# Video analysis of traffic conflicts on flooded roads

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## Introduction

This study focuses on the question of how road users behave in the case of a heavy rainfall event. The behaviour of road users during heavy rain events is relevant to find out whether a targeted temporary retention of rainwater in the road space is justifiable from the point of view of road safety. A targeted temporary retention of precipitation water in the road space is a possible measure to react to the increase in heavy rainfall events due to climate change. The increase in heavy rainfall events results from the intensification of the hydrological cycle, which is associated with global warming (IPCC 2013). Benden (2014) has already shown that the targeted and controlled inclusion of traffic areas helps to ease the flooding problem.

## Research Approach

Due to the increase in heavy rainfall events, it is essential to develop new options for rainwater management. Therefore, it is necessary to create places where a temporary retention of precipitation water is possible. In densely populated cities, roads occupy a large share of the settlement area. For this reason, road spaces play an important role in the temporary retention of water during and after heavy rain events. As some studies (e.g. Benden (2014)) have already shown in theory, the targeted and controlled inclusion of traffic areas helps to ease the flooding problem. In order to find out about the impact this has on traffic safety, the study focuses on the traffic behaviour during floodings.

## Research Method

Since heavy rainfall events are rare, local and unpredictable events, it is not easy to implement targeted monitoring to clarify the question of how road users behave in flood situations. For this reason, a selection of videos from the video portal YouTube is used to analyse the traffic flows on flooded inner-city streets. The selection of YouTube videos goes back to the works of Mettmann et al. (2016) and Hölsch (2018), in which the behaviour of road users in flood situations was already investigated. The evaluation of the behaviour of the road users in both works was based on the traffic conflict technique. Mettmann et al. (2016) distinguished between standard conflicts, which also occur in normal or dry conditions, and conflicts, which only arise due to the water on the roadway. Hölsch (2018), on the other hand, does not investigate the conflicts themselves, but rather the behaviour of road users in relation to the flooded road section. Concerning the behaviour of road users, she distinguishes between conflict avoidance behaviour and conflict confrontation behaviour.

The analysis methods of Mettmann et al. (2016) and Hölsch (2018) will now be combined within the framework of this study in order to be able to make as precise a statement as possible on the behaviour of road users in a flood situation in the road area. The video material from YouTube which consists of 60 videos, showing traffic sequences on flooded roads in urban environments, is viewed for a total of almost 4 hours. Altogether, 371 individual events are used to statistically evaluate the behavior of road users on flooded roads and to perform a traffic conflict analysis. A differentiation is made between standard conflicts and conflicts, which only occurred due to the water on the road. As forms of behaviour towards flooded street sections, a distinction is made between conflict avoidance behaviour, conflict confrontation behaviour and behaviour in between. The conflict avoidance behaviour includes turning in front of the flooded area, bypassing this area widely and reversing in front of the flooded area. In conflict confrontation behaviour, however, the conflict with the flooded section is sought, which is why accelerating, braking and driving fall under this form of behaviour. Between these two forms of behaviour lies evasion and waiting (figure 1).

| **conflict avoidance behaviour** | **conflict confrontation behaviour** | **behaviour in between** |
|---|---|---|
| turning | accelerating | evasion |
| bypassing | braking | waiting |
| reversing | driving | |

*Figure 1: Behaviour towards flooded road sections*

In the traffic conflict analysis, different conflict severities are distinguished. A differentiation is made between “interaction”, “light conflict”, “serious conflict” and “accident”. The classification of conflict severity is based on the criteria of traffic conflict technology.

In addition to the behavioural forms and the conflict types, the speed of the road users is also considered and an assessment of their adaptability to the flooding situation is given. Since aquaplaning only occurs at speeds above 60 km/h (Herrmann 2008), the 60 km/h limit is particularly important. To determine the influence of the water level on the roadway, the height of the water on the roadway is also estimated.

**Research Findings**

Regarding the aspect of speed it became clear that road users are slow on flooded roads (figure 2).

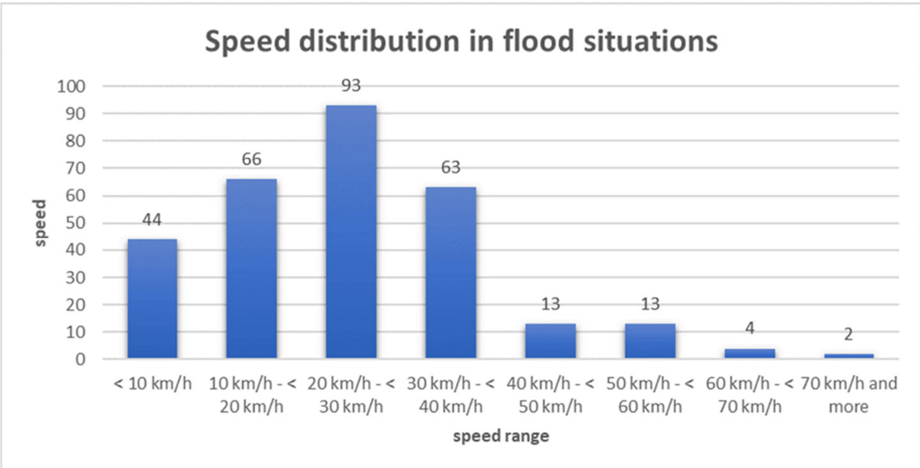


*Figure 2: Speed distribution in flood situations*

Since aquaplaning only occurs at speeds above 60 km/h (Herrmann 2008), the 60 km/h limit is particularly important. Only 2 % oft the road users were registered with speeds above 60 km/h. For this reason, only few conflicts occured. If the conflicts that have occurred are differentiated according to their conflict severity, about 2/3 of the conflicts can be assigned to the "accident" conflict category. The remaining conflicts are mainly "interactions". "Light conflicts" and "serious conflicts" are almost non-existent. If conflicts arose, then that were usually conflicts due to the water (figure 3). These conflicts due to the water are often single accidents. They could be traced back to an exceeding of the vehicles‘ ground clearance, resulting in a water hammer. A water hammer occurs at a motor vehicle when the mudflat depth of the vehicle is exceeded. The mudflat depth of motor vehicles is usually between 30 cm and 50 cm (Kramer et al. 2016). That is why with increasing water depth almost exclusively conflicts occur due to the water on the road. Besides, the probability of a water hammer rises with increasing water depth.

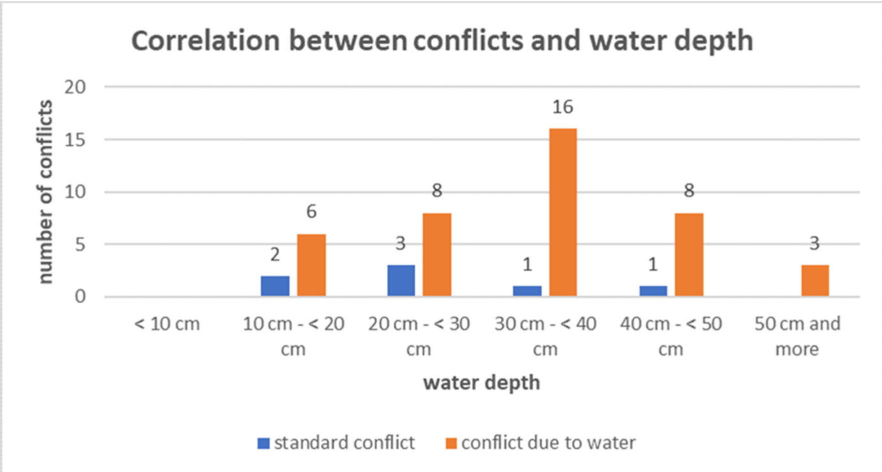


*Figure 3: Correlation between conflicts and water depth*

The conflict frequency is also considered in relation to rainfall intensity, route type and road category. With regard to rain intensity, it can be stated that conflicts occur predominantly in light and heavy rain, while the percentage conflict frequency for medium rain and no rain is significantly lower. The underpasses are particularly conflict-prone in the case of track types. Free routes are somewhat less prone to conflict and the lowest number of conflicts is registered at junctions. Regarding the road category, main roads with a built-up area are more prone to conflict than main roads without a built-up area or access roads.


*Figure 4: Conflicts by conflict type*

A further investigation of the conflicts takes place in such a way that the conflicts are subdivided into the conflict types "bending/crossing conflict", "conflict in longitudinal traffic", "turning", "avoidance", "other conflict" and "left behind" (figure 4). With a total of 28 conflicts, more than half of the conflicts fall into the category "left behind", which refers to a single accident resulting from a water hammer.

In the videos examined, 78% of road users show a conflict confrontation behaviour towards flooded road sections. A conflict avoidance behaviour or a behaviour between the conflict confrontation behaviour and the conflict avoidance behaviour is only shown by 11% of the road users. If only water depths of up to 20 cm are considered, the proportion of road users with a conflict confrontation behaviour is as high as 83%. The proportion of road users with a conflict confrontation behaviour is also higher if there is no vehicle in front.

## Conclusion and perspective

From the point of view that is concerned with traffic safety, a targeted temporary retention of precipitation water is justifiable up to a water depth of 20 cm. Up to this water level, a retention can be regarded as uncritical since road users drive slowly on flooded roads and the risk for water hammers is low. In order to test the actual implications of a targeted temporary retention of precipitation water in road space under real-life conditions, the implementation of pilot sites is planned.

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