Validation of a Signalization Scheme for Road Works at a Roundabout (Simulator Study)

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Abstract

Safe work zones are very important to road authorities. The European Parliament emphasizes this and "*Calls on the Commission to ensure that road work sites are made safer through guidelines for designing and equipping sites […]; calls for guidelines, which should include proper signing, removal of original road markings […]"*. The Flemish Agency for Roads & Traffic created different standard signalization schemes which ought to be used at road work sites. One of these schemes deals with the signalization of road works at a roundabout. Goal of this study was to test the comprehensibility of the proposed signalization by means of a driving simulator and to evaluate if drivers could reach the destination.

Fifty participants drove seven different routes (3.5 km) in a randomized order fixed-base simulator (NADS MiniSim™). The scenarios consisted of a realistic Flemish road in which the signalization scheme was implemented. Drivers were instructed to drive as they normally do and to drive to one of four destinations. The western roundabout branch was closed because of road works and participants needed to follow a detour. The route choice behavior of the participants at two decision points was qualified as correct or incorrect.

Across scenarios, 23% to 90% of the participants could reach the destination. Based on these results, several recommendations were provided. One important adaptation was recommended in the route where participants needed to use the roundabout clockwise (only 23% did this correctly). Drivers who did not comply to the signalization instructions in this situation, verbally gave the comment that the information at the advance direction sign in this route was not clear. Therefore, we suggest to modify the advance direction sign at this place. Another recommendation is to change the general temporary direction signs "detour" by specific temporary direction signs which state the municipality name.

Keywords

Driving Simulation; Road Works; Detour; Rerouting; Roundabout

1. Introduction

A large part of the current road network was built more than 50 years ago and the infrastructure is nowadays heavily used. Therefore, maintenance and an upgrade of the road network in the immediate future will occur more frequently than in the past [1]. Work zones imply temporary modified and complex road geometry with small warning times [2]. This explains why improving safety and operational efficiency of traffic flows at work zones is one of the major challenges in traffic engineering [3]. The European Parliament voted a resolution on 27 September 2011 on European road safety 2011-2020 which highlights work zone safety (article 59) as an action area and *"Calls on the Commission to ensure that roadwork sites are made safer through guidelines for designing and equipping sites, which should be standardized, as far as possible, at the European level, so that motorists are not faced with new, unfamiliar circumstances in each country; calls for guidelines, which should include proper signing, removal of original road markings, use of protective fencing and barriers, marking lane routing with warning beacons or bend signs and markings, voiding very narrow bends and ensuring safety at night"* [4].

In the past, a lot of European studies have already treated various aspects of road work zones and Flanders was a partner is this. The ARROWS project (Advanced Research on Road Work Zone Safety Standards in Europe) aimed to develop a unified range of applicable road work zone safety measures and principles that should govern the planning, design, implementation and operation of road work zones. Furthermore, a practical handbook with guidance to network managers at all levels was produced in this project [5]. In 2013, the STARs project (Scoring Traffic at Road works) aimed to optimize network availability, road worker as well as user safety during road works. A methodology to score road works schemes and a practical tool which can be used by contractors and contracting authorities in planning and assessing road works was developed [6]. The BRoWSER project (Baselining Road Works Safety on European Roads) aimed to reduce risks to road workers with an objective of Zero Harm. The project collected accident data during road works and gave recommendations for harmonizing work zones layouts across Europe [7]. Finally, the ASAP project (Appropriate Speed Saves All People) focussed on effective speed management measures for road work zones [8].

In Belgium, the legal basis for the categorisation of road works is determined by a federal Ministerial Decree from May 7th, 1999 concerning the signing of road work activities and other obstructions on public roads. The regulation describes the measures that should be applied for each of the six categories of road works and, within each category, for each zone. Regional rules (e.g. Flanders) provide further detailed information on how road work activities should be signalized for different site characteristics. For example, in Flanders, the standard tender specifications (in Dutch: "Standaardbestek 250") is used as a guide to build the signing scheme for signing of the more typical road works layouts and the regional service orders (in Dutch: "dienstorders") complement the standard tender specifications [9], [10].

The Flemish Agency for Roads & Traffic created different standard signalization schemes which should be used at road work sites. One of these schemes deals with the signalization of road works at a roundabout where the speed is between 50 and 90 km/h (category 2). As indicated before, already a lot studies were done regarding road works, but few of these studies paid attention to detours and rerouting during road works. This driving simulator study focuses on the tactical information for road users and not on the strategic information (cfr. hierarchical model of Michon [11]). In the tactical level (also called manoeuvring level or guidance level), decisions are taken within a few seconds and one falls back on rules. The objective of this paper is to investigate the effectiveness of the proposed signalization scheme in terms of the short term rerouting instructions.

For traffic signs, the effectiveness is very important. This depends on some critical characteristics which result in the action of the driver [12]. (a) The position of the sign relative to the road, the color, the contrast, etc. influences the *detection of a sign*. The signalization scheme works with temporary orange advance direction signs. The theoretical principle behind this is to maximize the change of an appropriate action under unexpected and dangerous circumstances [13]. (b) The *sign readability* is influenced by the size of the letters, the amount of information units of the message, the position of the message field relative to the road, etc. (c) Drivers should readily understand a sign's intended message (*sign comprehension*). It is very important that drivers are aware of the diversion route in time so drivers' decisions and actions are optimized [14].

1.1 Signalization scheme

In Belgium, and other right-hand driving countries, drivers should take a roundabout counterclockwise. As can be seen on Figure 1, due to the road works, in this study, the left branch is closed (purple area). Depending on the direction, drivers should take the roundabout clockwise (coming from the north and heading to the south or east (there is a physical guide in terms of lane separation signs to force the clockwise behavior) and coming from the east and heading to the south (there is no physical guide to force the clockwise behavior)) or counterclockwise (normal behavior at a roundabout). Temporary traffic lights will guarantee no conflicting traffic at the roundabout.

The standard signalization scheme does not contain municipality names at the (advance) direction signs but uses alphabetical letters. However, in reality, and in the simulation used in this study, municipality names are used (X = Bekkevoort, Y = Kortenaken, Z = Geetbets, T = Glabbeek). In the scheme, the northern, eastern and southern branch contains some specific temporary signs like a notice board road works, speed limit signs, lane separation signs, advance direction signs, detour signs, …

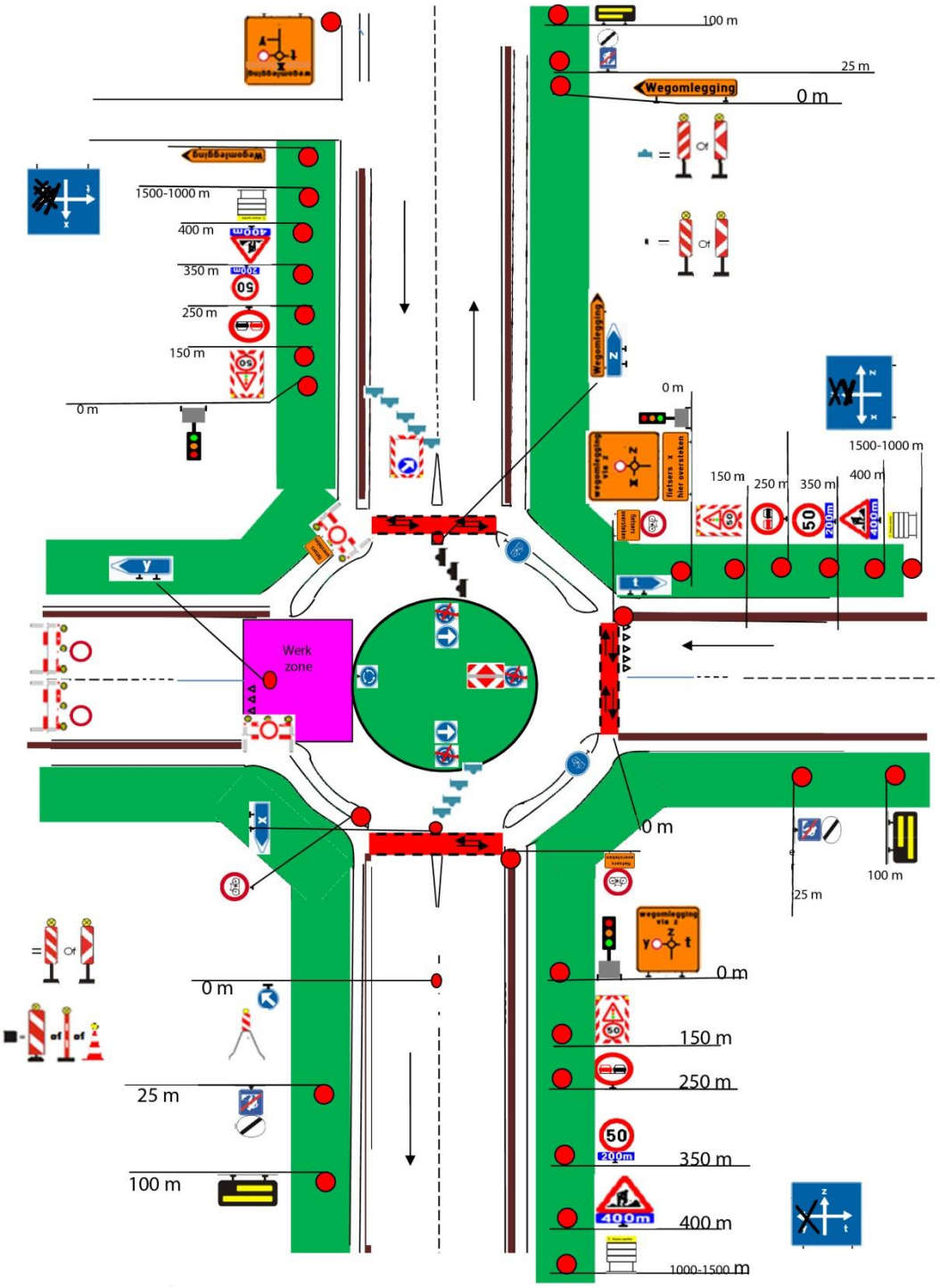

Figure 1: Standard signalization scheme

Next to some joint signs for each branch, specific orange advance direction signs are placed. These post mounted signs (cantilevers), are located alongside the road. According to Belgian regulation [15], the sign needs the be placed at the start of the detour if the driver could not proceed his normal route. In the signalization scheme, this is provided 100 m in front of the 3-way intersection at the northern branch (coming from the north) and next to the temporary traffic light at the southern and eastern branch (Figure 2). Furthermore, in front of (just after) the 3-way intersection, coming from the roundabout and heading to the north (coming from the north and heading to the roundabout), a general temporary "detour" sign is placed (left panel of Figure 7). Finally, also some lane separation signs are used at the northern and southern branch of the roundabout (Figure 3). These separations serve, for drivers coming from the north, as a physical guide to take the roundabout clockwise. The

normal blue advance direction signs, which are placed at 200 m in front of the intersection or roundabout [15], are adapted by taping the direction which is not accessible (Figure 4).

Figure 2: Specific temporary signalization at each branch (left: next to the temporary traffic light at southern branch (in front of the roundabout); middle: next to the temporary traffic light at eastern branch (in front of the roundabout); right: 100 m in front of the 3-way intersection at the northern branch (heading to the roundabout))

Figure 3: Temporary lane separation signs in the immediate vicinity of the roundabout (left: next to the temporary traffic light at southern branch (in front of the roundabout); middle: next to the temporary traffic light at eastern branch (in front of the roundabout); right: next to the temporary traffic light at northern branch (in front of the roundabout))

Figure 4: Regular blue advance direction signs with taped direction placed 200 m in front of the roundabout (left: southern branch; middle: eastern branch; right: northern branch)

2. Methodology

2.1 Participants

A varied sample in the Flemish region was recruited by means of social media, phone calls, flyers, etc. Fifty volunteers participated in the study and all gave informed consent. Two participants suffered from simulator sickness resulting in a total sample of 48 participants (aged 20 to 69; mean age = 37.9; *SD* = 16.9; 63% male). Participants had a car driving license for an average of 17.8 years (range 1 to 48 years; *SD* = 16.6). 44% of participants drove more than 15 000 kilometres a year, while the average in Belgium for 2015 was 15 151 km[16]. All had (corrected to) normal vision. The study was approved by the ethical review committee of Hasselt University. Participants received a gift voucher from a bookstore (€15) as a reward for their participation.

2.2. Apparatus

Focus groups and expert panels of road users and professionals may be excellent tools to evaluate design choices, and researchers should be able to utilize simulations and visualizations [17]. After expert judgement, some small adaptations were done on the provided signalization scheme (Figure 1 is the used scheme of the simulation). There were five experts from road authorities, researchers and consultants with all relevant

experience in signalization. The medium fidelity fixed-base driving simulator (NADS MiniSim™; version 2.0) of the Transportation Research Institute of Hasselt University was used. The vehicle dynamics were only visual and audible, thus no kinesthetic feedback was given to the participant. The mock-up consisted of a force-feedback steering wheel (Logitech G27) and pedals. Drivers used the automatic gearbox and had full control over their vehicle. The visuals were displayed on a 140° screen by means of three tv screens offering a total resolution of 4800 x 1024 pixels and a 60 Hz refresh rate. The dashboard with speedometer and tachometer was displayed on a fourth screen below the other screens. The two side mirrors and rearview mirror were visualized on the tv screens containing the driving environment. A sound system provided the sound of traffic in the surrounding environment and the participant's car.

Figure 5 NADS MiniSim™ (version 2.0) driving simulator of the Transportation Research Institute of Hasselt University

2.3 Procedure and scenario

After the introduction of the experiment by the researcher and completion of the informed consent and a questionnaire related to some demographic questions, the researcher explained the working of the simulator. There was a warming-up session of 2.5 km to acquaint drivers with the driving simulator. First, the driver needed to drive on a straight road, and had to stop and accelerate a few times. Next, there were a few small and large curves. After this, a second warming-up session was started. In this, the participant needed to take a roundabout to get familiar with this.

Each participant drove 7 experimental trips of each approximately 3.5 km (except scenario 4: 1.5 km) in a randomized order to cancel out order and potential learning effects [18]. For each drive, we instructed participants to drive as they normally do and to head for one of the four destinations (Kortenaken, Geetbets, Glabbeek and Bekkevoort). During the trips, the researcher did not influence the participants and noted all the verbal comments of the driver. Table 1 presents an overview of the experimental design. Two routes were not evaluated because there was no difference with the situation without road works (south > east and east > north). Route 1 and route 2 are also routes without changes to the normal situation, but we want to test if there were mistakes in decisions at the 3-way intersection. At each decision point (roundabout and/or 3-way intersection), participants' route choice was monitored as correct or incorrect.

Realistic scenarios were created with a typical Flemish road. There was randomly generated traffic in the opposing direction. At the roundabout itself, the temporary traffic light was always at green for the participant, and there was no opposing traffic neither there was a queue at the roundabout.

Table 1: Experimental design

Origin	**Destination**			
	South (Bekkevoort)	**West (Kortenaken)**	**North (Geetbets)**	**East (Glabbeek)**
South (Bekkevoort)	n/a	Route 1	Route 2	//
West (Kortenaken)	n/a	n/a	n/a	n/a
North (Geetbets)	Route 3	Route 4	n/a	Route 5
East (Glabbeek)	Route 6	Route 7	//	n/a

3. Analysis and Results

Table 2 gives an overview of the correct decisions. Depending on the route, 23% to 90% of the participants could reach the destination.

- Route 1: Bekkevoort > Kortenaken: All participants made a correct decision at the roundabout (straight ahead at the roundabout; counterclockwise) while 19% did not take the 3-way intersection correctly (they went straight ahead instead of taking the 3-way intersection to the left).
- Route 2: Bekkevoort > Geetbets: As in route 1, 100% was correct at the roundabout, but 12% made a mistake at the 3-way intersection (to the left instead of straight ahead).
- Route 3: Geetbets > Bekkevoort: Participants first encountered the 3-way intersection and only one person made a mistake and went to the right (2% was wrong). At the roundabout, 11% made a mistake and tried to take the roundabout counterclockwise (2 out of 47) while this was not possible because of road works or took the branch to Glabbeek (3 out of 47).
- Route 4: Geetbets > Kortenaken: 17% of the participants went straight ahead at the 3-way intersection while it was necessary to went to the right (coming from the north). The simulation was stopped when they made a wrong decision at the 3-way intersection because reaching the destination was not possible anymore.
- Route 5: Geetbets > Glabbeek: Similar to route 3 (and 4), participants first encountered the 3-way intersection and only one person made a mistake and went to the right (2% was wrong). At the roundabout, 9% made a mistake. 3 out of 47 tried to take the roundabout counterclockwise (while this was not possible) and one person took the branch to Bekkevoort.
- Route 6: Glabbeek > Bekkevoort: 77% (37 out of 48) made an incorrect decision at the roundabout (23% correct) and took the branch to Geetbets instead of to Bekkevoort. In this route, participants needed to take the roundabout clockwise while normally, as in most European countries, this is counterclockwise (see Figure 6). The simulation was individually terminated if a participant entered the roundabout not complying with the signalization provided.
- Route 7: Bekkevoort > Kortenaken: Only one person was wrong at the roundabout (2%) while most participants (98%) used the roundabout as intended (counterclockwise in this case). At the 3-way intersection, 15% made a wrong decision (7 out of 47) and went straight ahead.

Table 2: Overview decisions

Route	Correct decision at roundabout	Correct decision at intersection	Destination reached
Route 1: south > west *Bekkevoort > Kortenaken*	100% [48 out of 48]	81% [39 out of 48]	81% [39 out of 48]
Route 2: south > north *Bekkevoort > Geetbets*	100% [48 out of 48]	88% [42 out of 48]	88% [42 out of 48]
Route 3: north > south *Geetbets > Bekkevoort*	89% [42 out of 47]	98% [47 out of 48]	88% [42 out of 48]
Route 4: north > west *Geetbets > Kortenaken*	N/A	83% [40 out of 48]	83% [40 out of 48]
Route 5: north > east *Geetbets > Glabbeek*	91% [43 out of 47]	98% [47 out of 48]	90% [43 out of 48]
Route 6: east > south *Glabbeek > Bekkevoort*	23% [11 out of 48]	N/A	23% [11 out of 48]
Route 7: east > west *Glabbeek > Kortenaken*	98% [47 out of 48]	85% [40 out of 47]	83% [40 out of 48]

4. Discussion

The clockwise behavior at the roundabout was problematic for most of the participants when this was not guided by means of some physical separation signs. There was no physical guide in terms of lane separation signs in route 6 and 77% display incorrect behavior in that route. Twenty-five out of the thirty-five participants (68%) who made an incorrect decision at the roundabout in route 6, made the verbal comment that it was not clear that the roundabout was not complete and that it was allowed to take the roundabout clockwise. This means that the sign was not comprehensible which results, according to Lay [12], in a low effectiveness and consequently a wrong action of the driver. Also, in route 3 and 5, participants needed to take the roundabout clockwise, but, in these routes, there was a physical guide by means of lane separation signs (see Figure 3). This resulted in less incorrect behavior at the roundabout (respectively 11% and 9%).

Another important finding was the incorrect behavior at the 3-way intersection when the destination was Kortenaken (i.e. the west: route 1, route 4 and route 7). The percentage of correct decisions varied there between 81% and 85% (Table 2). When looking at the total number of encounters with the 3-way intersection in this study ($N = 287$), it can be concluded that 11% of them made an incorrect decision. 69% of those who were wrong (twenty-two out of thirty-two), spontaneously verbally commented that it was better to have specific temporary direction signs which state the municipality name instead of the general temporary direction signs "detour" (in Dutch: "wegomlegging").

In route 2, four out of the six participants (67%) who were wrong at the 3-way intersection, verbally commented that they followed the general detour sign (i.e. detour sign to the left at the 3-way intersection) while this was not needed in route 2. In route 3, the person who was wrong at the 3-way intersection made the same comment.

5. Conclusions

This validation approach seemed to be very useful to test a standard signalization scheme. Based on the results, we can conclude that not all of the proposed advance direction signs were comprehensible. We provided several recommendations (these are not exhaustive) and the Flemish Agency for Roads & Traffic has changed the scheme:

- The most important adaptation was needed if participants needed to use the roundabout clockwise, and only 23% did this (route 6). 68% of the drivers who were wrong verbally gave the comment that the information was not clear. The right panel of Figure 6 gives an overview of the correct and incorrect decisions (destination was "Bekkevoort") and also two suggestions to change the advance direction sign are given. One possibility is to change the advance direction sign next to the temporary traffic light by means of a sign which indicates that there is a central island before the roundabout. By doing this, it becomes clear that drivers with the direction of "Bekkevoort" should go to the left in front of the central island. Furthermore, this will be beneficial for trucks because the turning circle becomes better. Another possibility is to place, at the central island of the roundabout, specific temporary direction signs to the left and right with the municipality names on it (visualized with municipality names X, Y and Z on Figure 6).

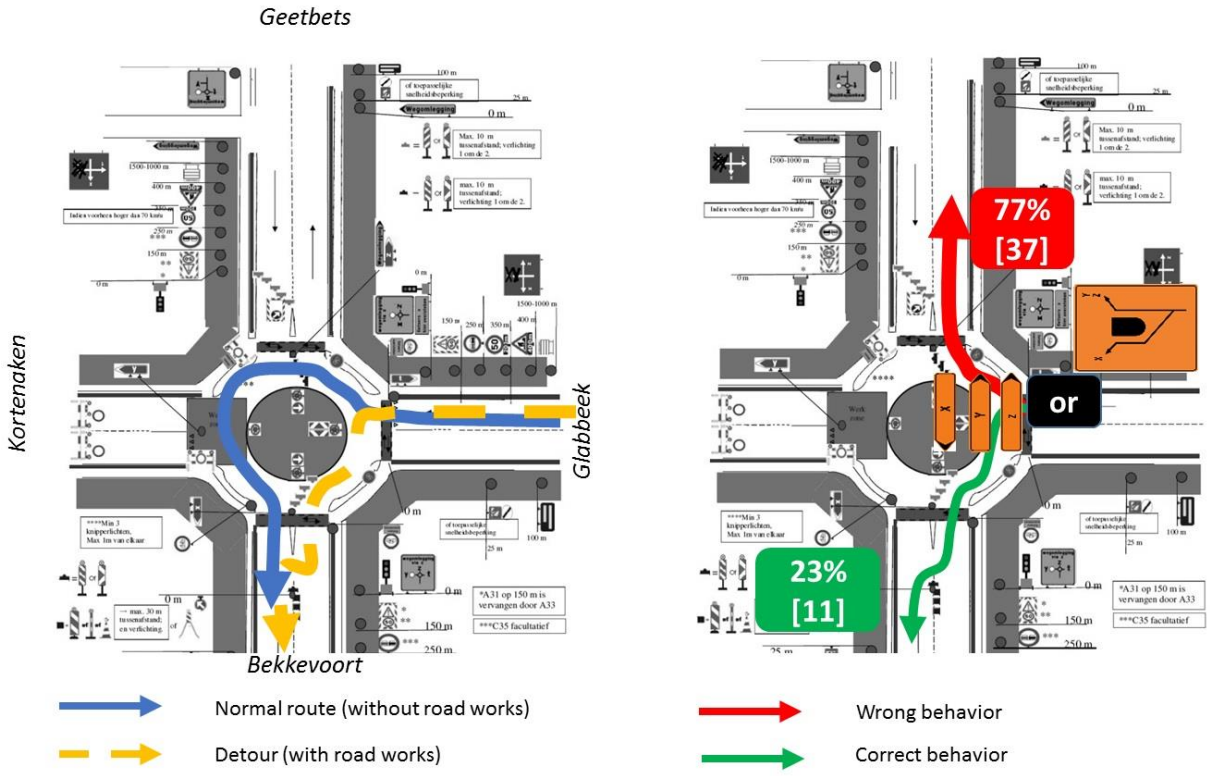

Figure 6: Route 6 (left: route at the roundabout (without and with road works); right: wrong and correct behavior + suggestions for improvement)

- Changing all the general temporary direction signs "detour" (in Dutch: "wegomlegging") by specific temporary direction signs which state the municipality name (Figure 7). This recommendation was especially important at the 3-way intersection (11% made an incorrect decision).

Figure 7: General temporary "detour" sign (left) & Specific temporary sign with municipality name "Y" (right)

- Placing the lane separation signs in such a way that it is not possible to drive thru it (smaller gap between the signs).

The general conclusion of this study is to make detour signs as clear as possible (clear instruction for unfamiliar behavior (taking a roundabout clockwise)) and as specific as possible (temporary direction signs with the municipality name).

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