Submerged vehicle crashes

SWOV Fact sheet, February 2021

SWOV Fact sheets contain concise relevant knowledge on topics within the road safety themes and are updated regularly. Recently updated SWOV Fact sheets can be found on swov.nl/fact-sheets.

Summary

In the Netherlands, on average, more than 50 people die every year in a submerged vehicle crash. More than two thirds die from drowning. The casualties are mainly car occupants, while cyclist and mobility scooter fatalities are also numerous. Casualties are mostly male and aged 18-24. Despite the large number of casualties, not much is known about possible causes of crashes in which vehicles end up in the water. Foreign studies show that alcohol and drug use, and/or speeding are often involved.

There are two ways to prevent fatalities in submerged vehicle crashes. Firstly, by preventing vehicles from ending up in the water at all; for example by means of barriers along open water. Secondly by having occupants leave their submerged cars as soon as possible. Public service advertising may increase knowledge about escape strategies. However, it is uncertain whether, in stressful situations, people will practise what was taught and whether they will not automatically act instinctively. Electric car windows that open automatically upon contact with water may be effective in increasing chances of survival for the car occupants.

1 How many casualties are caused by submerged vehicle crashes?

Every year, more than 50 people die (8.5% of the total number of road deaths in the Netherlands) in a submerged vehicle crash (*Figure 1)*. About 70% of them die by drowning, and about 30% either from other causes, such as the impact of the vehicle hitting the water, or from undetermined causes (e.g. if death by drowning could not be determined) (source: Statistics Netherlands, edited by SWOV).[1]

1. Statistics Netherlands base the number of fatalities of submerged vehicle crashes on their causes of death statistics, court proceedings and, up to 2015, also on police crash registration BRON. SWOV expanded this selection with injuries coded T75.1 (injuries caused by drowning and non-fatal submersion) indicated in the causes of death statistics.

Drowning is a logical cause of death in fatal submerged vehicle crashes. Foreign research also shows that most casualties die by drowning and not from injuries sustained by the impact of their vehicle hitting the water [1] [2]. Research by Stjernbrandt et al [2] showed that 92% of the casualties had a MAIS score[2] of 2 or lower caused by the impact itself. Hammet et al [3] and Wintemute et al [4] found that most injuries should not have prevented casualties from escaping. The casualties would most probably have survived if they had not drowned. Yet, it is unclear whether non-life-threatening (head) injuries limited their capacity to escape the vehicle.

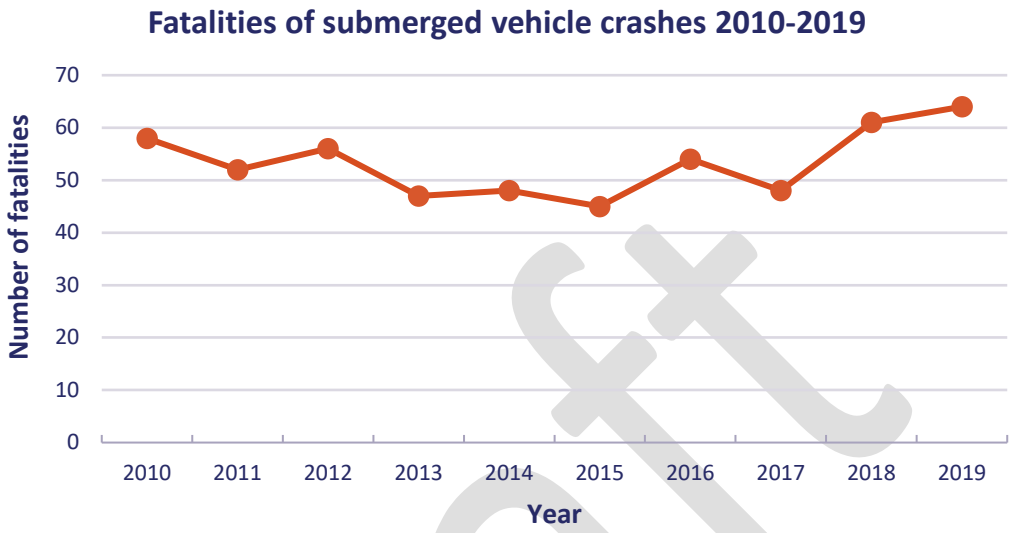

Figure 1. Number of fatalities of submerged vehicle crashes in 2010-2019. Source: Statistics Netherlands, edited by SWOV.

2 What are the characteristics of submerged vehicle crashes?

Data available about submerged vehicle crashes in the Netherlands provide information about a number of characteristics, such as vehicle category, and casualties' age and gender. Unfortunately, further breakdown of the data is impossible.

Vehicle category

Between 2010 and 2019, submerged vehicle crashes mainly affected car occupants (*Figure 2*), but cyclists and mobility scooter users were also frequent casualties.

2. MAIS is an international measure to indicate injury severity. The score can be derived from patients' injury codes. Examples of MAIS2 injuries are bone fractures and concussion accompanied by unconsciousness.

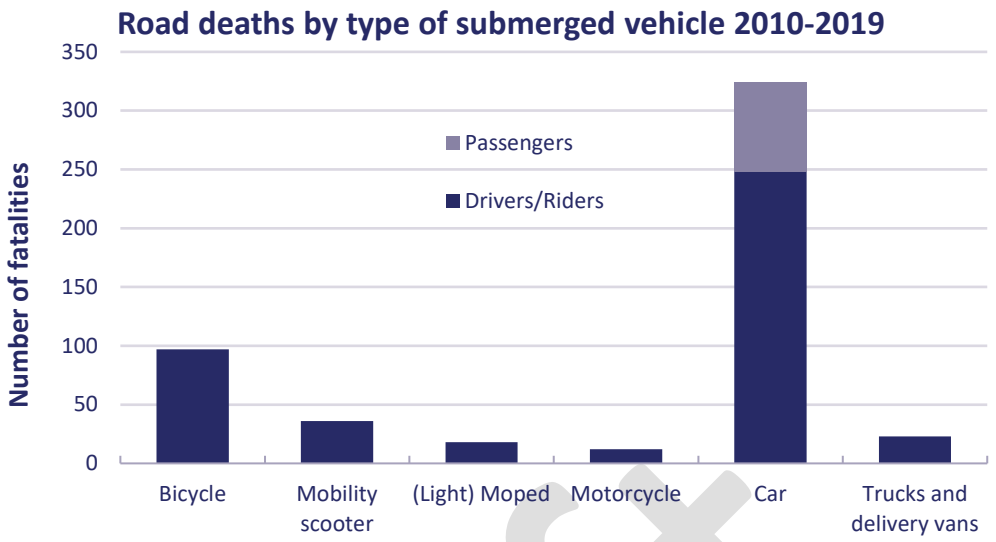

Figure 2. Modes of transport of all road deaths in submerged vehicle crashes in 2010-2019. Note: the categories pedelec, microcar and other/unknown were not provided by Statistics Netherlands because of recognisability; the number of casualties in these categories amounted to less than 10. Source: Statistics Netherlands, edited by SWOV.

Age

Figure 3 shows that casualties were particularly numerous among 18-24-year olds.

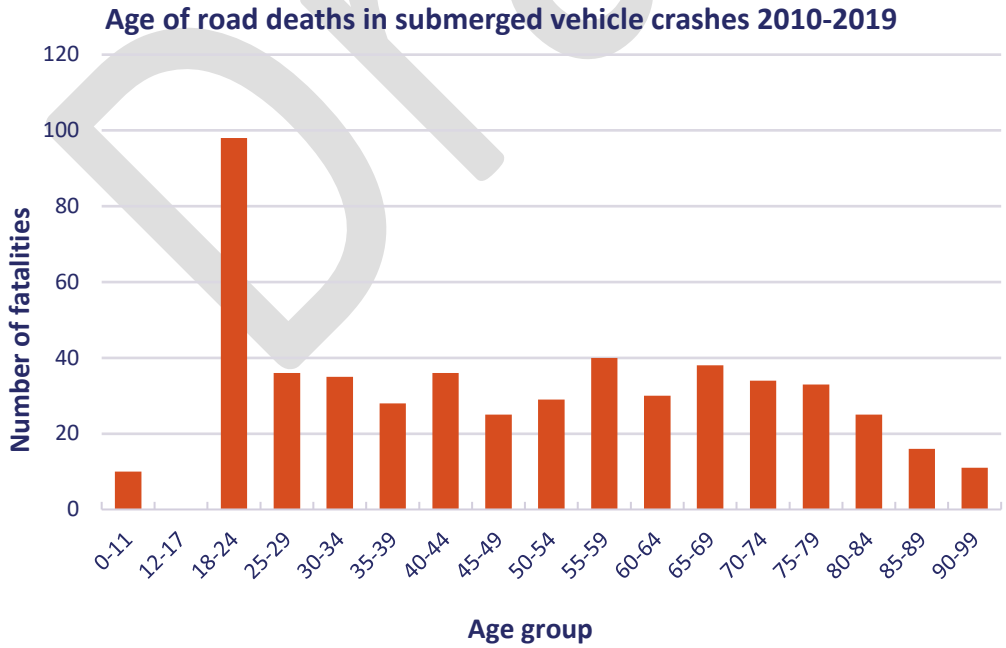

Figure 3. Ages of all road deaths in submerged vehicle crashes in 2010-2019. Note: age group 12-17 comprises fewer than 10 fatalities whose data were not provided because of recognisability. Source: Statistics Netherlands, edited by SWOV.

Gender

Male fatalities of submerged vehicle crashes are overrepresented. Statistics Netherlands data show that, between 2010 and 2019, 407 men and 124 women died in a submerged vehicle crash in the Netherlands (*Figure 4)*.

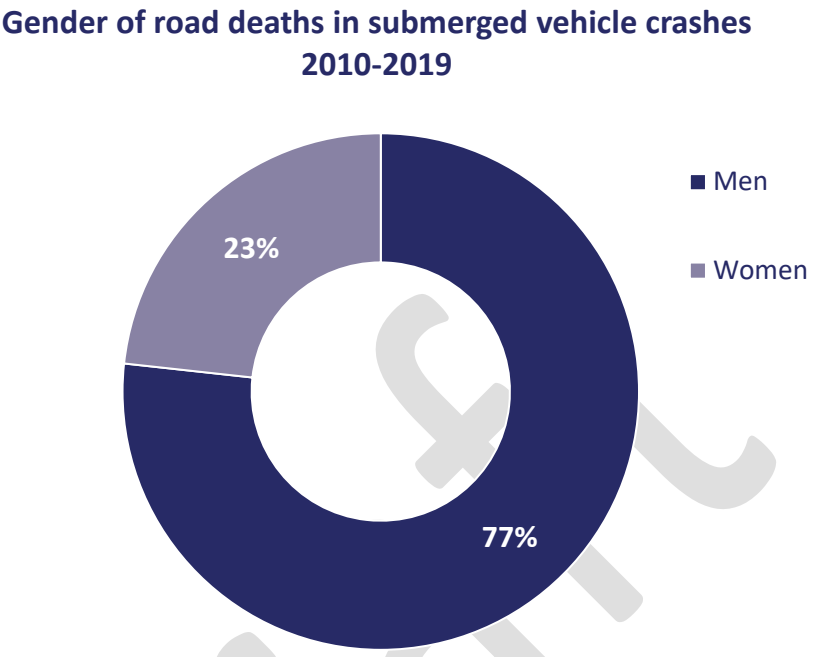

Figure 4. Gender of road deaths in submerged vehicle crashes in 2010-2019. Source: Statistics Netherlands, edited by SWOV.

Stjernbrandt et al. [2] found that, in Sweden, 69% of fatalities were male, among which 78% were male drivers. Female fatalities more often concerned passengers: 54% of them are women, 18% men [2]. These figures can mostly be explained by male and female traffic exposure. In the Netherlands, men drove a daily average of 28 kilometres while women drove 22 kilometres. What is more, women are passengers twice as often as men [5]. The gender split in submerged vehicle crashes therefore corresponds to that of the total number of road deaths in the Netherlands.

3 What are possible causes of submerged vehicle crashes?

Not much is known about causes and effects of submerged vehicle crashes in the Netherlands. Yet, on the basis of foreign research, something can be said about factors that may be at play. We should bear in mind that it is unclear to what extent these factors are also relevant for the Netherlands.

Drowning

Although drowning does not cause crashes, it is the reason why submerged vehicle crashes often end badly and end up in crash statistics. (Foreign) research shows that most casualties in submerged vehicle crashes do not have injuries that should preclude escape [2] [3] [4]. These casualties could most probably have survived the crash if they had not drowned. Car occupants are most at risk of death by drowning on account of the wrong choices made in panic [1]. Instead of a speedy exit through the car window, they will call emergency services, try to open doors (whether or not by first waiting for the car to fill), or hope that an air bubble in the car will save them. Being unable to swim or not knowing what to do are other possible problems. In addition, ending up in the water inside one's vehicle is very stressful. The longer one stays put, the more psychological stress will increase. This will result in hyperactivity, hypoactivity and/or inefficient decision-making [6].

Alcohol and drugs

It is unknown what part alcohol plays in submerged vehicle crashes in the Netherlands. A Swedish study showed that, in these crashes, 32% of drivers were under the influence of alcohol with an average level of 1,8g/L (three times the legal limit). In addition, 28% of drivers were under the influence of drugs [2]. In two American studies, different percentages were found: a 2011 study found 44% were drink-driving [7] and a 1990 study even found that 74% had consumed alcohol [4].

Speed

Direct information about the role of speeding in submerged vehicle crashes is missing. A Swedish study did however show that, in 10 out of 64 studied submerged vehicle crashes, guard rails did not provide sufficient protection when cars drove at too high speeds[2].

Causes of submerged bicycle crashes

According to the paragraph *What are the characteristics of submerged vehicle crashes?*, a significant share of fatalities (almost 10 a year) was cycling when ending up in the water. Unfortunately, it is unknown under what circumstances they ended up in the water and why they could not reach safety. Foreign research does not provide this information about cyclists either.

Causes of submerged mobility scooter crashes

In-depth research into mobility scooter crashes in the Netherlands shows that a rather large share (one seventh) is involved in a submerged vehicle crash [8] [9]. These crashes occur because the mobility scooter user is startled into accelerating instead of braking. This usually happens during special manoeuvres such as parallel parking. Once in a while, a mobility scooter user is forced to brake for a vehicle in front, but mistakenly accelerates instead and is forced to swerve and subsequently hits the water. The in-depth study showed the crash outcomes to be limited to, at most, minor injuries (MAIS score 1), since casualties are helped to safety by bystanders.

4 How to prevent casualties of submerged vehicle crashes?

Prevent submerged vehicle crashes

Of course, the best solution to prevent casualties of submerged vehicle crashes is to make it impossible for vehicles to end up in the water. Firstly, by not planning roads along waterways. If there is no alternative, the distance between the road and the water should be maximised. In this, the obstacle-free zone recommended by CROW could serve as a guideline.

In addition, a well-positioned barrier may help prevent submerged vehicle crashes. A Swedish 2008 study showed that in 46% of submerged vehicle crashes no barrier was present. In 23% of them, the barrier was not correctly positioned, and/or inadvertently functioned as a ramp because of an inadequate layout. The barrier ends often sloped to the ground, which guided or catapulted cars to the wrong side of the guard rail.

Finally, all measures that prevent submerged vehicle crashes may help, such as road signs and (profiled) road marking, rumble strips and a load-bearing roadside [2] [10] [11]. In-vehicle systems such as Lane Departure Warning (LDW)or Lane Keeping (LKS) may prevent a vehicle going off the road. For more information, see SWOV fact sheet *Intelligent transport and advanced driver assistance systems (ITS and ADAS)*.

Ensuring a speedy exit from submerged vehicles

To increase chances of survival, vehicle occupants should exit their submerged vehicles as soon as possible. The preferred method is by rolling down the window (if possible) or breaking the window with an emergency hammer [12] and exiting that way. These actions should be carried out without delay. A vehicle sinks in three phases: floating, sinking and submersion. The vehicle will remain *afloat* until the water outside the car reaches the bottom of the windows, and during this phase it is virtually impossible to open the door because of the external water pressure. During the floating phase, an escape through the window increases the chance of survival. As soon as the water is above the bottom of the windows and the water level outside is higher than inside, the vehicle will start to *sink*. By breaking the window in this phase, the glass will wash into the vehicle, which may cause serious injuries. In the final phase, the vehicle is completely under water and *submerged*, which minimises chances of survival [12].

5 Are courses to escape a submerged car effective?

Out of concern about submerged car crashes, several courses are available to teach participants how to react. Yet, the effectiveness of such courses in unknown. When a car hits the water, its occupants will get stressed and will mostly act instinctively, possibly not practising what was taught.

6 Is public service advertising about escaping submerged vehicles effective?

People should know that, on average, they only have one minute to exit a submerging vehicle and that they do not have time to call emergency services [13]. Public service advertising may increase this knowledge (see the examples of campaigns below), but the stressful nature of a submerged vehicle crash makes it uncertain whether people will practise what they have learned.

In 2009, the Ministry of Transport, Public Works and Water Management campaigned for drivers always having an emergency hammer within easy reach. A 2010 ministry evaluation [2014] indicated that the number of respondents knowing that an emergency hammer is one's best bet for escaping a submerging car had risen from 28% to 38%. The share of drivers having an emergency hammer in their cars increased from 51% to 55%.

Before and after the Canadian campaign 'Operation ALIVE', students filled in a questionnaire about what to do when their vehicles hit the water. In 2006, before the campaign, 52% had indicated the need for a speedy exit. In 2010, this percentage increased to 76%. The 2010 survey did, however, coincide with a tragic submerged vehicle crash that was widely reported, which make it harder to draw firm conclusions about the (net) effect of the campaign [6].

7 How effective is an emergency hammer?

To increase one's chances of surviving a submerged vehicle crash, a speedy exit through the window is paramount. An emergency hammer may be used to break the window and/or cut the seatbelts. Several versions of emergency hammers are now available, such as ResQME or Lifehammer Evolution, which require less effort to break a car window. It is unknown to what extent vehicle occupants are able to reach safety by using these hammers effectively in a stressful emergency. What is clear, however, is that it is often impossible to open the car door because of the water pressure outside the vehicle. In 2008, research by the Dutch national road authority showed that, in a submerging vehicle, there is a fair chance that windows and doors cannot be opened since the water adversely affects the often electronically operated windows and door locks [15]. Particularly car models equipped with an intelligent system such as a 'CAN-bus' are thus affected. There are no indications that this has changed fundamentally since the 2008 study.

8 What other measures are possible?

Obviously, the best solution to prevent casualties of submerged vehicle crashes would be to make them physically impossible (also see the question *How to prevent casualties of submerged vehicle crashes?*). Infrastructural measures, for example by shielding the water by means of barriers, are therefore most effective. Lane Departure Warning (LDW) or a Lane Keeping System (LKS), which warns or steers back vehicles threatening to leave their lanes, may also prevent submerged vehicle crashes. For more information, see SWOV fact sheet *Intelligent transport and advanced driver assistance systems (ITS and ADAS)*.

If a vehicle does end up in the water, the best chance of survival is a speedy exit from the vehicle. A potentially effective vehicle adjustment which may be helpful is the implementation of electric windows which automatically open upon contact with water. In a pilot study by Giesbrecht et al. [12] a test was done with a window that automatically opens upon contact with water or opens when the car remains afloat in an upright position. The underlying assumption is that, in case of stress, panic or ignorance, occupants may forget what to do but will be reminded of the need for a speedy exit by the automatically opening window. In addition, the open windows may enable possible bystanders to help occupants escape. However, the pilot concerned a prototype which has not yet been further developed or documented.

Finally, a minimum vehicle requirement should be that door locks and electric windows always keep functioning; also in submerging vehicles. At present, there is no regulation concerning this requirement, whereas a relatively simple adjustment could facilitate direct window control instead of use of the water-sensitive CAN-bus [15].

Publications and sources

Below you will find the list of references that are used in this fact sheet; all sources can be consulted or retrieved. Via Publications you can find more literature on the subject of road safety.

1]. McDonald, G.K., Moser, C.A. & Giesbrecht, G.G. (2019). *Public knowledge, attitudes and practices of vehicle submersion incidents: a pilot study*. In: Injury epidemiology, vol. 6, p. 21.

[2]. Stjernbrandt, A., Oström, M., Eriksson, A. & Björnstig, U. (2008). *Land motor vehicle-related drownings in Sweden*. In: Traffic Injury Prevention, vol. 9, nr. 6, p. 539-543.

[3]. Hammett, M., Watts, D., Hooper, T., Pearse, L., et al. (2007). *Drowning deaths of U.S. Service personnel associated with motor vehicle accidents occurring in Operation Iraqi Freedom and Operation Enduring Freedom, 2003-2005*. In: Military Medicine, vol. 172, nr. 8, p. 875-878.

[4]. Wintemute, G.J., Kraus, J.F., Teret, S.P. & Wright, M.A. (1990). *Death resulting from motor vehicle immersions: the nature of the injuries, personal and environmental contributing factors, and potential interventions*. In: American Journal of Public Health, vol. 80, nr. 9, p. 1068-1070.

[5]. CBS Statline (2020). Mobiliteit; per persoon, persoonskenmerken, vervoerwijzen en regio's CBS. Accessed on 08-01-2021 at https://opendata.cbs.nl/statline/#/CBS/nl/dataset/84709NED/table?dl=48F9F.

[6]. McDonald, G.K. & Giesbrecht, G.G. (2013). *Vehicle submersion: a review of the problem, associated risks, and survival information*. In: Aviation, space, and environmental medicine, vol. 84, nr. 5, p. 498-510.

[7]. Austin, R. (2011). *Drowning deaths in motor vehicle traffic accidents*. Paper Number 11-0170. National Highway Traffic Safety Administration NHTSA.

[8]. Davidse, R., Duijvenvoorde, K. van, Louwerse, R., Boele-Vos, M., et al. (2018). *Scootmobielongevallen: karakteristieken, ongevalstypen en kansrijke maatregelen om de veiligheid te verbeteren. Een dieptestudie naar scootmobielongevallen op de openbare weg*. R-2018-15A. SWOV, Den Haag.

[9]. Davidse, R., Duijvenvoorde, K. van, Louwerse, R., Boele-Vos, M., et al. (2018). *Scootmobielongevallen: Hoe ontstaan ze en hoe zijn ze te voorkomen?* R-2018-15. SWOV, Den Haag.

[10]. Davidse, R.J., Doumen, M.J.A., Duijvenvoorde, K. van & Louwerse, W.J.R. (2011). *Bermongevallen in Zeeland: karakteristieken en oplossingsrichtingen. Resultaten van een dieptestudie [Run-off-road crashes in the Province of Zeeland: characteristics and possible solutions. Results of an in-depth study]* . R-2011-20 [Summary in English]. SWOV, Leidschendam.

[11]. Davidse, R.J. (2011). *Bermongevallen: karakteristieken, ongevalsscenario's en mogelijke interventies. Resultaten van een dieptestudie naar bermongevallen op 60-, 70-, 80- en 100km/uur-wegen [Run-off-road crashes: characteristics, crash scenarios and possible interventions. Results of an in-depth study of run-off-road crashes on 60, 70, 80 and 100 km/h roads]*. R-2011-24 [Summary in English]. SWOV, Leidschendam.

[12]. Giesbrecht, G.G., Percher, M., Brunet, P., Richard, Y., et al. (2017). *An automatic window opening system to prevent drowning in vehicles sinking in water*. In: Cogent Engineering, vol. 4, nr. 1.

[13]. Giesbrecht, G.G. & McDonald, G.K. (2010). *My car is sinking: automobile submersion, lessons in vehicle escape*. In: Aviation, space, and environmental medicine, vol. 81, nr. 8, p. 779-784.

[14]. Minister van VenW (2010). *Informatie inzake verkeersveiligheid t.b.v. het algemeen overleg 12 mei 2010*. 29398-224. Ministerie van Verkeer en Waterstaat, Den Haag.

[15]. Buning, L.R., Kessels, J.F., Merts, M., Pauwelussen, J.P., et al. (2008). *Raambediening en deurvergrendeling. Effect van water op het functioneren van raambedieningen en deurvergrendelingen*. Ministerie van Verkeer en Waterstaat, Directoraat-Generaal Rijkswaterstaat, Dienst Verkeer en Scheepvaart DVS, Delft.

Colophon

Reproduction is allowed with due acknowledgement:
SWOV (2021). *Submerged vehicle crashes*. SWOV Fact sheet, February 2021. SWOV, The Hague.

URL Source:
https://www.swov.nl/en/facts-figures/factsheet/submerged-vehicle-crashe

Topics:
Transport mode – Passenger car; Transport mode – Bicycle; Infrastructure

Figures:

Prevent crashes
Reduce injuries
Save lives

SWOV

SWOV Institute for Road Safety Research

PO 93113

2509 AC The Hague

Bezuidenhoutseweg 62

+31 70 317 33 33

info@swov.nl

www.swov.nl

@swov / @swov_nl

linkedin.com/company/swov