VARIABILITY OF A PEAK HOUR FACTOR AT INTERSECTIONS

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ABSTRACT

The Peak Hour Factor (PHF) is used to convert the hourly traffic volume into the flow rate that represents the busiest 15 minutes of the rush hour. Past research indicated that PHF has a strong impact on traffic analysis results. The common practice is to use a default value recommended by national or local guidelines or to use limited field observations. This paper investigates the variability of PHF over time and across locations. The day-to-day variability of PHF was found to be as strong as the site-to-site variability. This finding prompts for estimating the PHF based on multiple field measurements or, where measurements are not possible, for using a model that returns the average value of PHF. This paper presents such a model, which links PHF with hourly volume, population, and time of day, and demonstrates that a large portion of the variability in the sample of observations can either be explained with the model or be attributed to the day-to-day fluctuation.

Keywords: Peak Hour Factor, traffic variability, traffic analysis

1. INTRODUCTION

The TRB *Highway Capacity Manual* (HCM) (*1*) and the AASHTO *Policy on Geometric Design of Highways and Intersections* (*2*) recommend evaluating traffic conditions during the worst 15 minutes of either a design hour or a typical weekday rush hour. Peak Hour Factor (PHF) is used to convert the hourly volume into the volume rate representing the busiest 15 minutes of the hour.

The existing guidelines provide typical values of PHF and advise using the PHF calculated from vehicle counts at analyzed or similar locations. The HCM recommends a PHF of 0.88 for rural areas and 0.92 for urban areas and presumes that capacity constraints in congested areas reduce the short-term traffic fluctuation. The HCM postulates 0.95 as the typical PHF for congested roadways.

Due to limited resources, the PHF is frequently calculated based on a single field observation or the default values are used without field studies to support this practice. Dowling (3) studied the consequences of using local rather than default parameters. He found that the use of local values for the PHF, saturation flow rate, and signal progression factor considerably reduced the errors in the delay estimates when the traffic stream was stronger than 85 percent of capacity.

The objective of this paper is to investigate the variability of PHF to increase the knowledge base of typical PHF values in various local conditions and to help select better PHF values in traffic analyses. We will show that PHF varies considerably day by day and that an expected value of PHF should be estimated from multiple field measurements. An estimate from data collected in a single day is insufficient. Further, we will demonstrate that PHF variability across locations is smaller than may be concluded if the temporary variability is overlooked. Finally, a convenient method of predicting the expected PHF for planned or designed roads is proposed.

3. DAY-TO-DAY VARIABILITY

Traffic volume varies with time. If vehicles are counted repeatedly at some location for several weekdays, then a traffic engineer ends up with several different values of PHF. This variability can be illustrated by simulating a rush hour as four 15-minute vehicle counts varying around their means according to the Poisson distribution. We have simulated a rush hour with the mean 15-minute counts: 100, 150, 200, and 150 vehicles, which represents a short rush period with a pronounced busiest 15-minute count - a typical pattern in a small town. For a comparison, we have also simulated a rush hour: 150, 150, 150, and 150 vehicles, which represents a flat traffic pattern typical for large towns with long rush periods. The calculated PHF values for 15 simulation runs (days) are presented in Figure 1. The average PHF in 200 simulation runs for the flat pattern was 0.92 and the range of values on individual days was 0.80-0.99. It may come as a surprise that random traffic fluctuations may generate such low PHF values when the traffic pattern is flat. The average PHF for a hypothetical small town with a pronounced single 15-minure count was 0.75 with the range of 0.63-0.90. These results are summarized in the first two rows of Table 1.

The variability of PHF was also investigated with vehicle counts on Northwestern Avenue near the Purdue University campus in West Lafayette, Indiana (Figure 2). Vehicles were counted continuously for almost three weeks in April 2000 using high-quality portable inductive loops and Peek vehicle classifiers. The data collection was performed by an experienced professional who tested the equipment on a regular basis. Morning and afternoon rush hours were identified for 13 consecutive weekdays and the PHF values were calculated for the morning and afternoon rush hours and for each of the two directions. The PHF was calculated using the formula:

$$PHF = \frac{V_h}{4 \cdot V_{15\max}}, \qquad (1)$$

where V_h is the hourly volume and V_{15max} is the highest 15-minute count. Figure 3 shows the obtained PHF values while Table 1 summarizes the results.

Two conclusions can be made from the simulation experiments and from the Northwestern Avenue study: (1) the day-to-day variability of PHF may be considerable and the difference between the lowest and the highest measured PHF for the same flow may reach value of 0.2; and (2) even at the same location, the average values of PHF differ between traffic directions and between different times of day.

We postulate that the primary source of variability in PHF is the random variability of vehicle counts. Let us derive an expression for the PHF variance starting with Equation 1.

$$PHF = \frac{V_h}{4 \cdot V_{15\max}} = \frac{V_{15\max} + V_{45}}{4 \cdot V_{15\max}} = \frac{1}{4} + \frac{V_{45}}{4 \cdot V_{15\max}}. \qquad (2)$$

With the frequently used assumption that traffic counts vary according to Poisson and independently one interval from another, the variability of PHF can be estimated using the delta method which uses the linear term of the Taylor series of the PHF function:

$$\begin{aligned} \operatorname{var} PHF &= \left(\frac{\partial PHF}{\partial V_{45}}\right)^2 \cdot \operatorname{var} V_{45} + \left(\frac{\partial PHF}{\partial V_{15\max}}\right)^2 \cdot \operatorname{var} V_{15\max} \\ \operatorname{var} PHF &= \left[\frac{1}{4 \cdot V_{15\max}}\right]^2 \cdot V_{45} + \left[\frac{-V_{45}/4}{(V_{15\max})^2}\right]^2 V_{15\max} \end{aligned} \quad . \tag{3}$$

Transforming the above expression and using the expression for PHF give the final expression:

$$\operatorname{var} PHF = \frac{V_h - V_{15\max}}{4 \cdot V_{15\max}^2} \cdot PHF \ . \tag{4}$$

Equation 4 includes the hourly and busiest 15-minute counts V_h, V_{15max}, and the calculated value of PHF. In the presented derivation, the assumption is made that the rush hour starts at the same time every weekday and the same interval in the rush hour exhibits the highest traffic. These assumptions are reasonable for small towns with a pronounced peaking pattern. The simulated standard deviation for this case was very close to the standard deviation calculated with Equation 4 (Table 1). On the other hand, the flat peaking pattern allows any 15-minute interval to dominate during the rush hour, reducing the variability of the PHF value. Equation 4 overestimates the variability of the PHF for such cases (Table 1). Table 1 also presents the measured variability on Northwestern Avenue and the predicted variability with Equation 4 values. The values estimated from the field data and those estimated with Equation 4 are reasonably close.

The strong variability of the PHF values from one day to another raises three questions:

(1) What value of PHF should be used in roadway design and traffic analysis? Should it be an expected value or a specific percentile?

(2) Does a single-day vehicle counting provide data sufficient for estimating the PHF value?

(3) What means can be used to help estimate the PHF where count data is not available?

Although an answer to the first question may be policy-related, let us express our opinion on this matter. The current design and traffic evaluation policies recommend checking traffic quality during the busiest 15 minutes of the design hour. The weekday rush hour during specific months is an often-used proxy of the design hour. Using the design hour is meant to promote solutions that provide acceptable traffic performance most of the time with a limited number of rush hours when the conditions may be questioned by the users. This condition is met if the volume assumed in design or traffic analyses represent the **expected volume** during the target 15-minute interval. This is accomplished when the **expected value of PHF** is used.

The strong day-to-day variability of PHF questions a single-day count as a sufficient basis for estimating the expected value of PHF. It should be noted that in some cases the obtained traffic volume rate used to decide about the number of traffic lanes or evaluate the future LOS can be lower or larger than the expected value by 20-30%. One of the methods of increasing the precision of the PHF estimate is counting vehicles for more than one day. Although justified, this recommendation may be difficult to implement where costly manual counts are needed.

An alternative to manual counts is a prediction model which estimates the PHF without requiring additional data. The results from the model can be combined with the measured PHF to further increase the precision of the PHF estimate. The model would be particularly useful where vehicle counting is not possible. The next section presents a regression model developed based on traffic counts at signalized intersections.

4. SITE-TO-SITE VARIABILITY

This section analyzes the variability of the PHF across sites. A regression analysis was applied to the traffic counts at 45 intersections located in population-diverse communities, which included large metropolitan areas, rural locations, and developed areas of an intermediate size. The 12-hour counts were obtained from the Indiana Department of Transportation (INDOT) districts; and only one-day measurements were available for each intersection. The morning and afternoon rush hours were determined first based on a total traffic at the intersections. Then, four PHF values were calculated for each intersection (one per approach) which resulted in 180 data points.

Table 2 presents the summary of the obtained PHF values. The observed range is between 0.58 and 0.99. It should be kept in mind that this wide range of observed values is caused not only by the site-to-site variability but also by the day-to-day variability. Some locations were “caught” at their above-average values of PHF while other at their below-average values. A regression analysis was used to try to explain as much of the site-to-site variability as possible.

In order to analyze the PHF variability across locations, several site-specific characteristics were recorded, which included the population, volume per direction, time of day, and road class.

Time of Day - It is believed that the morning peak is different from the afternoon peak. Afternoon peaks tend to be longer and flatter than morning peaks because most morning trips are work-related while afternoon trips are more diverse.

Population – The effect of the size of the town where the intersection is located was analyzed. Populations were classified as large, medium, small, and rural. The HCM indicates that rural roads exhibit lower PHF, i.e., higher sub-hour traffic variability than urban roads.

Rush hour volume – The effect of the hourly volume was investigated. In busy traffic the random fluctuation of vehicle counts is relatively lower and the peaking trend flatter and longer compared to low-volume traffic. If this opinion is correct, then the PHF should increase as the rush hour volume decreases.

Road Class – Roads were also classified as US, SR, and local.

A form of the PHF model is shown in Equation 5. The exponential expression is preferred over the traditional linear function because it ensures that the calculated values do not exceed 1:

$$PHF = 1 - \exp(a_0 + a_{AM} \cdot AM + a_{PSM} \cdot PSM + a_{PMD} \cdot PMD + a_{PLG} \cdot PLG \\ + a_{VOL} \cdot VOL + a_{SR} \cdot SR), \quad (5)$$

where:

$PHF =$ Peak Hour Factor,

$AM = 1$ if morning (AM); 0 otherwise,

$PSM = 1$ if population less than 20,000; 0 otherwise,

$PMD = 1$ if population 20,000-100,000; 0 otherwise,

$PLG = 1$ if population larger than 100,000; 0 otherwise,

$VOL =$ rush hour volume (in thousands/hour),

$SR = 1$ if a state administered road; 0 otherwise.

Rural locations were initially selected as a reference case and no variable represents them in the model. The corresponding regression model to be estimated with the collected data is:

$$\log(1 - PHF) = a_0 + a_{AM} \cdot AM + a_{PSM} \cdot PSM + a_{PMD} \cdot PMD + a_{PLG} \cdot PLG \\ + a_{VOL} \cdot VOL + a_{SR} \cdot SR + \varepsilon, \quad (6)$$

where ε is the disturbance term proportional to the expected value of log(1-*PHF*), or $\varepsilon = b \cdot mean$.

The maximum likelihood method was used to estimate the model in Equation 6. The analysis of the regression parameters prompted for dropping the *SR* variable as not statistically significant. Also, the *PSM* variable was not statistically significant, which indicated that rural areas and small towns can be treated together. This variable has also been removed from the model. The parameters in front of variables *PMD* and *PLG* were neither statitistically nor practically different from each other, which prompted for combining the two variables to a single variable named *POP*. After these changes and model recalibration, the following model was obtained:

$$PHF = 1 - \exp(-2.23 + 0.435 \cdot AM + 0.209 \cdot POP - 0.258 \cdot VOL) \quad (7)$$

with b = -0.252, and R^2 = 0.268 and where *POP* = 1 if population is larger than 20,000; otherwise is 0. Other variables are the same as in Equation 6.

The PHF values measured in the field and the PHF values obtained with Equation 7 are compared in Figure 4. Although the comparison does not indicate any obvious bias, the dispersion of points around the diagonal is rather large. The average prediction standard error of PHF that occurred at **a specific location on a single day** is 0.072. It has to be stressed that according to the remarks given in the previous section, the purpose of using Equation 7 is not to predict the PHF on a specific day but to predict the mean value of PHF over many days (expected value). The situation is similar to the one faced in crash frequency modeling where a Negative Binomial model is aimed to predict the expected annual number of crashes and not the crash count in some specific year. The Negative Binomial model is much better in doing the former than the latter.

Our vehicle count data does not allow for any direct estimation of the part of the PHF variability which can be attributed to the day-to-day randomness. The simulation experiments and the field study presented in the previous section have given some insight. We can claim that a considerable portion of the dispersion of points in Figure 4 is caused by a day-to-day variability as these points represent single days and not expected values. If the standard deviation of PHF across days is of range 0.04-0.06 and it is independent of the standard deviation of the mean PHF values across locations, then the standard deviation across locations not explained with the presented model can be estimated as between $(0.072^2 - 0.06^2)^{1/2} = 0.04$ and $(0.072^2 - 0.04^2)^{1/2} = 0.06$.

The range of **expected PHF values** estimated in the sample is 0.80-0.96 with the average value 0.88. The HCM mentions that a typical range of PHF is 0.80-0.98 which well concurs with our findings. The obtained model indicates that rural and semi-rural areas tend to have a PHF that is slightly lower than developed areas. The site-to-site variability of average PHF as a function of the population size, time of day, and hourly volume is depicted in Figure 5. The morning PHF tends to be lower than the afternoon PHF. This result was expected.

The graph in Figure 5 provides a convenient means of predicting the weekday-average PHF. It may be used if field measurements are not possible. It may also be used as supplementary information about PHF if the field measurements are limited; for example, vehicles were counted only once.

CONCLUSIONS

The paper discusses PHF variability, and in particular, a study by the authors that focused on weekday morning and afternoon rush hours at intersections. Two types of variability were studied, day-to-day and site-to-site, and convincing evidence that temporal variability is as strong as the spatial variability was presented.

It is recommended that PHF should be estimated based on several days of vehicle counting to improve the precision of the average PHF estimate. Where counting is not possible, the model developed as a part of the presented study can be used. It requires the hourly volume, the community population, and the time of day as input. The precision of the model seems to be reasonable when considering the temporal variability. A graph was provided as a convenient means of PHF prediction.

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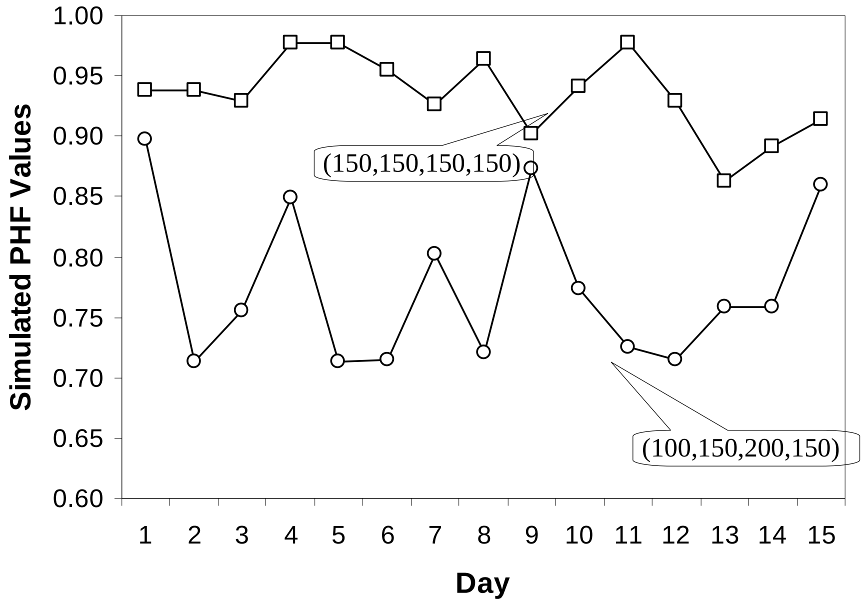

Figure 1 Simulation results

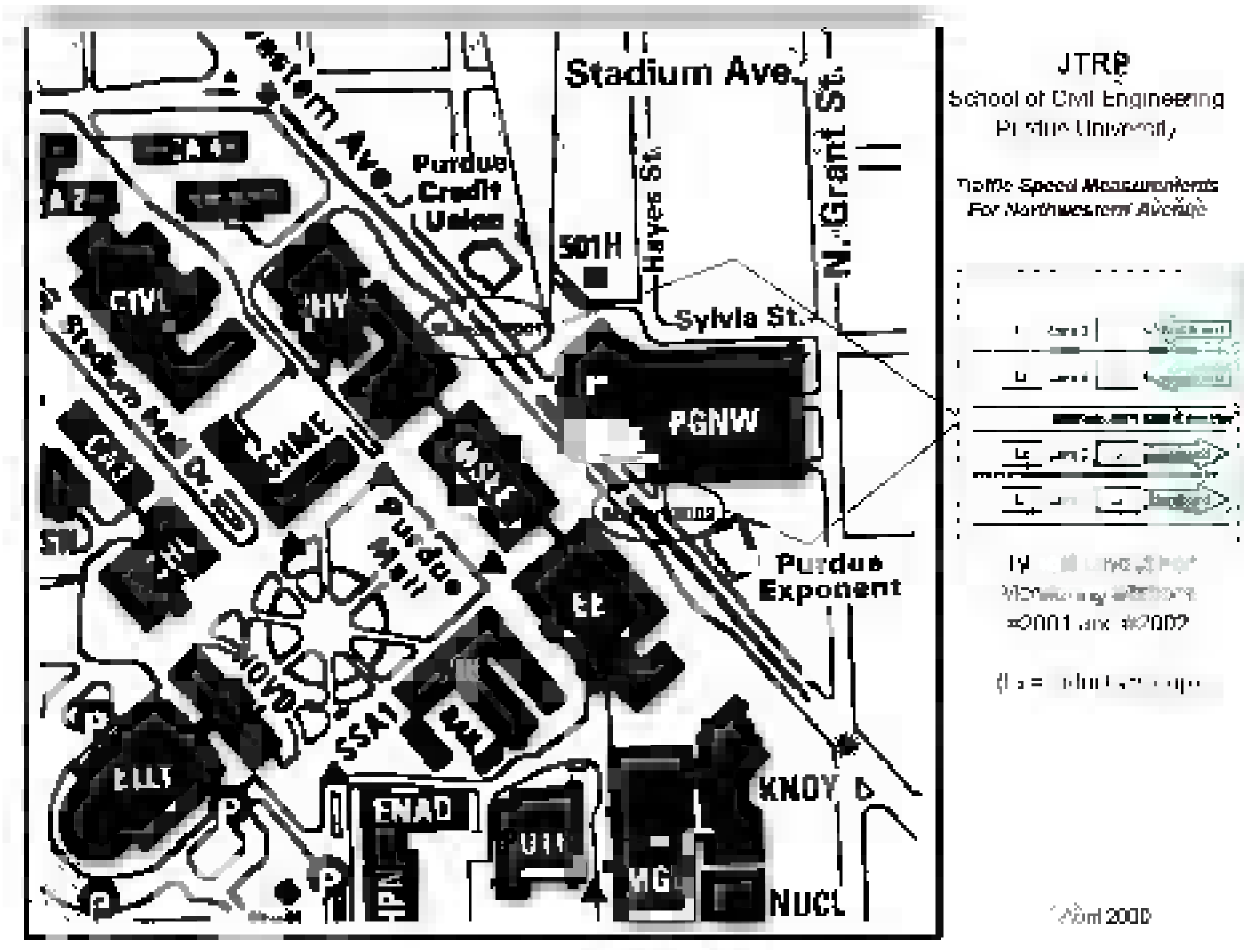

Figure 2 Data collection location (by courtesy of David Cochran)

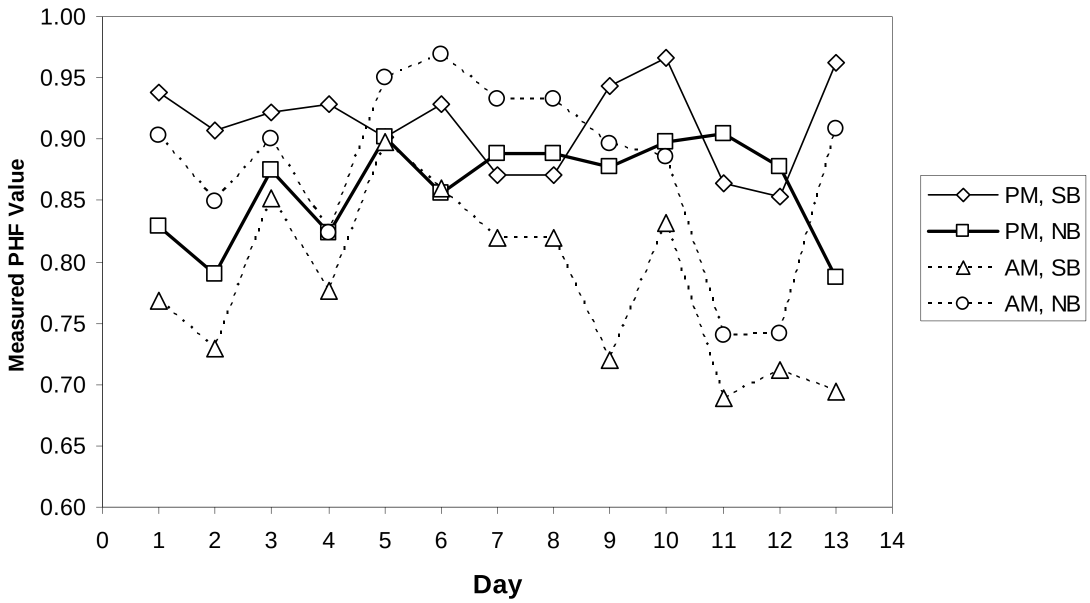

Figure 3 PHF values on Northwestern Avenue in April weekdays, 2000

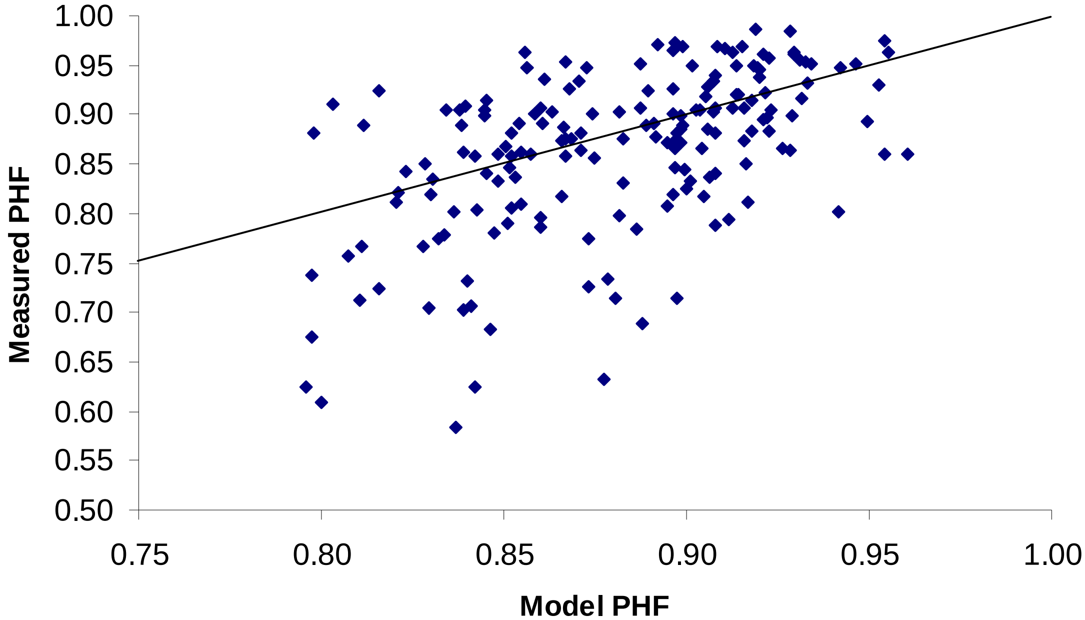

Figure 4 Comparison between the measured and modeled PHF values

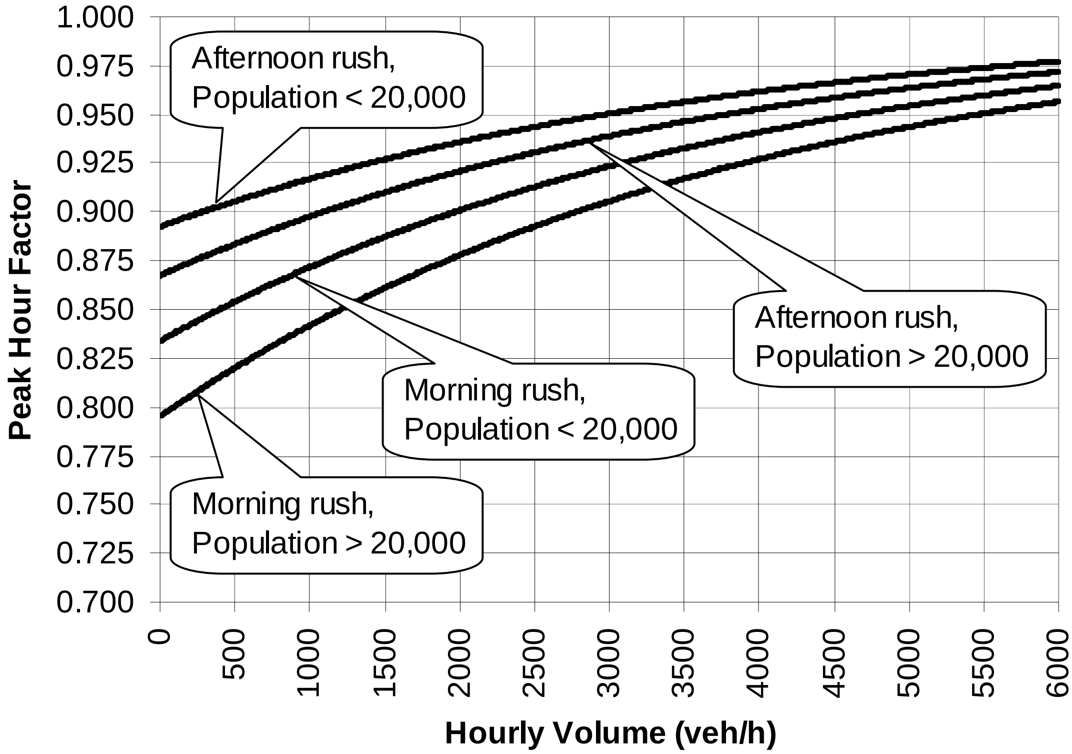

Figure 5 Variability of Peak Hour Fact or (mean value on weekdays)

Table 1 Simulated, Measured, and Predicted Variability of PHF

Case	Simulated or Measured				Equation 7 Std Dev
	Mean	Minimum	Maximum	Std Dev	
Simulated Pronounced Pattern	0.752	0.629	0.897	0.046	0.044
Simulated Flat Pattern	0.925	0.805	0.994	0.037	0.062
Northwestern, PM, SB	0.912	0.854	0.966	0.038	0.045
Northwestern, PM, NB	0.861	0.787	0.904	0.041	0.039
Northwestern, AM, SB	0.782	0.689	0.898	0.070	0.038
Northwestern, AM, NB	0.879	0.740	0.969	0.073	0.058

Table 2 Sample of Indiana intersections used to develop the PHF model

#	Intersection	City/rural	County
1	US 27/US 33 & US 224 Nuttman	Decatur	Adams
2	US 27 & US 33/ CR 400 N	rural	Adams
3	US 27/ US 33/ 13th St & CR 450 Winchester Ave.	rural	Adams
4	US 27/US 33/ 13th St & US 224/Monroe	Decatur	Adams
5	US 27/US 33/ 13th St & CR 500 N / Bollman	Decatur	Adams
6	US 27/ Lafayette & Anthony Blvd	Ft. Wayne	Allen
7	US 27/ Lima & Production Rd.	Ft. Wayne	Allen
8	Coliseum & Clinton	Ft. Wayne	Allen
9	US 1/Dupont & I-69 NB Ramps	rural	Allen
10	US 27/ Lima & Fernhill Ave.	Ft. Wayne	Allen
11	US 27/ Lafayette & Tillman Rd.	Ft. Wayne	Allen
12	US 37/ Maysville & I-469 NB Ramps	rural	Allen
13	SR 930/ Coliseum & Parnell st.	Ft. Wayne	Allen
14	US 1/Dupont & I-69 SB Ramps	rural	Allen
15	US 27/Lima & Glennbrook Commons Ent.	Ft. Wayne	Allen
16	US 27/Lima & Ley/Progress Rd	Ft. Wayne	Allen
17	SR 930/Coliseum & Anthony Blvd	Ft. Wayne	Allen
18	High St & SR 32	Muncie	Delaware
19	SR 32 & Liberty St	Muncie	Delaware
20	US 20 & CR 16	rural	Elkhart
21	SR 19/ Nappanee & CR 18 /Hively	Elkhart	Elkhart
22	SR 1(Eastern Ave) & 6th St	Connersville	Fayette
23	SR 1(Central Ave) & 9th St	Connersville	Fayette
24	SR 431 & 96th St.	Carmel	Hamilton
25	US 40 & SR 109	Knightstown	Henry
26	US 40 & Jefferson St.	Knightstown	Henry
27	US 31 & Alto Road	Kokomo	Howard
28	US 31 & Boulevard St	Kokomo	Howard
29	US 27 & SR 26/67	Portland	Jay
30	US 9 & SR 120	Howe	Lagrange
31	US 20/Central & SR 9/ Detroit	Lagrange	Lagrange
32	SR 9 & Applewood St.	Anderson	Madison
33	US36/67/9 & SR38	Pendleton	Madison
34	US 52 & Post Road	Indianapolis	Marion
35	I-465EB & SR 431	Indianapolis	Marion
36	US36/67 & Sunnyside Road	Lawrence	Marion
37	US 36 / SR67 & Walmart	Lawrence	Marion
38	US 20 & I-69 SB Ramps	Angola	Steuben
39	US 40 & Center St.	Cambridge	Wayne
40	US 40 & Round Barn Rd	Richmond	Wayne
41	US 27 & Waterfall Rd	Richmond	Wayne
42	US 1 & SR 224	rural	Wells
43	US 30 & SR 205	rural	Whitely
44	US 30 & CR 600	rural	Whitley
45	US 30 & CR 300/Lincolnway	rural	Whitley

Table 3 Summary of PHF values at 45 intersections

Parameter	Value
Average	0.86
Min. value	0.58
Max. value	0.99
Std. deviation	0.082