Speed limits and traffic breakdown flows:
An evaluation of a limit change from 120 km/h to 130 km/h

W.H. van Lindonk[a,b,*], S.P. Hoogendoorn[a], V.L. Knoop[a], H. Taale[a,b], S. van Cranenburg[c]

[a]*Faculty of Civil Engineering and Geosciences, Delft University of Technology*
[b]*Rijkswaterstaat*
[c]*Faculty of Technology, Policy and Management, Delft University of Technology*

Abstract

Speed limits are an important factor affecting driving speeds on freeway facilities. In this paper, an investigation is performed into the effect of two different freeway speed limits on the level of flow at which traffic breakdown occurs. To this purpose, a speed limit change from 120 to 130 km/h at a number of two-lane freeway bottlenecks in The Netherlands has been analyzed. The categorization procedure from the Product Limit Method has been used for the identification of flows at which traffic breakdown has occurred. Subsequently, a fixed effects regression procedure has been used to identify the effect of the change in the speed limit on the breakdown flow, whilst taking account of location specific effects, truck traffic levels and changes to the lane flow distribution. By performing eight different regressions with the speed limit variable as a primary variable of interest, it was found that the estimator for this variable was significantly positive for 7 out of 8 regressions and that the period with a limit of 120 km/h was characterized by breakdown flows that were 60 to 90 vehicles per hour higher than under the 130 km/h limit. Results in this paper are evidence that a significant relation between speed limits and breakdown flows is likely to exist and serve as an indication that capacity may potentially be negatively affected as a result of the increase of the general limit to 130 km/h. Consequently, more research addressing the limitations of this study is needed, to determine whether overall roadway capacity has been negatively affected.

Keywords: Breakdown Flows, Speed Limit, Freeway Capacity, Product Limit Method, Lane Flow Distribution, Bottlenecks, Two-lane Freeway

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1. Introduction

Due to the imposition of a new general speed limit on freeways of 130 km/h, a number of freeway speed limit changes have occurred in recent years at several locations throughout The Netherlands. Since the limit change was primarily based on political aspirations, it represents an exogenous change in a relevant explanatory variable.

Given that speed is one of the three fundamental variables of the fundamental equation of traffic, one would expect that the height of the limit would have an effect on the level of breakdown flows. A lot of research has been performed on the potential of variable speed limits to improve stability and resolve traffic jams through homogenization [1] and inflow reduction [2] [3]. Not much is known yet, however, about the effects of a change in static speed limits. In a study performed on German freeways by Geistefeldt[4] it was found that the capacity on sections with a speed limit of 100 km/h and 120 km/h was slightly higher than on sections without a limit, but no similar studies have been found for The Netherlands.

Because the change from a 120 km/h to 130 km/h limit was a much debated topic at the time of implementation and because sufficient data regarding this change is now available, it is deemed interesting to investigate whether changes in breakdown flow can be detected as a result of the change in the limit. For this reason the following research question is posed:

To what extent does the speed limit affect the flow at which traffic breakdown occurs?

In the remainder of this paper, data from several locations throughout The Netherlands, where a speed limit change from 120 to 130 km/h has occurred, will be analyzed to find an answer to this question. In this paper the categorization process from the Product Limit Method as applied by Brilon et al.[5] will be used for the identification of breakdown flows, which will subsequently be analysed by means of fixed effects regression techniques. As such, it is expected that the effect of a speed limit change on the mean breakdown flow, in absence of other relevant factors, can be observed.

2. Theoretical Framework

Traffic can either be in the free flow state F or in the congested state C. Generally, the free flow state is characterized by forward propagating characteristics (also known as ”waves”), while the congested state is characterized by backward propagating characteristics [6]. Ideally, the critical speed U^* is the

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[*] Corresponding author.

speed which separates these two states of traffic, with speeds in state F above this critical speed and speeds in state C below this critical speed. Two transitions are possible between these states of traffic, the $F \rightarrow C$ transition, which is associated with the "free-flow" capacity, and the $C \rightarrow F$ transition, which is associated with the "queue-discharge" capacity [6].

The principal interest of this thesis is the level of flow at which the $F \rightarrow C$ transition occurs ($Q_{F \rightarrow C}$), which is also known as the "breakdown flow", and how it is influenced by the speed limit. It is well known from literature [5] [7] [4] [8] that the level of breakdown flow is dependent on many factors that, even for a specific location, can vary a lot, thus making the breakdown flow a stochastic variable that follows a distribution ($Q_{F \rightarrow C} \sim (\mu_{Q_{F \rightarrow C}}, \sigma Q_{F \rightarrow C})$).

Several factors influence breakdown flows. First of all, infrastructural factors at a specific location have an influence on the capacity. Factors which negatively influence the average breakdown flow are, among others, the width of lanes [9], distance to objects along the roadway, vertical inclines [10], horizontal and vertical arcs and the type of roadway surface [11]. It is therefore important, when investigating the effect of speed limits on breakdown flows, that these factors stay the same at a location between measurements from one speed limit to the other or are explicitly accounted for in the analysis.

In addition to infrastructural factors, also traffic management factors such as a truck overtaking ban, motorway traffic management systems and ramp metering installations exhibit effects on the average breakdown flow [11] and should, therefore, remain the same from one period to the next, if they are present at a measurement location.

Meteorological factors such as rain, fog and illuminance conditions will induce day-to-day variation in breakdown flows throughout the measurement period [11] [8]. It is expected, when taking a measurement period of sufficient length during the same period of the year, that variation in weather conditions between different years will generally be small. If, however, this is not the case, it may affect the validity of the results in this study.

Additionally, traffic composition and, especially, vehicle lengths have a pronounced effect on breakdown flows [11] [6]. For this reason, levels of truck traffic should be included in the analysis wherever possible.

Lastly, evidence was found in several studies that there seems to be a significant effect of the speed limit on the lane flow distribution. Generally, it is found that when the speed limit becomes higher, a stronger tendency to drive on left-most lanes is present under conditions of high demand, with a corresponding reduction in the utilization rate of the shoulder lane [12] [13] [14]. As such, it is expected that, at least through this channel, the speed limit will affect the mean level of breakdown flows on the roadway. Which provides an argument for the inclusion of a variable which can represent the lane flow distribution.

3. Methodology

3.1. Research Question and Hypothesis

To answer the research question, a speed limit change from 120 to 130 km/h will be analyzed and the following hypothesis will be tested:

- H_0*: The speed limit does not have a significant affect on the breakdown flow*
- H_1*: The speed limit does have a significant affect on the breakdown flow*

For the purpose of testing this hypothesis, data from eight different two lane freeway locations will be investigated which will be analyzed by means of fixed effects regression

3.2. Method

3.2.1. Product Limit Method

In this paper, the categorization process from the Product Limit Method as applied by Brilon et al. [5] will be used for the identification of breakdown flows. For each location a time-series of 1-minute flow and speed measurements will be obtained for an upstream and downstream detector (see Figure 1). Subsequently, these 1-minute data will be converted to rolling time horizons of 5 minutes, for which the flow is the sum of the flows of the past five minutes and for which the mean speed is a harmonic average of the mean speeds observed in those past five minutes. Five-minute flows at the upstream detector are defined as Q_t^{up} and 5-minute harmonic speed averages as V_t^{up}, while 5-minute harmonic speed averages at the downstream detector are defined as V_t^{down}.

For each 5-minute observation, the following statements are evaluated, conditional upon which a category will be assigned to the observation:

- **IF** at observation time t the measured speed at the upstream location (V_t^{up}) is below the critical speed ($V_t^{up} < V^*$) then the measurement Q_t^{up} must be categorized as a congested measurement, which is denoted as **category** $C1$ (which indicates traffic state C)
- **ELSE IF** at observation time t and at observation time $t+1$ the measured speeds at the upstream location are above or equal to the critical speed ($V_t^{up} \geq V^*$ **AND** $V_{t+1}^{up} \geq V^*$), then the measurement Q_t^{up} must be categorized as **category** F (which indicates traffic state F).
- **ELSE IF** at observation time t **OR** at observation time $t-1$ the measured speeds at the downstream location are below the critical speed ($V_t^{down} \leq V^*$ **OR** $V_{t-1}^{down} \leq V^*$) then the measurement Q_t^{up} must be categorized as **category** $C2$ (which indicates traffic state J, which is a sub-state of C, for a jam coming from downstream of the study area).
- **ELSE** the measurement Q_t^{up} should be defined as a capacity measurement of **category** B (which indicates the $F \rightarrow C$ transition), because $U_{t+1} < U^* \leq U_t$ holds and the jam does not originate from downstream of the study area.

The critical speed $V*$ is defined as 85 km/h in this paper, because it was found that this threshold assigned category B to observations in the fundamental diagram that seemed to correspond best to where one would expect traffic breakdown to occur. Moreover, through closer examination of the data, it was found that a drop in the 5-minute mean speed from above the threshold to below the threshold was related to 1-minute average speeds that were a lot lower than 85 km/h (generally in the range of 30 to 70 km/h), thus providing evidence for the correct identification of traffic breakdown.

In the Product Limit Method, breakdown flow data are subsequently compared to observation from both categories B and F, which is a correct way to infer the capacity distribution at a location [5]. This has, however, not been done in this paper, as such a distribution generation process tends to lead to incomplete capacity distributions, which makes parametric testing and the application of regression techniques impossible. Instead, the distribution generation process as prescribed in the Empirical Distribution Method [15] is applied in this paper, where the observations of category B are only compared to other measurements of category B, which does always lead to a distribution that has been fully estimated (see Figure 2). As a result, the distribution of breakdown flows constitutes the capacity distribution, but is not equal to the capacity distribution per se. As such, any inference made in this paper about the breakdown flow distribution is an indication that the capacity distribution could have changed, but is not necessarily proof that capacity has changed.

3.3. Fixed Effects Regression

Since each location in the sample will have location specific factors that influence the breakdown flow. Performing a regression analysis without taking account of these inter-location differences is prone to lead to incorrect estimates. As an example, it is assumed that the following population model holds in reality:

$$Y_{i,t} = \beta_0 + \sum_{k=1}^{K} \beta_k * X_{k,i,t} + Z_i + u_{i,t} \tag{1}$$

Where the estimator ($\hat{\beta_k}$) of the variable of interest X_k is calculated as [16]:

$$\hat{\beta_k} = \frac{s_{x_k y}}{s_{x_k^2}} = \frac{\sum_{i=1}^{n}(X_{k,i,t} - \bar{X}_k)(Y_{i,t} - \bar{Y})}{\sum_{i=1}^{n}(X_{k,i,t} - \bar{X}_k)(X_{k,i,t} - \bar{X}_k)} \tag{2}$$

And where $Y_{i,t}$ is the dependent variable, $X_{k,i,t}$ are k independent variables, Zi indicates the location specific effects of location i and $u_{i,t}$ is the error term. If we assume that independent variable X_k is unrelated to the other explanatory variables X_{k^-} as well as the error term, but $Z_i \neq 0$ and location specific effects are not accounted for, the estimator $\hat{\beta_k}$ will be biased because it will also absorb some of the location specific effects [16]:

$$\begin{aligned}\hat{\beta_k} = \frac{COV(X_k, Y)}{COV(X_k, X_k)} &= \frac{COV(X_k, \beta_0 * \sum_{k=1}^{K} \beta_k * X_k + Z_i + u_{i,t})}{COV(X_k, X_k)} \\ &= 0 + \beta_k + \frac{COV(X_k, Z_i)}{COV(X_k, X_k)} + 0 \neq \beta_k \end{aligned} \tag{3}$$

This bias in the estimator poses a problem to the validity of the analysis. To solve this problem, $I - 1$ location dummies can be included in the regression, where I is the total number of locations, to function as "intercept-shifters" to take account of location specific effects that may induce higher or lower levels of capacity at different locations [16]. In this way, the effects of time-invariant factors such as infrastructural layout and traffic management systems are taken into account in the regression, making it less likely that the estimator of interest is biased as a result of omitted variable bias.

4. Data

4.1. Detector Locations

All locations in this study are two-lane freeway bottlenecks at different places throughout The Netherlands. All locations, except the A58-R Goirle location which is a three-to-two lane reduction, are on-ramp locations such as depicted in the schematic layout in Figure 1. In Figure 1, A represents the distance from the gore to the end of the merging area, B represents the distance to the upstream loop detectors and C represents the distance to the downstream loop detectors. In some cases distance A is more than distance B, which entails that the upstream detector is in the merging area. At these detectors, vehicle counts, mean speeds and, sometimes, vehicle lengths are measured, which are subsequently outputted in 1-minute intervals to a national database, from which the data can be retrieved.

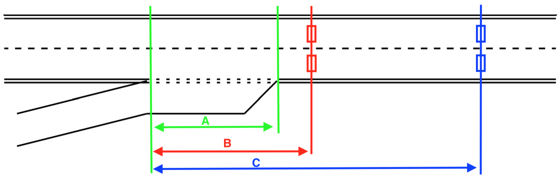

Figure 1: Schematic layout of on-ramp locations

Location	Distance A	Distance B	Distance C
A2-L Valkenswaard	220	220	1330
A2-R Valkenswaard	370	240	1470
A27-L Lexmond	310	310	1360
A27-R Lexmond	340	340	1380
A58-L Bavel	340	190	880
A58-L Moergestel	320	130	1320
A58-R St. Annabosch	350	350	1510
A58-R Goirle	N.A.	160*	610*

Table 1: Positioning of detectors at different locations (distances in meters)

4.2. Measurement periods

Several speed limit changes from 120 to 130 km/h have occurred in the period between 2012 and 2019. In Table 2 an overview is given of the date at which this limit change has occurred, as well as the years from which the data for the 120 and 130 km/h limits have respectively been obtained. For each year, the months of March, April and May have been used as a study period, which has been done to minimize the influence of differences in weather and illuminance conditions between measurement periods of different speed limits.

Location	Limit Change	120 km/h	130 km/h
A2L Valkenswaard	21-12-2018	2018	2019
A2R Valkenswaard	21-12-2018	2018	2019
A27L Lexmond	05-02-2016	2015	2016
A27R Lexmond	05-02-2016	2015	2016
A58L Bavel	05-02-2016	2015	2016
A58L Moergestel	05-02-2016	2015	2016
A58R St. Annabosch	05-02-2016	2012	2016
A58R Goirle	01-09-2012	2012	2013

Table 2: Date of speed limit change and years of study

4.3. Summary Statistics

In Table 3 the summary statistics are presented for the explanatory variables in this study, where BF stands for "breakdown flow", $V120$ is a dummy for the speed limit (V120=1 implies a limit of 120 km/h and V120=0 implies a limit of 130 km/h), TT stands for truck traffic level as a portion of the flow, LFF stands for Lane Flow Fraction which represents the portion of flow in the passing lane and LFF^2 is the square of LFF.

Variable	N	μ	σ	Min	Max
BF	2294	3,615.10	505.71	1608	4824
V120	2294	0.5026	0.5001	0.0000	1.0000
TT	1149	0.1266	0.0594	0.0000	0.6667
LFF	2294	0.6313	0.0426	0.3357	0.7535
LFF^2	2294	0.4003	0.0531	0.1127	0.5678

Table 3: Summary Statistics for explanatory variables

It can be seen from Table 3 that the average breakdown flow in the sample is 3615.10 vehicles per hour, with a standard deviation of 505.71 with a minimum breakdown flow of 1608 and maximum flow of 4824. For the V120 dummy variable it can be seen that 50.26% of the measurements is observed under a limit of 120 km/h and the remaining 49.74% is observed under a limit of 130 km/h, making this sample relatively balanced. For truck traffic an average proportion of 12.66 % has been observed with a standard deviation of 0.0594 and for the fraction of flow in the passing lane an average of 63.13% has been found at the moment of breakdown with a standard deviation of 0.0426. Despite some extreme maximum and minimum values for these variables, the coefficients of variation are all relatively low (less than 20%), which indicates that most measurements are relatively close to the mean.

Lastly, it should be noted that the sample of truck traffic measurements contains a lot of missing observations ($N_{TT} = 1149 < 2294 = N_{BF}$). There are two reasons for this. Firstly, whenever truck traffic data was unreliable at a given location, it was not included in the sample. Additionally, for some locations no loop detector was present close to the bottleneck, at which truck traffic could be reliably inferred. Locations for which no data is available are: A2-L Valkenswaard, A2-R Valkenswaard (2018), A27-R Lexmond, A58R-Sint Annabosch. Thus, every regression which includes truck traffic data is based on a smaller sample of locations.

Location	Portion of Sample
A2-L Valkenswaard	15.04%
A2-R Valkenswaard	8.85%
A27-L Lexmond	4.14%
A27-R Lexmond	18.18%
A58-L Bavel	22.71%
A58-L Moergestel	5.58%
A58-R St. Annabosch	11.94%
A58-R Goirle	13.56%

Table 4: Location Representation in Sample

Because of differences in congestion sensitivity between locations, the portion of measurements obtained from particular locations is less balanced (see Table 4). With 4.14% of measurements the A27-L lexmond location has the smallest representation in the sample and with 22.71% the Bavel sample has the largest representation. In an Ordinary Least Squares regression, it is expected that this will influence the results, but through the inclusion of location dummies in the regression (Fixed Effects) it is expected that location specific effects can be filtered out of the results.

5. Results

In this section, results for the regressions on the sample of breakdown flows are presented. As can be seen from the distributions plotted in Figure 2, the breakdown flow distributions under the 120 km/h limit and the 130 km/h limit are relatively similar and the distribution under the 130 km/h limit seems to be slightly below the 120 km/h limit. It is, however, important to note that measurements from all locations have been included in these distributions. As such, location specific effects have not yet been accounted for in Figure 2. Additionally, it can be seen that the median breakdown flow values are lower than the (median) capacity value of 4300 vehicles per hour that has been proposed for a two lane freeway with on-ramp in the highway capacity manual [11, [p.31].

For the evaluation of the effect of the speed limit on the breakdown flow, the following regression equation will be applied:

$$\hat{BF}_{i,t} = \hat{\beta}_0 + \hat{\beta}_1 * V120_{i,t} + \hat{\beta}_2 * LFF_{i,t} + \hat{\beta}_3 * LFF^2_{i,t} + \hat{\beta}_4 * TT_{i,t} + \sum_{m=1}^{M}(\hat{\gamma}_m * D_{m,i}) \quad (4)$$

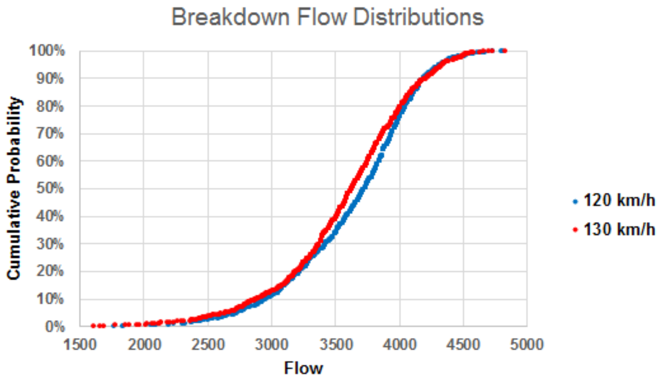

Figure 2: Plots of breakdown flow distributions under different speed limits.

Where $D_{m,i}$ stands for the location dummy of location i, which is either 0 or 1, and where $m = 7$ which equals the number of locations (8) minus one.

A quadratic term has been included for the Lane Flow Fraction variable (see Figure 3), as it was found to represent the pattern in the data better than a linear relation or a logarithmic transform (higher R^2 values). Moreover, from a theoretical perspective a quadratic function makes more sense, as a linear or log-linear relation would imply that the breakdown flow would be maximized at 100% passing lane flow (assuming a positive relation), which is clearly an inefficient lane flow distribution.

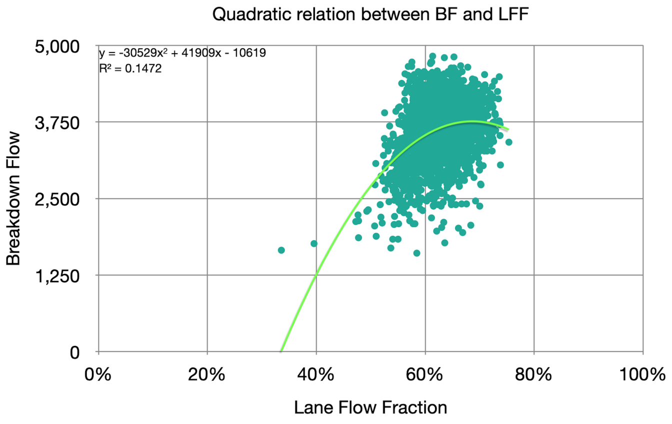

Figure 3: Quadratic Relation between LFF and BF (no location dummies included)

When examining the effects of $V120_{i,t}$ on $BF_{i,t}$ in Table 5 it can be seen that the coefficient of $V120_{i,t}$ is positive in all regressions and that it is significant for at least the 5% level in all regressions but one (regression 7). Given that this estimator is consistently positive and mostly significant, it can be argued that there is a lot of evidence to support the alternative hypothesis and that the average breakdown flow is found to be higher under the 120 km/h limit, even when taking account of location specific effects.

In regressions 1 through 4, regular least squares regression was applied and it can be seen from the results of the Breusch-Pagan test that heteroscedasticity is induced in the model by variables $LFF_{i,t}$, $LFF^2_{i,t}$ and $TT_{i,t}$, which causes the problem of inflated estimators and R^2 values. To correct for this effect, robust regression has been applied in regressions 5 through 8, for which higher standard errors are produced (with respect to the coefficient) and thus also lower R^2 values. However, due to this robust regression, it is found in regressions 5 through 7 that the t-test for the mean of the error term ($\mu_{\hat{u}_{i,t}}$) is significant, which means that the mean of the residuals is non-zero, which is a fundamental assumption of least squares regression. As such, estimators of regressions 5,6 and 7 should be interpreted with care, as they are likely to be biased.

Additionally, a Shapiro-Francia test has been performed to check for the normality of the error term. As can be seen from Table 5 all of the results from this test estimate significance at a level of 1%, which means that the regression residuals are non-normally distributed. Non-normality of the residuals does not imply biased estimators, but it does imply that the significance of estimators can be a little off, as it is assumed in the t-tests in the regression that the residuals are normally distributed. Histogram plots of the residuals have been checked visually and it was found that the residuals are not extremely non-normally distributed. Moreover, because the estimators are very significant, it is expected that this non-normality will reduce the actual significance of the estimators, but will not make them insignificant.

Furthermore, when inspecting results from the regression of variable $V120_{i,t}$ on the error term $\hat{u}_{i,t}$ in Table 6, it is found that no significant relation between the error term and the variable of interest has been found, indicating that the conditional mean of the error term is equal to zero ($COV[\hat{u}_{i,t}, V120_{i,t}] = 0$), which is another important condition for unbiased least squares estimators. From this regression (see Table 6) it can also be observed that the coefficient of the constant term is significantly different than zero for regressions 5 through 7, which is consistent with the significant results of the t-test for a zero mean of the residuals in Table 5.

In addition to the estimates for V120, significance is also proven for all estimators of the variables related to the lane flow distribution and truck traffic levels. For the truck traffic variable $TT_{i,t}$ a negative effect is found, which is consistent with findings in literature. In this paper, the effect on breakdown flows is assumed to be linear and it is found to be in the range of -23 to -30 vehicles per hour, per percentage point increase in truck traffic. The effect of the lane flow distribution term $LFF_{i,t}$ is, due to its non-linear nature, more difficult to interpret, but because the coefficient of $LFF_{i,t}$ is positive and the coefficient of $LFF^2_{i,t}$ is negative, the function is concave and assumes a parabolic shape (such as displayed in Figure 3). Which reasons a maximum at values when the passing lane accounts for approximately 70% of the flow (see Table 5). It is not necessarily the case that this value is exactly realistic as a representation of the lane flow distribution at which the breakdown flow is maximized, since flow measurements are derived directly from vehicle counts and have not been corrected for passenger car equivalents.

In conclusion, it can be stated that there is sufficient evidence for the fact that the mean breakdown flow is higher under the 120 km/h limit than under the 130 km/h and that regression es-

BF	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
V120	72.35***	87.93***	69.11**	72.82***	68.95***	85.22***	36.46	59.99**
	(19.47)	(18.66)	(26.98)	(24.75)	(18.46)	(18.41)	(23.71)	(23.88)
LFF		33,397.08***		31,148.57***		37,085.64***		43,778.99***
		(3,986.01)		(4,045.84)		(3,931.05)		(5,348.43)
LFF^2		-23,874.63***		-20,857.29***		-27,096.29***		-31,015.20***
		(3,234.00)		(3,245.64)		(3,189.42)		(4,216.91)
TT			-2,305.17***	-2,733.24***			-2,766.57***	-2,987.32***
			(262.38)	(243.02)			(230.64)	(234.63)
Constant	3,575.07***	-7,904.19***	3,956.95***	-7,257.46***	3,618.45***	-8,935.19***	4,161.23***	-10,965.99***
	(27.30)	(1,233.45)	(61.57)	(1,264.37)	(25.89)	(1,216.44)	(54.12)	(1,701.59)
Location Dummies	YES	YES	YES	YES	YES	YES	YES	YES
Robust Regression	NO	NO	NO	NO	YES	YES	YES	YES
Observations	2,294	2,294	1,149	1,149	2,294	2,294	1,149	1,148
# Parameters	9	11	10	12	9	11	10	12
R^2	0.1606	0.2334	0.1215	0.2640	0.1579	0.1938	0.0836	0.1398
Breusch-Pagan test (χ^2)	1.19	26.69***	110.95***	192.97***	N.A.	N.A.	N.A.	N.A.
Shapiro-Francia test (Z)	9.00***	6.85***	8.12***	4.61***	9.41***	7.45***	8.61***	5.70***
T-test ($\mu_{\hat{u}_{i,t}}$)	0.00	0.00	0.00	0.00	-4.18***	-2.56**	-3.29***	-1.11
Implied Optimal Lane Flow Fraction	N.A.	0.6994	N.A.	0.7467	N.A.	0.6843	N.A.	0.7058

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 5: Regression results for Breakdown Flow dependence

$\hat{u}_{i,t}$	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
V120	0.00	-0.00	0.00	-0.00	5.72	2.77	33.26	8.53
	(19.35)	(18.49)	(25.59)	(23.42)	(19.41)	(18.54)	(25.73)	(23.57)
Constant	-0.00	0.00	-0.00	0.00	-43.45***	-25.15*	-60.10***	-17.57
	(13.72)	(13.11)	(18.74)	(17.15)	(13.76)	(13.14)	(18.84)	(17.26)
Observations	2,294	2,294	1,149	1,149	2,294	2,294	1,149	1,149
R^2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 6: Regression for the evaluation of error term dependence of variable V120 on residual $\hat{u}_{i,t}$

timates imply that a difference of 60 to 90 vehicles per hour is likely to be present in breakdown flows between both limits. As such the null hypothesis can be rejected in favor of the alternative hypothesis and it is concluded that the speed limit does have a significant effect on the breakdown flow distribution.

6. Discussion

Even though significant results have been found for the change in the breakdown flow distribution, this does not necessarily mean that the capacity distribution has changed. For the correct specification of the capacity distribution, one must apply the distribution estimation process from the product limit method as applied by [5], which compares the set of measurements of category B to the complete set of both categories B and F. The reason for this is that instances of flow for which the traffic flow did break down (category B) are known from the categorization process, but instances in which higher flows did not cause a breakdown (category F) indicate that for these cases capacity has not been reached yet. As such, if it is the case that the 130 km/h limit has led to lower mean values of breakdown flow whilst also leading to higher values of free flow traffic in which traffic break down does not occur, it may well be the cases that capacity under both the 120 km/h and 130 km/h limit is similar or, perhaps even higher. It is not very likely that this may have been the case, but it is possible. Especially so, as it has been found that the mean speed at most locations under a limit of 130 km/h was only 2 to 4 km/h higher than under the 120 km/h limit [17].

Additionally, time-invariant location specific effects (e.g. same infrastructure, same traffic management systems) have been accounted for by the inclusion of dummy variables in the regression. Also, an attempt was made at including relevant variables that do change over time (such as the level of truck traffic). Nonetheless, effects from other variables such as weather conditions have not been explicitly included and may lead to biased results. For this reason, the results in this paper are not conclusive.

7. Conclusion

In this paper the following research question was posed:

To what extent does the speed limit affect the flow at which traffic breakdown occurs?

For which the following hypotheses were formulated:

- H_0: *The speed limit does not have a significant affect on the breakdown flow*
- H_1: *The speed limit does have a significant affect on the breakdown flow*

Based on the significant results for the $V120$ variable in Table 5 it can be stated with a large degree of certainty that the null hypothesis can be rejected in favor of the alternative hypothesis and that a significant change has occurred in the breakdown flow distribution with a change in the speed limit. Notwithstanding the comments that have been made in section 6, these results provide evidence for the fact that small changes in freeway speed limits may affect capacity and that this relation may be negative for limits higher than 120 km/h.

As it has been shown in this paper that a significant relation exists between breakdown flows and speed limits, it is recommended that more research is performed on whether this effect can be found at more freeway bottleneck locations and whether it also affects capacity. It is expected that stronger evidence for this hypothesis can be found, by finding ways to work around the limitations presented in this study and by performing studies on other locations than those presented in this paper.

Also the mechanism through which the level of breakdown flow is affected is worth investigating. It is most certainly the case that traffic breakdown will generally occur in the passing lane of a two-lane freeway, given that most of the flow is present in this lane at the moment of breakdown (see Figure 3 and Table 3) and that this will be caused by dynamics related to platoon stability. However, the lane flow distribution is likely to have a significant effect on this as well and there are indications that a positive relation exists between passing lane use and the speed limit.

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