IDENTIFYING 16000 UNSAFE CURVES ON STATE ROADS IN SWEDEN

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1. Introduction

In January 2019, six young tourists from Switzerland died as their minivan entered a hidden sharp curve and skidded on the slippery snowy road into the oncoming lane on Rd 395 in Sweden. There the minivan collided with a 90-ton High Capacity Truck, fully loaded with iron ore. The Swedish Association of Road Transport Companies (SÅ) ordered an expert investigation of the (lack of) safety in the curve. The resulting report [1] concluded that improper design of the horizontal curve alignment and crossfall - in combination with way too high curve speed limit - were strong contributing factors to the horrible crash. The report caught interest from the Swedish National Television (SVT). On Sep 25th, the SVT investigative weekly show *'Uppdrag Granskning'* (UG) broadcasted a one-hour in-depth TV-episode on the tragic crash [2]. The next day, SVT released results from a unique investigation, where their team of data journalists had identified 16 000 unsafe curves on state roads in Sweden, using the method from the SÅ-report but with big data [3]. Regional and local news all over Sweden broadcasted news about the unsafe curves on the local roads, including videos from test drives and interviews with locals at some of the unsafe curves. This is probably the largest data journalistic in-depth road data mining research in the world, so far. It was performed with methods for analysis of hazards on rural roads that were presented in a paper [4] at the HVTT11 symposia in Melbourne 2010. This paper presents experiences from the data journalistic research. The paper demonstrates how presentation of accurate road data, available publicly, can be well analyzed and assist in improvements in road safety outcomes. Similar research is feasible to achieve in many more countries.

Keywords: Horizontal curvature, adverse cambered curves, crossfall, cornering force, lateral friction, point mass model, high speed outside offtracking, pavement width, road widening in curves, road roughness, rut bottom cross slope variance, drainage gradient, macrotexture, split friction.

2. Research approach

An expert-report [1] on the curve with the tragic crash where six tourists died made a strong impact on the Swedish National Television (SVT UG) team, as they realized that it is possible to calculate whether a car driving in a curve will stay on the road or not. When designing new safe roads, road agencies worldwide use a basic formula for analyzing cornering forces acting on a simple point mass model. As described by Granlund (2010) [4] at the HVTT11 symposia, analysis of crash risk in existing curves can be made by using the same formula in 'rearward mode'. The formula then calculates the lateral friction demand to keep a vehicle safely on the road, based upon data on horizontal radius in the curve, on cross slope of the lane, and the curve speed (speed limit). Finally, the resulting parameter 'Side friction demand' is evaluated against the road agency´s limit values for side friction supply. Figure 1 shows the side friction demand, calculated from measured horizontal curvature, crossfall and posted speed limit at the Curve of Death on Road 395. In order to make the side friction demand not exceeding the design value for side friction supply, the speed limit must be reduced from 90 km/h to 60 km/h, see Granlund (2019) [1].

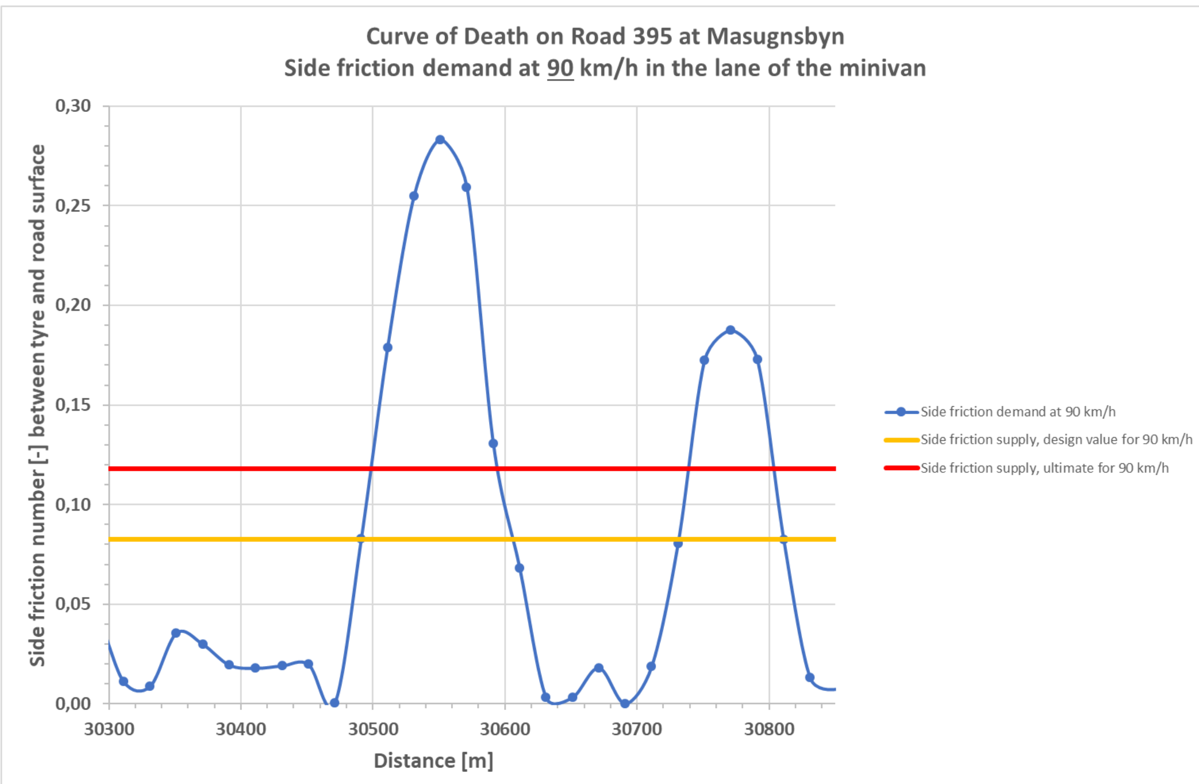

Figure 1 - Side friction demand and supply at the sharp and S-shaped Curve of Death

In order to collect geometric data and speed limits for all paved state roads in Sweden, the SVT UG team downloaded existing measured road data from the Swedish Transport Administration´s (STA) open Pavement Management Systems database '***PMSv3***' [5.a], or - to be more correct – from the STA open Application Programming Interface [5.b]. The SVT team collected data for all registered road traffic crashes with human injuries, by downloading crash data from the Swedish Transport Agency's confidential database '***STRADA***'. The confidential dataset on crashes was downloaded from an open website published by the National Society for Road Safety [6]. The SVT team first filtered away road sections with less five crashes in the last five years. After that, road sections with less than 70 km/h speed limit, as well as road sections with a central crash barrier was filtered away. Furthermore, road sections with roundabouts and other junctions where filtered away. The remaining sections where chopped into straight sections and horizontal curves. For each curved section, the side friction demand was computed as described below. Each curve where the side friction demand exceeds the limit value for side friction supply, where classified as an unsafe curve.

The SVT UG team also contacted the Swedish National Road and Transport Research Institute (VTI) and got the institute to reconstruct the full skid crash into the oncoming heavy goods vehicle (HGV), by using VTI´s unique car driving simulator.

3. Results

The data journalistic research is reported in detail by Andersson et al (2019) [7]. After the above described filtering, some 26 000 km of state roads were analyzed. The roads were analyzed in a 100 m window that was moved in 20 m steps. For each of the 100 m road segments, it was determined whether it was a curve or not, by using curvature limits defined on page 106 in the Swedish national guideline for road design 'VGU 2015' [8]. For segments identified as curves, the side friction demand to avoid skidding sideways while cornering was calculated as per Figure 2 and by use of Equation (1).

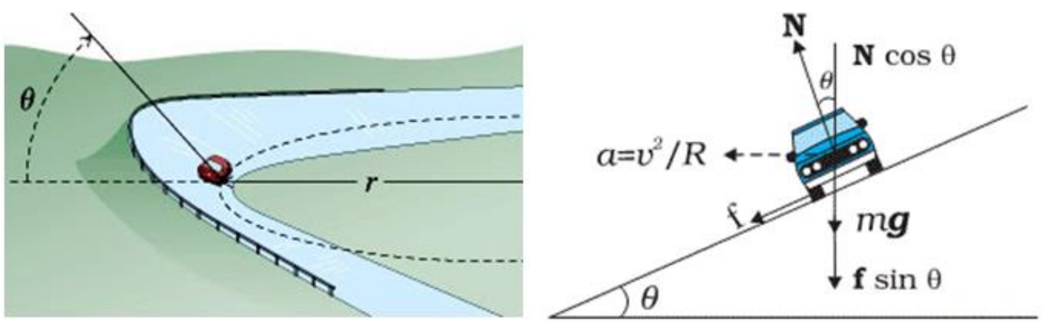

Figure 2 - Basic analysis of cornering forces, see Granlund et al (2014) [9]

$$f_s \approx \frac{v^2}{R*g} - \tan(\theta) \qquad (1)$$

In Equation (1), the side friction factor between tyre and road is denoted $\boldsymbol{f_s}$ [-], the design speed is $\boldsymbol{v}$ [m/s], curve radius is $\boldsymbol{R}$ [m], the gravitation constant is $\boldsymbol{g}$ [m/s^2], while the pavement crossfall (superelevation) is given by tangent of the angle θ, **tan(θ)** [%].

When examining all the road segments, it was found that 13 percent of the curve segments cause high side friction demand. Crash data show that 17 percent of crashes occur in these curve segments. This analysis, and numerous related analysis, show that these 13 percent curve sections are overrepresented in crashes. See Andersson (2019) [7] for details.

4. Conclusions and discussion

On Sep 25th 2019, the SVT investigative weekly show *'Mission: Investigate' (Swedish: 'Uppdrag Granskning'*, UG) broadcasted a one-hour in-depth TV-episode on the tragic crash where six tourists died [2], The episode included videos from test drives both in reality and in a large vehicle simulator [10]. Some photos from the episode are shown in Figure 3. The car driving simulator confirmed to the TV viewers in repeated tests that when driving close to the posted speed limit on normal winter road friction in the sharp adverse cambered curve, it is virtually impossible to avoid a skid crash into the oncoming HGV.

The next day, on Sep 26th, SVT released results from a unique investigation where their team of data journalists had identified 16 000 unsafe curves on state paved roads in Sweden [3]. The unsafe curves are presented as red dots on the map of Sweden presented in Figure 4. These curves are hazardous due to bad combinations of road curvature, adverse camber and too high posted speed limit. Regional and local news all over Sweden broadcasted news about the unsafe curves on roads in their area (an example is given in [11]), as well as interviews with locals at some of the unsafe curves. The Police stated publicly that the in-depth research has missed some of the roads considered unsafe by the Police Authority, including a road they claim to be the deadliest road in Västernorrland County (two drivers of heavy timber logging trucks died in single vehicle crashes in curves on that road during the autumn of 2018) and where they think that horizontal curves need to be redesigned [12]. This statement by the Police indicates that it may be possible to enhance the accuracy of the analysis method by adjusting the filtering procedure. The statement of the Police Authority also underlines that several horizontal curves on state roads have hazardous geometric properties.

It was not possible to establish traditional statistical significance for the findings, since there are just too few crashes on rural low volume roads (AADT < 1000 vehicles/day) and on medium volume roads (1000 < AADT < 4000). This fact underlines the need for more advanced analysis of safety risks on such roads, than merely looking at crash statistics. The method demonstrated in the current research, utilizing an evaluation of side friction demand, is an example of more complex road safety analysis relevant also for low volume roads.

When the Swedish Transport Administration (STA) were confronted with the conclusion that 16 000 curves are unsafe, they claimed that they must focus their road management efforts on the largest roads where most people travel. So, the roads identified in this research are not given much priority. They also said that focusing road safety actions to the curves with high friction demand is not efficient, as many other factors contribute to crashes. After the fatal crash on Rd 395, STA reduced the posted speed limit from 90 km/h to 70 km/h in the Curve of Death. The new speed limit is thereby 10 km/h higher than the curve speed where the side friction demand meets the side friction supply allowed by STA. This insufficient reduction in speed limit shows that STA seriously lacks understanding of its own standards for road safety.

After the TV-episodes in late September 2019, the Swedish government's Minister for Infrastructure, Mr. Tomas Eneroth, was interviewed on the SVT Nine o'clock news. He congratulated the SVT team for delivering important research results and said that the findings call for corrective actions at the unsafe horizontal curves.

Figure 3 – Sample photos from the TV-episode

Figure 4 – Map with the 16 000 unsafe horizontal curves on paved state roads in Sweden

This data journalistic in-depth road data mining research is probably the largest in its kind, so far.

The research was performed with methods for analysis of hazards on rural roads that were presented on behalf of The Nordic Road Association in a paper by Granlund (2010) [4] at the HVTT11 symposia in Melbourne. The HVTT11-paper presents the following road parameters that affects health and safety for occupants in passenger cars and to even higher degree in heavy good vehicles:

1. *High side friction demand due to high curvature and lack of cross slope.*
2. *Insufficient drainage gradient at outer curve transitions.*
3. *High ride vibration & mechanical shock, as indicated by International Roughness Index.*
4. *Roll and lateral truck cab vibration due to uneven deformation at pavement edge.*
5. *Low or split friction due to low and/or different macrotexture in the two wheel-paths.*

In the current research, parameter no. 1 in the list above was used as indicator of unsafe curves. These curves were found to be clearly overrepresented in the crash data. The parameters 2, 4 and 5 require data with higher spatial resolution than available from the Swedish database '***PMSv3***' (20 m average values as shortest 'step length'). These parameters could therefore not be tested in this research. An earlier study [13] have showed parameter no. 3, the IRI-value, correlates strongly with crash frequency. However, the current study was not able to clearly reproduce such correlation. This was most likely due to lack of public access to detailed data on the position for each crash. Despite the lack of detailed position data of crashes, the current research clearly demonstrates that open public data on both road properties and on crash positions can be used to create large benefits to the society, when studied by skilled big data analysts. Governments should therefore seek to publish such data as open to the public, of course after making data anonymous regarding the persons involved in crashes. Such practice has been proved feasible by the Norwegian Public Roads Administration [14], which hereby is recommended also to Swedish Authorities as well as to road agencies and authorities in other countries.

Parameter no. 1 was in the current study calculated without respect to roll-related lateral weight transfer. In HGV's with the Centre of Gravity high above the road surface, particularly trailers, the influence of weight transfer can be significant on the crash risk due to skidding as well as rollover, as shown by Granlund et al (2014) [9]. In the fatal crash on Rd 395 at Masugnsbyn, the skidding vehicle was a van/pickup hybrid vehicle with a large crew cab, not an HGV. Anyhow, when mapping unsafe roads on a road network, the relevance for heavy goods vehicle safety would be even better with a model that considers vehicle body weight transfer as presented by Granlund et al (2014).

This research is based on knowledge from numerous international references. Those references are present in a comprehensive report (in Swedish) by Granlund (2016) [15].

Acknowledgements: The expert investigation of the crash curve made by Helgums Grus AB was initiated and funded by The Swedish Association of Road Transport Companies, represented by Mårten Johansson, Göran Danielsson and Patrick Magnusson. Without your funding, there would have been no expert report, and hence no data journalistic research. The SVT team included Lena Ten Hoopen, Rickard Andersson, Helena Bengtsson, Fredrik Stålnacke and Ola Hjalmarsson. Due to SVT policy reasons, the TV team members are not allowed to participate in HVTT16. Nevertheless, this paper is attributed to the very talented and enthusiastic SVT team.

References

[1] Granlund, J. (2029). *The unsafe S-curve on road 395 at Masugnsbyn. Analysis of road data and traffic data after the fatal crash on Jan 12th, 2019.* (*Trafikfarlig S-kurva på länsväg BD 395, NV Masugnsbyn. Analys av väg- och trafikdata efter allvarlig trafikolycka 2019-01-12*).

[2] SVT 'Mission: Investigate': *The Curve of Death* (SVT Uppdrag Granskning: *Dödens kurva*). Internet 2019-11-16: https://www.svtplay.se/video/23787186/uppdrag-granskning/uppdrag-granskning-sasong-20-dodens-kurva

[3] SVT: *The unsafe road curves in Sweden* (SVT: *Sveriges osäkra kurvor*). Internet 2019-11-16: https://www.svt.se/datajournalistik/sveriges-osakra-kurvor/

[4] Granlund, J. (2010). *Reducing Health and Safety Risks on Poorly Maintained Rural Roads*. International Heavy Vehicle Transport Technology Symposia HVTT11, Melbourne, Australia. Internet 2019-11-16: http://road-transport-technology.org//Proceedings/HVTT%2011/Papers//Granlund%20-%20Reducing%20Health%20and%20Safety%20Risks%20on%20Poorly%20Maintained%20Rural%20Roads.pdf

[5.a] Swedish Transport Administration. *Pavement Management Systems database, version 3, 'PMSv3'*. Internet 2019-11-16: https://pmsv3.trafikverket.se/

[5.b] Swedish Transport Administration. Application Programming Interface. Internet 2019-11-16: https://api.trafikinfo.trafikverket.se/.

[6] Swedish Transport Agency: *Swedish Traffic Accident Data Acquisition 'STRADA'*. Accessed via the National Society for Road Safety website. Internet 2019-11-16: https://ntf.se/trafikolyckor/

[7] Andersson, R., Bengtsson, H. & Stålnacke, F. (2019). *Finding 16 000 unsafe curves.* SVT Summary of the Data Journalistic Research. Internet 2019-11-16: https://medium.com/the-svt-tech-blog/finding-16-000-unsafe-curves-427889afde8b

[8] Swedish Transport Administration. *Design of highways and streets. (Vägars och gators utformning*). VGU 2015:086. Internet 2019-11-16: https://trafikverket.ineko.se/Files/sv-SE/12046/RelatedFiles/2015_086_krav_for_vagars_och_gators_utformning.pdf

[9] Granlund, J., Haakanes, I. & Ibrahim, R. (2014). *Lowered Crash Risk with Banked Curves Designed for Heavy Trucks*. International Heavy Vehicle Transport Technology Symposia HVTT13, San Luis, Argentina. Internet 2019-11-16: http://road-transport-technology.org//Proceedings/HVTT%2013//Granlund%20-%20Lowered%20crash%20risk%20with%20banked%20curves%20designed%20for%20heavy%20trucks%20with%20high%20CoG2.pdf

[10] SVT: *Our Journalist Drives the Curve of Death at 90 km/h and Always Crashes*. (*Här testar reportern kurvan i 90 km/tim och frontalkrockar varje gång*). In Swedish. Internet 2019-11-17: https://www.svt.se/nyheter/granskning/ug/har-testar-reportern-kurvan-i-90-kilometer-i-timmen-frontalkrockar-varje-gang

[11] SVT: *One Thousand Unsafe Curves in Småland County*. In Swedish. Internet 2019-11-17: https://www.svt.se/nyheter/lokalt/smaland/tusen-osakra-kurvor-pa-smalandska-vagar

[12] SVT: *The Police Authority Says the Road Needs to be Redesigned*. (*Polisen: Vägen borde ses över*). In Swedish. Internet 2019-11-17: https://www.svt.se/nyheter/lokalt/vasternorrland/polisen-vagen-borde-ses-over

[13] Ihs, A., Velin, H. & Wikström, M. (2002). *The influence of road surface condition on traffic safety*. (*Vägytans inverkan på trafiksäkerheten)*. In Swedish. Väg- och TransportforskningsInstitutet, VTI meddelande 909. Internet 2019-11-18: https://www.diva-portal.org/smash/get/diva2:673728/FULLTEXT01.pdf

[14] Norwegian Public Roads Administration. *In-depth investigations of fatal road traffic crashes.* (In Norwegian: *Dybdeanalyser av dødsulykker*). Internet 2019-11-16: https://www.vegvesen.no/fag/fokusomrader/Trafikksikkerhet/Ulykkesdata/Analyse+av+dodsulykker+UAG

[15] Granlund, J. (2016). *Design of crossfall for reduced rollover risk at horizontal curves.* (*Utformning av tvärfall för minskad krängningsrisk i kurva)*. Report to the Swedish Transport Agency. Internet 2019-11-16: https://transportstyrelsen.se/globalassets/global/regler/jarnvag/avslutade-foi-projekt/ts-rapport-krangningsrisk-i-kurvor.pdf