td>C-proxy</td>
<td>0.891</td>
<td>0.897</td>
<td>0.888</td>
<td>0.912</td>
<td>0.980</td>
<td>1.109</td>
</tr>
<tr>
<td>Reference C-proxy&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>0.891 (2009)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.891 (2009)</td>
<td>0.891 (2009)</td>
<td>0.891 (2009)</td>
<td>0.980 (2013)</td>
</tr>
<tr>
<td>Change in C-proxy (%)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-</td>
<td>0.7</td>
<td>0.3</td>
<td>2.4</td>
<td>10.0</td>
<td>13.2</td>
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<tr>
<td>Recalibration Needed?</td>
<td>-</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>C-factor</td>
<td>0.961</td>
<td>0.961</td>
<td>0.946</td>
<td>0.994</td>
<td>1.058</td>
<td>1.120</td>
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<tr>
<td>Change in C-factor (%)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>-</td>
<td>0.0</td>
<td>1.6</td>
<td>3.4</td>
<td>10.1</td>
<td>5.9</td>
</tr>
</tbody>
</table>

<sup>a</sup> The number in parenthesis indicates the reference year (the time that the model was recalibrated).

<sup>b</sup> The time that the reference year was changed for the first time is marked in bold.

<sup>c</sup> The underlined numbers show the cases when recalibration was recommended.
Table 3. Recalibration for the Michigan Four-Legged Signalized Intersections.

<table>
<thead>
<tr>
<th>Period</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year</strong></td>
<td>2008</td>
<td>2009</td>
<td>2010</td>
<td>2011</td>
<td>2012</td>
</tr>
<tr>
<td><strong>Total Crashes</strong></td>
<td>2,855</td>
<td>2,825</td>
<td>2,937</td>
<td>2,900</td>
<td>2,850</td>
</tr>
<tr>
<td><strong>Avg. Major Flow</strong></td>
<td>20,889</td>
<td>20,997</td>
<td>21,455</td>
<td>21,111</td>
<td>21,542</td>
</tr>
<tr>
<td><strong>Avg. Minor Flow</strong></td>
<td>8,781</td>
<td>8,832</td>
<td>9,034</td>
<td>8,890</td>
<td>9,056</td>
</tr>
<tr>
<td><strong>No. of Intersections</strong></td>
<td>349</td>
<td>349</td>
<td>349</td>
<td>348</td>
<td>345</td>
</tr>
<tr>
<td><strong>C-proxy</strong></td>
<td>1.346</td>
<td>1.323</td>
<td>1.338</td>
<td>1.352</td>
<td>1.307</td>
</tr>
<tr>
<td><strong>Change in C-proxy (%)</strong></td>
<td>-</td>
<td>1.7</td>
<td>0.6</td>
<td>0.5</td>
<td>2.9</td>
</tr>
<tr>
<td><strong>Recalibration Needed?</strong></td>
<td>-</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>C-factor</strong></td>
<td>1.827</td>
<td>1.802</td>
<td>1.825</td>
<td>1.844</td>
<td>1.785</td>
</tr>
<tr>
<td><strong>Change in C-factor (%)</strong></td>
<td>-</td>
<td>1.4</td>
<td>0.1</td>
<td>0.9</td>
<td>2.3</td>
</tr>
</tbody>
</table>

<sup>a</sup> The number in parenthesis indicates the reference year (the time that the model was recalibrated).

<sup>b</sup> The time that the reference year was changed for the first time is marked in bold.
Figure 1. The Value of C-proxy in Each Period of Analysis for Texas Four-Lane Divided Arterials.
Figure 2. The Value of C-proxy in Each Period of Analysis for Texas Multi-Lane Divided Rural Segments.