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For capacities at more roads (no remote-sensing observations), see:

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**Capacity Reduction at Incidents: Empirical Data Collected from a Helicopter**

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**ABSTRACT**

Incidents on freeways cause large delays for road users. These delays depend largely on the capacity at the incident location, which is determined by the drivers' behavior at the accident location. Few empirical facts are available regarding traffic operations during an incident. This paper presents high quality videos of the traffic flow around two accidents recorded from a helicopter. From the collected images, traffic counts have been performed at the exact location of the incident. This has two advantages. First of all, the capacity at the bottleneck per lane could be estimated. Second, truck counts could be converted to passenger car units at the location of the bottleneck. Counts show that the (outflow) capacity of the remaining lanes is about 50% lower than the (free flow) capacity of the same number of lanes. This means that the road capacity at the opposite direction is reduced by half by the "rubbernecking" effect. The capacity of the road in the direction of the accident is reduced by more than half as not all lanes are in use.

The images provide information on the causes for the capacity reduction. A leader accelerates and the follower accelerates a short time later. The average time between these two accelerations is estimated at around 3 seconds, but the video shows also a large spread of these times. The results can be used to assess consequences of incidents, both in an analytical way and in macroscopic or microscopic traffic simulators.

## INTRODUCTION

A significant part of road-users delays is caused by incidents (1, 2). The incident reduces the road capacity. In the end, the road capacity determines, together with the demand and route choice, the delays. For a good description of the road users' actions, it is necessary to have detailed measurements of their behavior. Estimates for the capacity reduction are given for instance in the highway capacity manual (3). Qin and Smith (4) carry out a more detailed analysis, still based on macroscopic data. In microsimulation packages the driving performance of individual vehicles is modeled hence the capacity is an output of the model. For instance, Sinha et al. (5) use several of these software tools to calculate the capacity with a partial road blocking. To the best of our knowledge, detailed, microscopic, measurements to calibrate and validate the models have not been collected nor presented until now.

Capacity is reduced by the blocking of the lanes. Moreover, the driving behavior at the remaining lanes can differ from the usual behavior. The available aggregated cross-section (inductive loop) data do not give behavioral insight into the causes of capacity reduction. In The Netherlands, the location and time of an incident are stored, as well as the loop detector data. From loop detector data, one could derive some properties of the flows around accidents, but this data will not give detailed information about the behavior of the drivers. Ossen et al. (6) describe what happens to (unaggregated) counts at a loop detector near an incident location. Moreover, it is usually not possible to measure at the exact location of the accident. This paper describes the unique way of microscopic data collection, using a helicopter. These observations enabled us to analyze real-life behavior of road users passing at the location of an incident. The data can also be used for fitting car-following models to the collected trajectory data (7, 8).

Empirical data have been collected to analyze the driving behavior around accidents. At two accident locations, the traffic operations have been on high resolution video. The use of this technique enabled us to measure all aspects of the operational driving behavior for drivers in both directions. This paper focuses on the capacity of the freeway if a lane is blocked; it will also show the capacity reducing effect on traffic in the opposite direction

("rubbernecking" effect). An explanation for the observed capacity effects is established by careful consideration of the driving behavior from the video data collected.

Unless explicitly mentioned, all capacities that are described here are the maximum flow values that are obtained when driving out of congestion (queue discharge rate). These flows are substantially lower than the free capacity. Research in the past decades discusses this phenomenon, the capacity drop, as well as the magnitude of this effect, which typically estimated at around 10% (9-12).

## RESEARCH APPROACH OUTLINE

This section will explain why trajectory information is needed to gain a better insight into the macroscopic and microscopic traffic flow operations near incidents. The second part introduces the observations that are used for this report. Both the exact way of collecting them and the details of the accidents are given.

### Experimental Set-Up

There are many different ways to measure real-life traffic behavior. Data of (double) loop detectors is the most common way to gather traffic data. These will however not provide detailed information about the driving behavior dynamics around accidents, since they only provide local (cross-sectional) information. However, spatial information (in fact, trajectory information) is needed, because this will yield information of the behavior upstream of the incident and at the incident location itself. This allows for instance to observe speed adaptation, car-following behavior (including estimation of the reaction times), and to observe lane choice behavior (13). For the capacity estimation just the passing times are needed. Nevertheless, data from one loop detector will not be sufficient, as the detector is generally not located at exactly the place of the accident. Furthermore, one needs to know whether there is a queue waiting. It is also necessary to distinguish between trucks and cars at the moment of passing the accident (and not at another location further on down the road). If one takes data from a detector located further on the road, the different traffic classes (trucks and cars) are probably already mixed due to a difference in speed: trucks accelerate and drive slower than passenger cars. For one interval, the traffic composition at a detector more downstream is therefore not the same as the traffic composition at the bottleneck. To show the differences, the result of a detector count is also presented in the section data analysis.

### Data Collection Using Remote Sensing

The following approach was taken to get the data of an accident. A digital photo camera was attached to a helicopter. The helicopter stayed approximately at the same position, above the accident. The camera could move in all directions to compensate for the helicopter movements. Digital photographs were taken at a rate of 15.1 images per second and saved to a hard drive. The size of the pictures is 1392 x 1040 pixels. The height of the helicopter is around 400 m (around 1300 ft) and length of the long size of the image is also around 400 meters (440 yards). Therefore, this implies that one pixel equals around 30x30 cm (12 x 12 inch) on the road. The procedure is also described by Hoogendoorn et al. (14).

The observation team waited at the Traffic Management Center in the centre of the Netherlands until an accident had occurred somewhere nearby, after which it flew with the helicopter to the accident location. From the moment of arrival, traffic operations for both directions were recorded. From the other side of the road, the incident was visible but there was no physical obstruction. The video therefore shows the so-called "rubbernecking effect"

(i.e. people watching the accident at the other side of the guardrail). The helicopter was high enough not influence the traffic operations.


**FIGURE 1 The two accident locations indicated on a map of the Netherlands – size plotted area 250 x 350 km (about 150 x 220 miles)**

The remainder of the paper presents the data for two accidents. At the first accident, a light van rolled over. It ended in the median strip, the unpaved area between the two carriageways of the freeway. The accident happened at June 6, 2007, at around 9:15 am, near Apeldoorn at the motorway A1 in the Netherlands (see also FIGURE 1). The road has two carriageways in each direction and no grade. For the eastbound direction, one lane was used by the emergency vehicles and blocked for the traffic, therefore. For the other, westbound, direction, the delay was only caused by rubbernecking. Unfortunately, around 100 meters (110 yards) west of the blocking of the lane, there was a tunnel, hence the traffic operations there are invisible (see FIGURE 2). The crosses mark the blocked lanes, the arrows the available lanes.


**FIGURE 2 Accident location near Apeldoorn (right=east)**

The other accident was an accident where several trucks and passenger cars were involved. At the instant the measurement started, the accident blocked one lane of the two-

lane freeway as well as the shoulder lane. From time to time, the police stopped the traffic for a while to recover a car from the accident. The accident happened at June 6, 2007, at around 11am, at the westbound carriageway of the two-lane motorway A15. It happened several hundreds of meters downstream of the freeway junction Gorinchem (see FIGURE 3); there is no grade. Traffic had to twice in several hundreds of meters: the regular merging of traffic from the two freeways and the merging from two to one lane. The traffic demand in the eastbound direction was not sufficiently high to cause a traffic jam. The main interest lies in the causes for the delay caused by incidents. Although traffic operations might change, there will be no substantial delay without a traffic jam. Hence, we did not analyze the traffic operations at the accident location near Gorinchem in the uncongested eastbound direction.


**FIGURE 3 Accident location near Gorinchem (right=east)**

All properties are summarized in TABLE 1 below. The recording was stopped when the road was clear or no queue was waiting any more.

**TABLE 1 Properties of the accidents for which data are collected**

| **Nearby city** | **Apeldoorn** | **Gorinchem** |
|---|---|---|
| **Road** | A1 | A15 |
| **Date** | June 6, 2007 | June 6, 2007 |
| **Time** | 9:39 – 10:15 | 11:59 – 12:56 |
| **Weather** | Clear | Clear |
| **Type** | Freeway | Freeway |
| **Number of lanes** | 2 x (2 + shoulder) | 2 x (2 + shoulder) |
| **Grade** | none | None |
| **Weather** | Clear | Clear |
| **Lanes used by traffic:** | | |
| eastbound | right & emergency | right & left |
| westbound | left & right | Left |
| **Jammed** | eastbound & westbound | Westbound |
| **imaged area** | 400 m (440 yard) | 400 m (440 yard) |
| **Remarks** | just east of tunnel | just east of merging |

## DATA ANALYSIS

From the image sequence, the passing times of the vehicles at the incident were recorded. In doing so, we distinguished for the different lanes and two different vehicle types: heavy vehicles and light vehicles. It is possible that there are small errors in the passing times of the vehicles, which might (in some cases) cause a vehicle to be counted in the wrong time

interval. This would have no effect on the median flow, since the extra vehicle in one time interval would be compensated in the other.

From these passing times, we computed flows, aggregating over time and over the carriageway. For the sections that have a queue of waiting vehicles behind them, this flow represents the outflow capacity. This outflow capacity differs from the free flow capacity. The free flow capacity is the maximum number of vehicles per unit of time that can pass a cross-section of a road in free flow. This free flow capacity is usually obtained before congestion sets in. The number of cars that flows out of a queue per unit of time is usually lower. This phenomenon is called the capacity drop. It is described extensively in literature and estimations for the reduction vary, but are typically around 10% (9-11).

Both the free flow capacity and the outflow capacity are stochastic variables (15). Their value depends on external conditions (such as weather, road geometry) and individual characteristics of the drivers. Usually, they are characterized by their median values: the maximum flow value that is obtained in half of the cases. For one measurement, the external conditions are fixed. The variability of the capacity is an interesting property of the capacity. It gives an indication of the extent of the inter-driver differences and the reliability of traffic flow operations. Not all aggregation intervals can be used for outflow capacity estimation. There should be a queue of cars waiting to pass and the flow should be uninterrupted (not always the case at the accident location near Gorinchem). If there is no constant queue outflow capacity, that aggregation interval should be ignored in the capacity estimation. The amount of data that should be ignored increases with the aggregation time. We took a relatively short aggregation time of 30 seconds.

The short periods gave plenty of measurements. This made it possible to get a distribution of the capacity. The flows are sensitive for the (mis) count of one vehicle, as only few vehicles pass in a period, so the consequences of missing one vehicle are large. However, there is no bias. Let's for example consider an example with a constant flow rate. Suppose that just at the start of aggregation interval *A* a vehicle passes the detector and also at the very end of that interval a vehicle passes. The next interval, *B*, now starts with a gap. The flow value of interval *A* is higher than the average flow rate, whereas in interval B the flow rate is lower. However, there will be no bias for the median value: the vehicle passing in interval A is subtracted from the value in interval B. By taking the median value, the sensitivity for a single value is reduced. Taking short intervals increases the variability. This is the effect of both the increased impact of (mis) counts and by the higher variability between the drivers' population between aggregation intervals.

Using the 30 seconds intervals, there are about 35-40 aggregation intervals for the location near Apeldoorn (the number of usable intervals depends on the lane and direction) and 45 for the location near Gorinchem. To come to a single value for the flow, we converted all passing vehicles to passenger car equivalents. Hence, the passing of a truck is counted as 1.5 passenger car (3, 16). The flows were converted in this way to passenger car units, pcu/lane.

This results in 5 different outflow capacity estimates:

- Apeldoorn eastbound - carriageway
- Apeldoorn westbound - right lane
- Apeldoorn westbound - left lane
- Apeldoorn westbound - carriageway
- Gorinchem – westbound

The first value is for the amount of traffic that passes the accident near Apeldoorn, the eastbound direction. The lanes used change over time: sometimes, the emergency lane is used,

sometimes, the right lane is used, and sometimes, they are used both. From the video we have observed that some drivers choose to avoid a specific lane without an apparent reason. Both lanes are available for the drivers. Taking the flow values of each of the lanes separately, would yield nonsensical results (often no-one uses the lane, although there is a queue waiting). We focus on the capacity, which is a result of the driver's behavior. Adding the flows of the emergency and the right lane gives information of the realized queue outflow capacity if these two lanes are available. In this way, we do not get a capacity value for each lane. However, the value we get for the roadway is a result of drivers' behavior to pass the accident location. The resulting flow values are divided by 2 to get an outflow capacity per lane.

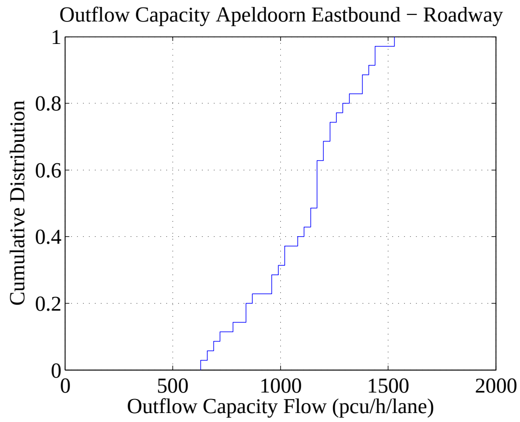
Traffic in the opposing direction uses both lanes continuously. We can therefore compute a capacity value for each of the 2 lanes, as well as the average outflow capacity (distribution) per lane. The fifth capacity value is the capacity of the remaining lane passing the incident at the accident location near Gorinchem.

## CAPACITY ESTIMATION RESULTS

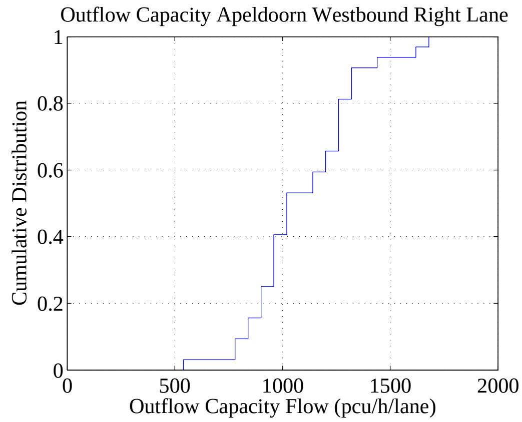
For incident one, congestion occurs in both directions. The heads of both queues appear to be at the location of the accident. That is, the accident is an active bottleneck. In FIGURE 4 we have plotted the distributions for the capacities (in pcu/h).

The steps in the capacity distribution of the left lane are explained by the aggregation interval. Since there are no trucks in this lane, the flow values of one aggregation interval are an integer times 1 pcu. 1 pcu per 30 seconds converted to an hourly value gives steps of (1 pcu/s * 3600 s/h=) 120 pcu/h, which are the steps that are seen in FIGURE 4c.

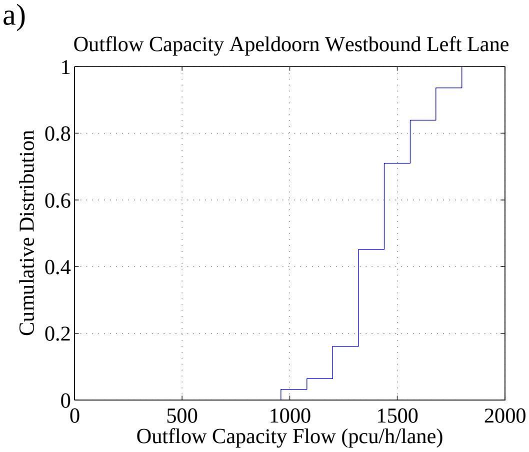
In FIGURE 4f, the flow distribution on a more downstream detector for the Westbound direction of the Gorinchem accident site is plotted. There are more intervals with no cars passing. In the data collected from the helicopter, the periods in which the road is completely blocked are discarded, while such is impossible if one has only detector data. Furthermore, these are counts without distinction between trucks and passenger cars; consequently the flow is given in veh/h and not in pcu/h. In The Netherlands, the detectors only give reliable data for the counts and not for the different car classes. If one were able to distinguish between trucks and cars, the traffic would be mixed after a distance. Think for instance of passenger cars overtaking the trucks that were in front of them. This clusters car counts at one moment (the moment of overtaking), whilst the number of cars on another position (e.g. in front of the truck) could be lower. The median will remain the same, but an increase in spread of flow is the result of counts at a more downstream detector.



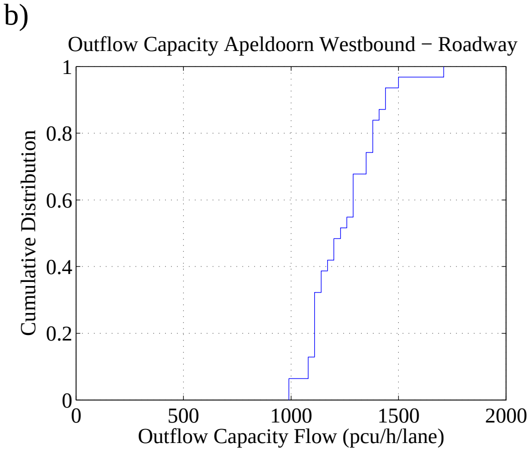

a)



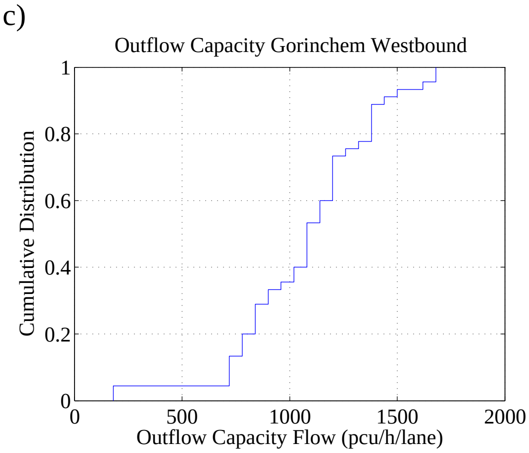

b)



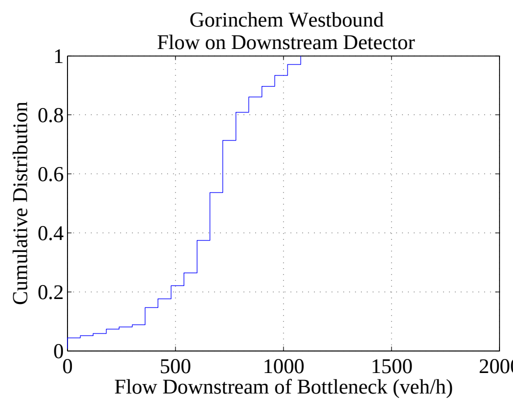

c)




d)




e)




f)

**FIGURE 4 Empirical cumulative distribution functions for different locations, 30s aggregation time: a) Apeldoorn eastbound roadway; b) Apeldoorn westbound right lane; c) Apeldoorn westbound left lane; d) Apeldoorn westbound roadway; e) Gorinchem westbound roadway (=left lane); f) Counts (60s aggregate) on downstream detector Gorinchem westbound (in veh/h)**

FIGURE 5 is a boxplot of the capacity flows. The middle line indicates the median flow value; the box is made of horizontal lines at the 25% and 75% percentile. The whiskers (at the outside) give the total range of the values: all values except for the crossed outliers lie within these 2 whiskers.

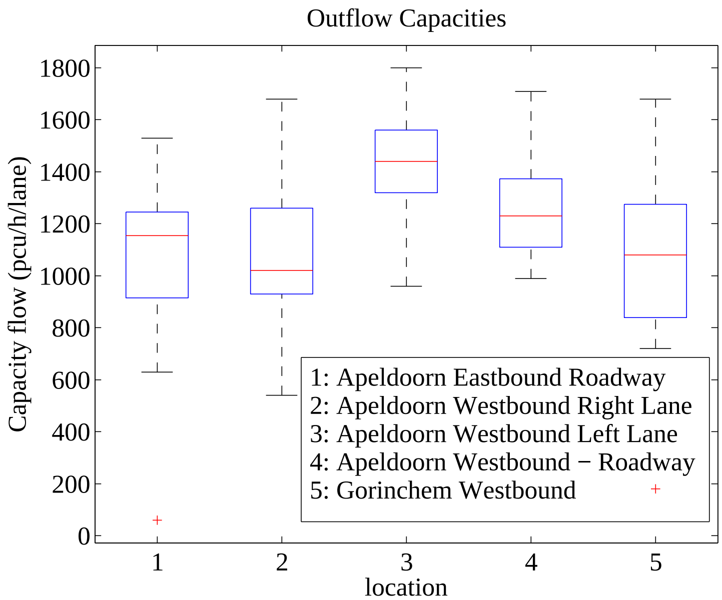



**FIGURE 5 Capacity values for the different locations**

Under normal conditions, a 2-lane motorway is assumed to have a median free capacity of 4650 pcu/h in The Netherlands (16). In addition to FIGURE 5, the (outflow) capacities of the accident locations are stated in TABLE 2. The values are converted to pcu/h/lane. As expected, the flow values for the locations with an accident drop to values under the usual (free flow) ones based on the remaining lanes (TABLE 2). The stated expected capacity is the reference free flow capacity (16) for the number of lanes that is open.

**TABLE 2 Capacity values for different locations**

| Location | Lanes | Median (pcu/h/lane) | Mean (pcu/h/lane) | St dev (pcu/h/lane) | Expected without rubbernecking (pcu/h/lane) | Percent of capacity remaining |
|---|---|---|---|---|---|---|
| Apeldoorn eastbound roadway | 2 | 1170 | 1103 | 239 | 2325 | 50% |
| Apeldoorn westbound right lane | 1 | 1020 | 1095 | 249 | 2325 | 44% |
| Apeldoorn westbound left lane | 1 | 1440 | 1417 | 195 | 2325 | 62% |
| Apeldoorn westbound roadway | 2 | 1230 | 1246 | 163 | 2325 | 53% |
| Gorinchem westbound | 1 | 1080 | 1072 | 326 | 2310 | 47% |
| Netherlands average 1 lane | 1 | 2310* | *free capacity | | | |
| Netherlands average 2 lanes | 1 | 2325* | *free capacity | | | |

For example, in the case of Gorinchem the reference capacity was already taken for one lane. Thus, the near 50% reduction of capacity cannot be explained by the reduction of number of lanes. The general view, for all locations, is that because of rubbernecking, the average queue discharge rate at the location of the incident is around half of the free flow capacity. This reduction is much larger than the differences normally quoted between free flow capacity and outflow capacity.

In the first case, Apeldoorn eastbound, one of the two remaining lanes is the emergency lane. This has two consequences for the estimation of the capacity reduction. First, the reference capacity is probably lower than the capacity for two full-width lanes. Secondly, as described in the section on data analysis, the use of both lanes at this location varies in time: sometimes the shoulder lane is used, sometimes the right lane is used and sometimes, both of them are used. If they were using both lanes continuously, the flow would probably have been higher. However, the data represents the drivers' behavior around the accident, including their lane choice. Thus, the net effect is that the resulting outflow capacity is 50% lower than the free flow capacity would have been for a two lane road.

This reduction can be caused by "rubbernecking", the fact that people are distracted by watching what has happened. Another possibility is that people drive extra carefully since there are people working at the roadway. Other publications show lower reductions (4, 17) expressed as a percentage of the road capacity. The confidence bounds for the values in the references are unclear, and thus it is impossible to tell whether the difference is significant. A possible explanation for a larger reduction found in this study is the high free flow in the Netherlands. A similar congestion flow would then lead to a higher capacity reduction.

It is remarkable that the resulting maximum flow rates at the accident near Apeldoorn are about the same for the eastbound and the westbound direction, whereas in the eastbound direction one lane is blocked. Drivers will use the emergency lane from time to time. Blocking of lane and looking at the accident causes the same reduction of flow as the rubbernecking from the opposite direction.

## QUEUE ESCAPE TIMES

The found capacities are very low, much lower than expected. This section will explain the low capacities. It will connect the low capacities to queue escape times and provides an insight in the distribution.

We can find an explanation of the rubbernecking effect by a detailed observation of the collected video images. For both incidents, we have pinpointed one position at which the head of the queue is located. The locations are marked with an arrow in FIGURE 2 and FIGURE 3. From that point on, people accelerate and the traffic jam dissipates. We believe this is the point where the drivers have the best view on the accident. The response to the acceleration of the leader is sometimes very slow, up to several seconds. This time is the queue escape time, $T_q$. This time is larger than the reaction time: drivers are probably physically able to respond faster, but due to the incident, they do not react as fast as they can. If there was a traffic jam that dissipates, the head of the queue would move backwards, since $T_q$ is usually shorter than the gross headway, $h$, within the traffic jam. Here, the head of the queue moved backwards and than came back to the in the same place. This leads to the conclusion that, on average, the queue escape time equals the average gross time headway, $h$.

The gross average time headway can be derived from the flows:

$$\langle h \rangle = \frac{1}{q} \tag{1}$$

In this equation, *h* is the gross headway, *q* is the flow and the brackets indicate the median operator. The table below gives this headway or time delay. The unit for flow is *pcu/h/lane*; the corresponding unit for headway is *lane.h / pcu*. In TABLE 3, the units are converted to lane.s /pcu.

**TABLE 3 Time headways for different locations**

| **Location** | **<h> (lane.s / pcu)** |
|---|---:|
| Apeldoorn eastbound carriageway | 3.1 |
| Apeldoorn westbound right lane | 3.5 |
| Apeldoorn westbound left lane | 2.5 |
| Apeldoorn westbound carriageway | 2.9 |
| Gorinchem westbound | 3.3 |
| Netherlands average 1 lane | 1.6 |
| Netherlands average 2 lanes | 1.5 |

All the values are computed from TABLE 2. The average time headway for the free flow situation is shown in the last 2 lines of TABLE 3. For the free flow situation, this is not a queue escape time (there is no queue). The capacity drop (already stated in the Introduction) will increase the average headway by around 10%. In case of a backward moving head of the queue, the time delay between the leader and follower to accelerate will be shorter than the headway.

The average time between the acceleration of the follower and the leader is roughly two times larger than the average headway time for following at capacity in The Netherlands. Hoogendoorn and Bovy (18) show an distribution of headways in the Netherlands for a non-incident-location. The times presented here are converted times from the flows in passenger car units. That should already correct for the higher number of trucks. That the headway in the fast lane is smaller should be attributed to the faster response of the drivers and not to the lower percentage of trucks in the left lane.

In the video, we see a large spread of the times that people take to look at the accident location before accelerating. Platoons of passenger cars in the left lane accelerate normally out of the jam, in which case the head of the queue temporarily moves upstream. But then there is one driver that keep driving slowly until they reach the incident site. We conclude these drivers are the main cause for the very large average queue escape times at the location of the incident, and hence for the low capacity.

Also in the left lane, some cars take a long time before accelerating. We observe that the average platoon length in the left lane is longer than in the right lane. This means that the flow is higher, because of the number of cars per platoon is higher, and thus the average headway is lower.

## CONCLUSIONS AND FUTURE RESEARCH

We measured the two-directional traffic passing two different accident locations on freeways. From the video data we determined the traffic flows at the location of the incident. Because both incidents considered resulted in congestion, one in two directions and the other one in one direction, we could estimate the queue discharge rate for the partially blocked roads, as well as the magnitude of the rubbernecking effect.

We have pinpointed the location of the active bottleneck at the location where there is a clear sight line to the accident. We have estimated the maximum outflow out of the jam, which turns out to be roughly 50% lower than the flow that could be obtained on the same number of lanes without an incident. There are two behavioral reasons for this effect. People could take the time to watch the accident ("rubbernecking") or, alternatively, they could drive with extra care (i.e., slower) to respect the workers. It was pointed out that the time headway equals the queue escape time. This time is, on average, around 3 seconds at the incident location. A normal average headway is around 1.6 seconds in the Netherlands. The video shows a large spread in the times drivers need to accelerate before their leaders do.

These results can be used in the analysis of delays caused by incidents and accidents. The traffic behavior of road users is an input for both analytical planning models, and microscopic and macroscopic simulation models. In most analyses, the capacity is now reduced only in the direction of the incident. This research shows that the effects in the opposing direction could be of the same order.

In this contribution, the collected video data was used to estimate capacity at the location of the accidents. We have presented some qualitative findings about the reasons for the observed low queue discharge rates. There are tools to change the video into trajectory data. When converted, the dataset provides an excellent basis to calibrate car-following models (14). With these calibrated models, we can describe the drivers' behavior more closely, including the intra-driver and inter-driver variability in car-following behavior. A more extensive study, including more incidents, will show the differences in capacity reductions for various incidents and indicate the effects of incident management measures like screening the incident location using non-see-through screens.

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