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Field research concerning contra-flow as a measure for massive evacuation

Allert S. Knapper[a]*, Karel A. Brookhuis[b]

[a]*Delft University of Technology, Faculty of Technology, Policy and Management, Jaffalaan 5, 2628 BX Delft, The Netherlands*
[b]*University of Groningen, Department of Psychology, Grote Kruisstraat 2-1 9712 TS Groningen, The Netherlands*

Abstract

The present study concerns a practice test that aimed at investigating to what extent contra flow or reverse laning (Dutch: tegenverkeer) works well in the Netherlands and how participating car drivers evaluate it. Reverse laning may be a solution for a capacity problem in case all lanes of roads are needed to evacuate large areas. To that end, the lanes of the Bornholmstraat (an entry / exit street near the Euroborg Soccer Stadium in Groningen) were reversed in one, outward-bound direction after a selected FC Groningen soccer match. The coincidental participants received a short questionnaire that contained a few questions concerning their behavior, opinions and feelings about the evacuation. To maximize the response rate a bonus was announced; if they returned the questionnaire, it gave them a chance of winning VIP tickets for a FC Groningen match. The 690 useful respondents who had driven in the reversed lanes situation thought that the test setup was safe and understandable; 79.3% had chosen the right lane corresponding to their stated destination, 79.2% had felt safe. Capacity gains by an extra traffic lane in the outward-bound direction were estimated at 50 to 80%, leading to the conclusion that reverse laning may well be used in Dutch evacuation plans. Recommendations are made to that purpose.

Keywords: contraflow; reverse laning; evacuation; traffic; tegenverkeer; Netherlands

* Corresponding author. Tel.: +31 (0)15 27 87269; fax: +31 (0)15 27 82719.
E-mail address: a.s.knapper@tudelft.nl.

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1. Introduction

For a while now, effort is devoted to the practice of evacuations from buildings and recently from whole areas, for instance, because of (a threat of) inundations. For example, the South-East coast of the United States is swept by hurricanes regularly, promptly followed by evacuations at different scales, from small on a local basis to very large when whole cities are evacuated. A well-known example of the latter is the major evacuation of New Orleans in 2005 when Katrina came by and flooded large parts of the city.

Because the Netherlands is largely below sea level, it is assumed that there is an actual flooding risk in case of a major storm. In 1953, a disastrous flooding took place, resulting in large parts of the southern part of Holland being covered with seawater, taking1835 lives [1]. In 1995, the Waal river was filled with melt water to such an extent that authorities decided to evacuate the Ooijpolder in the Gelderland area [2]. In spite of large amount of dikes in the Netherlands, a flooding is regarded possible, although regarded unlikely for the near future. However, preparing for evacuations is a sensible thing to do, even in case of an unlikely event. The Dutch Department of Public Works and Water Management (Rijkswaterstaat) has acknowledged this hazard and is making preparations and plans for organizing evacuations. The presented research is part of the pilot study intended to investigate how the traffic infrastructure can be used as long and efficiently as possible.

In the US, authorities have already gained experience with large scale evacuations nowadays, resulting in few traffic jams. In the past, hurricanes Georges and Floyd led to huge congestion when the first evacuations were organized [3]. Research led to the conclusion that massive relocation of people was not anticipated and that traffic volumes were too large, partly because population growth and tourism was not accounted for [4].

1.1. Contra flow

Part of the solution to overcome congestion and traffic jams during evacuations may be established by contra flow [5], also called reverse laning, lane reversals or one-way-out (Dutch: tegenverkeer). Contra flow comprises using all available road lanes to exit a threatened area. In large scale evacuations, large amounts of motor vehicles are to leave an area within a short time window, while close to none are to enter it (and often are prohibited for better evacuation control). Outward-bound lanes are then much more prone to congestion, while inward-bound lanes are virtually empty. As in a contra flow condition the inbound lanes are reversed, more lanes are available to leave the evacuated zone [6], increasing the road capacity. Especially after hurricane Floyd had passed, a number of states in the US were convinced to adjust their highways to contra flow [7]. Urbina and Wolshon [3] reported that 11 out of 18 often hurricane threatened states use contra flow in their evacuation plans.

The (theoretical) increase of road capacity, when applying contra flow, is substantial. In the normal situation approximately 2,000 vehicles per hour (vph) can cross a highway lane, whereas in an evacuation condition this amount lowers to about 1,500 vph [4]. In a four-lane motorway, this means about 4,000 vph, while in the most efficient contra flow option, with all lanes reversed, this number increases to 6,000 vph, a 50% road capacity increase [4]. Wolshon et al. [8] reported a 40% increase on the I-55 during Katrina. The Lousiana evacuation has cost half the time estimated, supposedly because, despite the application of contra flow, other roads were used well to avoid congestions on the highway network [9]. Wolshon [10] reported a maximum of 2,500 vph on a two-lane highway during a 38 hour contra flow on the I-10. He recommends 800 to 1,000 vph per lane estimate for four-lane contra flow highways and a 1,000 to 1,200 vph estimate per lane on interstate highways.

During contra flow, as Willems [6] remarked, it is of utmost importance to inform drivers about the situation, preferably beforehand but real-time as well. Although it is hard to come up with a ready for use contra flow plan, drivers should be informed about congestion, weather and travel time. Willems [6] provided a list of possible ways for information supply.

Van der Doef and Cappendijk [5] recommended not to apply contra flow if the traffic can leave the area in time without it. Moreover, preparation time should be estimated in order to be able to decide better and in time whether

or not to start contra flow. Additionally, it is recommended to have freight traffic drive only on the normal right lanes, inform emergency services, make road and exit numbers visible from the air for monitoring reasons and to man closed exits to prevent ghost-drivers [11]. In 1995, in the Ooijpolder evacuation in the Netherlands, sound trucks, television messaging and local radio station were used to inform the people. It proved important to have good and up to date area maps and to involve local people who know the local area.

1.2. Research questions

Urbina and Wolshon [3] stated that little is known about costs and benefits concerning capacity gains, safety and required personnel. Williams et al. [12] analyzed and constructed an I-40 simulation model, but they could not include evacuee behavior. For the Dutch situation major questions remain after the 1995 Dutch experiences with respect to predicting the effects of evacuation. What are practical requirements for applying contra flow? How will people behave? Many of these questions can only be answered in a real large scale evacuation, but some questions can be investigated in a practice test. The present study set out to look for a big event with large amounts of cars exiting an area in a short time span, resembling an evacuation situation, to measure how contra flow will work and to study preconditions. The event was not specifically sought in a potentially threatened area, because its purpose was investigating contra flow preconditions and solutions applicable to general traffic. The main research goal was to gain insight in how contra flow works in practice. Focus of the field study was on the coincidental participants, how they behave and feel during contra flow. The questions to be answered were:

1. How efficiently, in terms of road capacity, does a contra flow evacuation work?
2. How do people respond to signals indicating lane choice?
3. To what extent do the (involuntary) participants understand the situational change?
4. To what extent do the participants feel safe and comfortable in the deviant traffic situation?

2. Method

The actual event occurred after 12.30 P.M. under bad weather conditions on Sunday October 5th 2008 (continuous rain), during and after the FC Groningen – ADO Den Haag soccer match (3-0), at the Bornholmstraat in Groningen, the Netherlands. This road (fig. 1 provides an overview) was chosen because most of the FC Groningen fans park their cars somewhere alongside this street when going to the FC Groningen soccer stadium Euroborg. The local police estimated that usually between 2,000 and 3,000 cars park in this area during a soccer game. The deviant traffic situation was announced in a local newspaper 2 days before the test, and via a flyer on the FC Groningen website.

2.1. Contra flow situation

During the second half of the game, the contra flow measures, signs and personnel were installed. At the one end, near the stadium the Bornhomstraat was closed, while at the other end contra flow terminated and drivers could choose one of four roads to continue traveling to their destination. On the Bornholmstraat, orange cones were intermittently placed on the white line to keep the two traffic streams largely separated to avoid frequent weaving. All relevant crossroads and side-ways were manned with a traffic controller who took care that drivers safely merged into the traffic lanes. The (25) traffic controllers were instructed not to talk with drivers to let traffic flow as smoothly as possible. Two motorcycle policemen assisted the traffic controllers. The motorway exit and the main crossroads into the area were closed, traffic was re-routed.

Earlier placed and covered traffic signs were uncovered, indicating that drivers should choose the lane corresponding to their destination (see Fig. 2, left sign). This pre-announcement sign was placed twice; the right sign in Fig. 2 was placed at the start of the road section intended for weaving, where the orange cones were omitted.

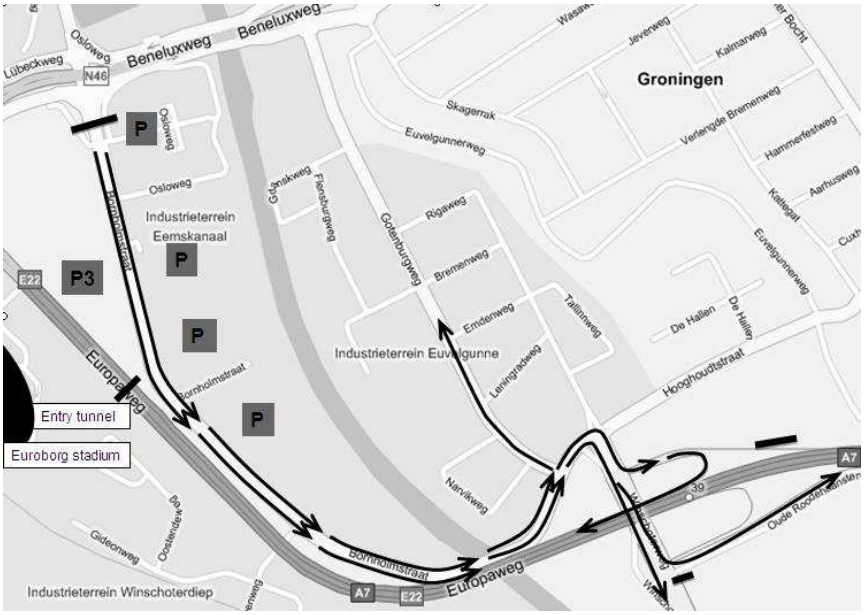

Figure 1: overview of the situation, with arrows indicating traffic streams (4 possible directions).

Figure 2: Traffic signs, pre-announcement (left), stating: Choose driving lane (Kies rijbaan) and sign at weaving section (right).

Emergency services were instructed to use the cycling lanes parallel to the Bornholmstraat in case of emergency. The emergency control room had been informed and had received the research plans. A command post along the test track was manned with police, local authorities, traffic control manager and one of the investigators.

2.2. Design

During the half-time break, the stadium speaker announced the deviant traffic situation telling people to act just as they would do in normal traffic, following signs by traffic controllers and signs. Participants were kindly asked to complete the questionnaire that was distributed after the soccer match with a potential bonus of winning two VIP tickets for a future FC Groningen soccer match.

After the match, 1,800 envelopes were handed out in the entry tunnel (see fig. 1), containing a return envelope, an accompanying letter with room for the participants to fill in their contact information and a short questionnaire (for an extended report, see [13]).

2.3. Questionnaire

The questionnaire started with general questions about age, gender, driver, destination, and number of persons in the car. The subsequent nine questions were multiple-choice question on how participants had felt during the adjusted traffic situation, to what extent they understood what had happened and how they actually had behaved. The questionnaire contained some space for voluntary remarks.

2.4. Participants

In total 754 out of 1,800 questionnaires were returned (41.9%), whereof 35 participants stated not to have parked at the Bornholmstraat, 23 respondents were under 18 (no drivers' license), and 6 questionnaires were returned blank. These questionnaires were removed from the data, rendering 690 usable questionnaires (38.3% out of 1,800). Some 80% (553 of 690) stated they had driven the car themselves. Average age was 47.1 (sd 12.6), the oldest participant was 85; 581 (84.2%) were male, 104 (15.7%) were female; 1 person did not report gender. All participants had a destination within reasonable distance, i.e. the Northern provinces Groningen, Friesland or Drenthe. On average, 2.5 people were in the motor vehicle; a maximum of 6 was reported.

2.5. Registering traffic flow

To be able to estimate traffic density, cars were counted per driving lane in blocks of 5 minutes between 12.30 and 14.00 P.M. On September 14th and November 9th, similar control registrations were conducted to estimate the normal situation.

3. Results

3.1. Questionnaires

To analyze how well people had understood the signals concerning lane choice, the participants' destination was compared to the reported lane of choice. This was possible for 609 respondents due to the fact that some had not filled in either of those questions. In total 253 respondents had chosen the left lane, 370 cars had driven in the right lane. In sum, 483 respondents appeared to have chosen the lane responding to their destination, 126 had apparently made the wrong choice (20.7%).

Of 690, 59.1% respondents said the traffic signs had helped them to choose the right lane, 14.8% was neutral, 26.1% reported the signs were of no help in determining lane choice; 61.5% reported traffic controllers were helpful

in route choice, 12.6% was neutral, while 25.8% responded traffic controllers had not been of any help. Responses to both questions did not differ significantly for drivers / non-drivers.

In the remark section, a few respondents reported not having seen any traffic signs, whereas some respondents said there were too few. Most of the uncertainties concerned the weaving section, people did not know where it started and they sometimes did not dare to cross the cones because of the many police cars. Some respondents did not understand that both lanes could be used. Traffic controllers did their jobs well, although some respondents complained about them not being familiar to the area.

3.2. Safety and comfort, self-report

Three questions were asked about the extent to which the contra flow situation made the respondents pay more attention to traffic, feel unsafe and feel insecure. One question was about how often participants had changed lanes. Most reported hardly having changed lanes (74.3%), while 9.6% responded neutrally and 16.0% reported to have changed lanes often. Table 1 gives an overview of the relationship between these four questions (Spearman's Rho correlation coefficients).

Table 1: Spearman's Rho correlation coefficients between lane change, paying attention, feeling unsafe and feeling insecure based on self-reports.

	Lane change	Paying attention	Feeling unsafe	Feeling insecure
Lane change	-	0.06	0.24*	0.29*
Paying attention	0.06	-	0.08	0.18*
Feeling unsafe	0.24-	0.08	-	0.66*
Feeling insecure	0.29	0.18	0.66*	-

* significant ($p < 0.05$)

Free space reporting showed that many respondents thought the large amounts of pedestrians in the area were dangerous. It was mentioned that a situational change alone leads to more careful driving and thus increased safety. Based on possible differences in these data, there was no reason to believe that drivers (80%) and non-drivers (20%) differed in their reports.

3.3. Traffic flow

The counts of baseline and test day are shown in Fig. 3. It is clear that leaving the area took about 10 minutes extra in the test, compared to the baseline setting. The number of vehicles per hour (vph) can be measured in several ways, all slightly imprecise because of the short test duration (approximately 90 min). The "truth" for the baseline count lies somewhere between 1,575 vph (measured over the full 90 min) and 2,400 vph (maximizing, between 30 and 65 minutes). In the contra flow condition, the count amounts to somewhere between 1,425 vph (90 min) and 2,150 vph (30 – 65 min). Total road capacity in the contra flow condition was about 10% less than normal (two lanes in two directions). Another possible comparison between the normal and the contra flow situation lies in the the second southbound driving lane gain (the reversed lane). Normally, the one lane capacity lies somewhere between 800 (90 min) and 1,300 vph (30 to 65 min). The second lane gain is then 65% (maximizing) to 82% (90 min). A third way to compare is by looking at maximum traffic flow. For baseline conditions, that is 132 per five counting minutes on the south bound lane, and during the contra flow condition 194 over two south bound lanes. The road capacity gain is then (194-132)/132*100%=47%.

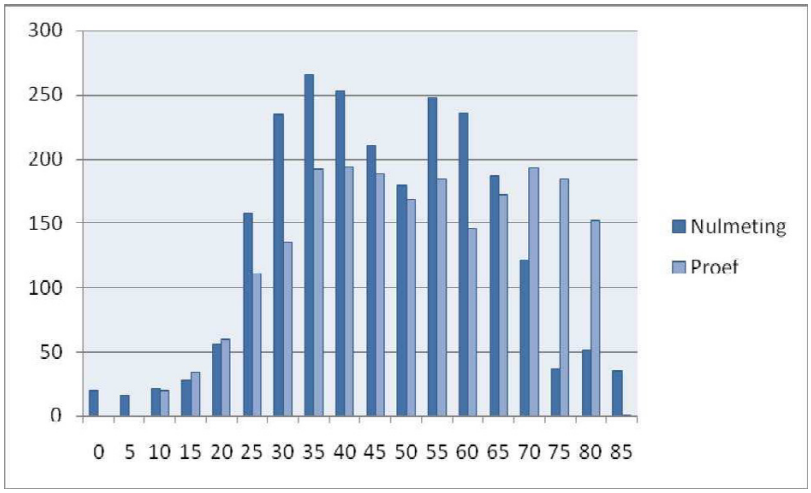

Figure 3: Counts of cars per 5 min for both lanes together, for baseline (dark, "Nulmeting") and contra flow (light, "Proef") conditions. Time=0 is at 15 minutes before end of game.

4. Discussion

Dutch literature on how evacuations in the Netherlands can be enhanced using contra flow is rather scarce. In an analysis on traffic data in two large scale evacuations in the US, Wolshon [10] recommends conducting research on how contra flow roads compare to normal roads in both evacuation and baseline conditions. That type of study is hard to conduct in the Netherlands without realistic evacuations, a condition that is not easily created ethically sound, although the 1995 Ooijpolder case might be considered an example. The present study provides a surrogate evacuation situation which can be used to fulfill the recommendation by comparing actual contra flow traffic to normal traffic and asking participants about their experiences.

In the present study it was of primary importance to keep traffic as safe as possible. Therefore, 25 traffic controllers were hired who would not have been present in a real evacuation situation. An intersection just before the end of the Bornholmstraat led to occasional stops in the evacuation flow for leaving through a few cars. Furthermore, some stores were open on Sunday October 5th, with a few customers of a builder's merchant mingling in traffic on the Bornholmstraat. These facts compromise external validity, while it remains unclear how contra flow works in real emergency situations as well.

4.1. Behavior

Almost three-quarter of the participants had chosen the correct lane to exit the Bornholmstraat, which could perhaps be improved by removing the cones, by better weather conditions and removing or better indicating the loose weaving area. However, 60% of participants indicated that traffic signs and controllers had been helpful in finding the right lane.

About 45% of participants reported paying better attention to traffic in the contra flow situation than they would have done otherwise. This somewhat low percentage could be due to the fact that many people already pay attention very well in dense traffic, therefore not improving it in the present, dense situation.

People felt safe and secure, possibly because of the large amount of traffic controllers and police. Also, traffic moved relatively slowly. Low correlations between paying attention and feelings of safety and security and lane changing stem from the flat distribution of the responses. The weak but significant correlation between lane change and feelings of (un)safety ($r=0.24$) may indicate that often changing lanes leads to insecurity or stems from it. The same can be concluded from the correlation between changing lanes and feelings of (in)security. Safety and security show a strong correlation ($r=0.64$), indicating differences but overlap as well.

In consistency with the 1995 Ooijpolder experiences, it may be concluded that on a relatively short track no big problems are foreseen concerning the people's attitude to contra flow; participants felt safe and secure enough and there is no indication of paying less attention.

4.2. Traffic flow

From the counts it is clear that contra flow capacity gains are somewhere between 47% and 82%. The fact that this margin is fairly large stems from the short road section used and from the fact that there is no unambiguous way to determine the number of vehicles per hour. Comparison with US findings therefore is difficult. US road design and size, people and measurements are quite different from those in the Netherlands. On the other hand, capacity gains for a second outbound driving lane correspond quite well to US measurements.

4.3. General recommendations

Several matters are important for the application of contra flow. In this specific study, the bad weather was probably a cause of the bad traffic sign visibility. It may safely be assumed that if this study would had been done at night, an even higher percentage of drivers would have chosen the wrong lane. Furthermore, there would have been

fewer possibilities for monitoring and control, so safety would have been compromised. It is therefore strongly recommended to apply contra flow only during day time, if feasible.

The termination point at the end of the Bornholmstraat worked quite well. Traffic participants could choose their driving lane corresponding to their destination, and were thereby given ways to take control of the situation. Traffic divided well at the designated point and was able to continue driving most of the time. Disturbances were the occasional crossing traffic and sometimes the traffic controllers, who could not always prevent participants from stopping and asking questions, causing a traffic flow halt. Shortly, any form of crossing traffic should be avoided and traffic participants should not be given the chance to ask questions in order to enhance traffic flow.

Weaving itself did not appear to be a problem; it merely seemed to be the information supply concerning the place to weave. A weaving section should be well announced and marked, thus making people feel free to weave at the proper time and place, and doing so safely.

4.4. Further research

The present study provides a preliminary view of contra flow operation and what people think of it, but it is also an onset for further research. Remaining questions concern the comparison of American to Dutch research. Futhermore, Wolshon's question remains: how does current research compare to a real emergency evacuation? Other questions are about traffic signs; what is needed, how to make them understandable, unambiguous and notable? The latter is quite relevant, because a lot of people in a real contra flow situation will try and leave an area they know very well, so they think they know how to travel and potentially do not pay much attention to traffic signs.

It also would be interesting to see what is needed in case of contra flow on much longer road tracks. In a contra flow system setup for road work study, Martens et al. [14] found that in setups longer than 8 kilometers, crash risk increases. To what extent does this assertion apply to contra flow setups at evacuations? Additionally, when contra flow distance increases, toilet and fuel services should be taken in consideration. Finally, the data from this small scale study can not be copied to a large scale emergency evacuation. Before doing that, it should be investigated what is needed to evacuate, for example, a large city.

4.5. Conclusion

Obviously, the results of this study are not only applicable to (flooding) evacuations, but also to providing an area exit to large amounts of vehicles in a short time frame, like at large scale events. The traffic flow increase estimates as gained by applying contra flow can run up to 80%.However, traffic safety should always be considered more important than the speed of evacuating an area.

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