Two-Car Rural Highway Collision

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This example is taken from the book Technische Analyse von Verkehrsunfällen anhand von Beispielen, but the analysis is my own and somewhat different from the analysis in the book. The German solution uses crush damage to calculate energy lost in the collision. Since I did not have access to the automobiles to assess this damage, I used, instead, the principle of impulse/momentum for my solution. In accident reconstruction impulse/momentum is the favored method, yielding usually more credible results.

Events

Two vehicles—(A) a VW Golf and (B) a VW Polo—collided on a wet asphalt highway, after dark, in light fog. On this stretch of highway, the speed limit is 100 kph. The air temperature at the time of the collision was -4°C. The Golf (A) was proceeding from left to right in the drawing, the Polo (B) from right to left. Over this stretch of roadway, the highway gently curves to the right from the standpoint of the Golf (A). The Golf (A) apparently crossed the roadway centerline and struck the Polo (B). After the collision, both cars moved upward in the drawing and struck and slid along the guardrail along the edge of the road. The post-collision skid distances are shown, measured from the collision point.

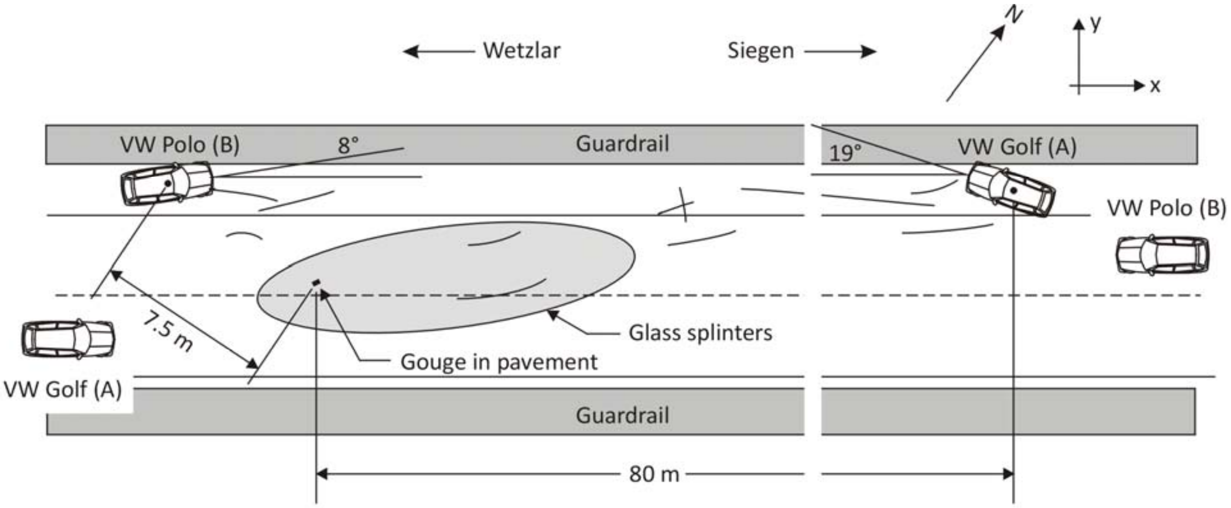

Figure 1 – Diagram of two-car collision on a highway

From the collision photos (see source) it can be assumed that the Golf (A) was aimed obliquely, at an angle of about 45° from the right at the time of collision and was skidding partially sideways at an angle of about 22.5° from the right at the time of the collision. This is illustrated in Figure 2.

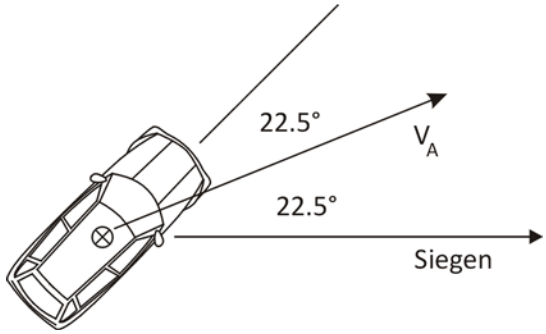

Figure 2 – Orientation of Golf (A) at time of collision

After the collision the front left tire of the Golf (A) was locked, and the two left tires of the Polo (B) were locked. The driver of the Golf (A) was seriously injured in the crash. He smelled of alcohol during the accident investigation. The driver of the Polo (B) sustained fatal injuries in the collision.

Vehicle masses

A. VW Golf – 1110 kg
B. VW Polo – 850 kg

Solution

Both cars wound up against the guardrail, so the end positions and directions of the post-collision skidding were influenced by the guardrail. From the skid marks it looks as if the Polo (B) turned through 187° and the Golf (A) turned through about 523° from its initial direction of motion.

It is difficult to get a drag factor for the post-collision skid because of the additional impact with the guardrail. Note that this will not reduce the friction force on the roadway, because the guardrail does not exert a vertical force on the cars but rather only an additional, horizontal force.

From the damage photos it looks as if the Golf (A) impacted the Polo (B) obliquely on the left front corner but with a considerable frontal component. Damage to the Polo (B) is great along its left side. Also both cars were pushed upward, toward the side of the road where the Polo (B) was proceeding. This indicates that perhaps the Golf (A) had some velocity toward the north side of the roadway. It impacted the Polo (B) along its side and provided the upward impulse. The assumed impact configuration of the automobiles is as is shown in Figure 3.

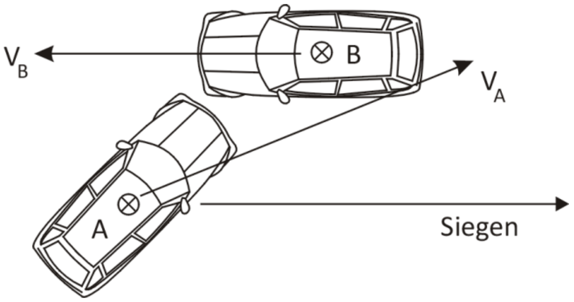

Figure 3 – Assumed initial impact configuration of both vehicles

This initial impact configuration is difficult to determine more precisely without better measurements of the vehicles. Since the road was wet and the air temperature was below freezing, this scenario is certainly feasible. The front of the Golf (A) was substantially damaged, the left front corner the worst, and the entire left side of the Polo (B) back to the rear tire was substantially damaged. So

$$\theta_{Ai} = 22.5°$$
$$\theta_{Bi} = 180°$$

Rotation of vehicles

Figure 4 shows the conjectured post-collision trajectory of both vehicles. This scenario has been assembled using the existing skid marks.

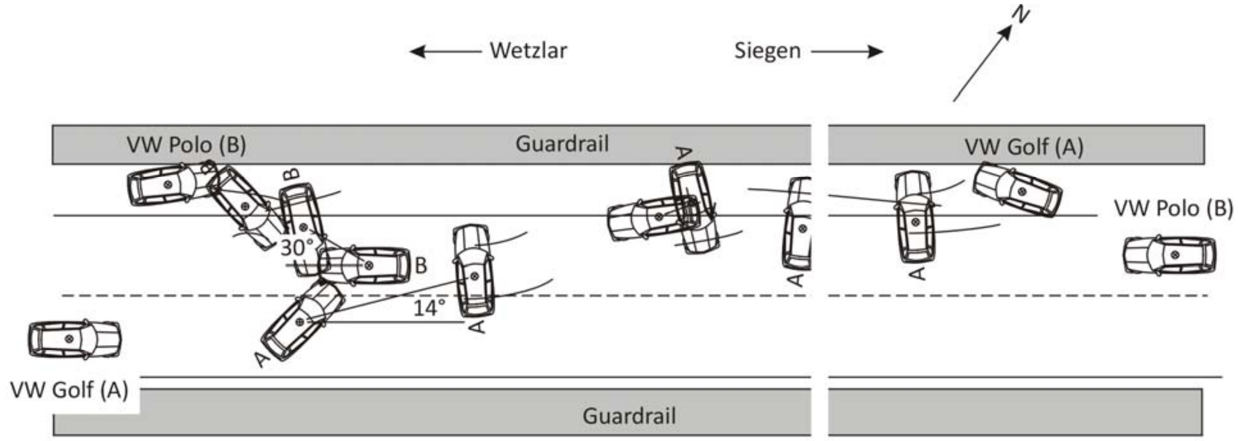

Figure 4 – Post-collision trajectories

The Polo (B) was pushed upward in the drawing by the Golf (A) and then spun around 188°. Judging from the skid marks left by the Golf (A) and the fact that the Polo (B) delivered to it a very non-direct impulse (i.e. far removed from the center of mass of the vehicle), the Golf (A) spun around a complete turn and then another 116°, its complete rotation was then 476°.

Drag factor

For the unlocked wheels, we need the average sine to calculate the drag factor *f*.

Average sine for A (476°) = 0.687
Average sine for B (188°) = 0.580

If we use a friction coefficient of 0.5 for wet asphalt and then adjust each drag factor up by 10% to account for drag force along the guardrail, the drag factors can be calculated.

$$f_{Al} = 1.10 \cdot 0.5 = 0.55$$

For the unlocked wheels we need to apply the average sine values to allow for rolling.

$$f_{Au} = 0.687 \cdot f_{Al} = 0.378$$

For the Golf (A), one wheel is locked and the other three unlocked. Assuming the weight of the car is evenly distributed on all four wheels, the drag factor for vehicle A is

$$f_A = 0.75 \cdot f_{Au} + 0.25 \cdot f_{Al} = 0.421$$

Similar calculations are used for the Polo (B) except two wheels are locked and two unlocked.

$$f_{Bl} = 1.10 \cdot 0.5 = 0.55$$

$$f_{Bu} = 0.580 \cdot f_{Bl} = 0.319$$

$$f_B = 0.5 \cdot f_{Bu} + 0.5 \cdot f_{Bl} = 0.434$$

For the force of both cars against the guardrail, assume it is 10% of the drag force caused by the pavement. For wet pavement, use $f = 0.5$. From the damage photos the two left tires of the Polo (B) are locked after the collision, the front left wheel of the Golf (A) is locked too after the collision.

Post-impact movement of vehicles

The point of impact is marked by a gouge in the pavement. Directions of post-collision velocities (θ_{Af}, θ_{Bf}) relative to direction to Siegen:

$\theta_{Af} = 14°$
$\theta_{Bf} = 150°$

Skid distances:

$d_{Af} = 80.6$ m
$d_{Bf} = 7.5$ m

Velocities:

$$\frac{1}{2} m \cdot v_f^2 = f \cdot m \cdot g \cdot d_f$$

$$v_f = \sqrt{2 \cdot \frac{1}{m} \cdot f \cdot m \cdot g \cdot d_f} = \sqrt{2 \cdot f \cdot g \cdot d_f}$$

Thus

$$v_{Af} = 92.9\ kph\ @\ 14°$$

$$v_{Bf} = 28.8\ kph\ @\ 150°$$

Linear momentum is preserved in both the *x* and *y* directions, so

$$m_A \cdot v_{Aix} + m_B \cdot v_{Bix} = m_A \cdot v_{Afx} + m_B \cdot v_{Bfx}$$

The Polo (B) had no initial *y* velocity, so

$$m_A \cdot v_{Aiy} = m_A \cdot v_{Afy} + m_B \cdot v_{Bfy}$$

$$v_{Aiy} = v_{Afy} + \frac{m_B}{m_A} \cdot v_{Bfy} = 33.5 \text{ kph}$$

With v_{Aiy} and the initial direction for v_{Ai}, we can calculate v_{Aix}.

$$\tan(\theta_{Ai}) = \frac{v_{Aiy}}{v_{Aix}}$$

$$v_{Aix} = \frac{v_{Aiy}}{\tan(\theta_{Ai})} = 80.9 \text{ kph}$$

So

$$v_{Ai} = 87.5 \text{ kph @ } 22.5°$$

Then

$$v_{Bix} = \frac{m_A}{m_B}\left(v_{Afx} - v_{Aix}\right) + v_{Bfx} = -12.83 \text{ kph} = v_{Bi}$$

Conclusions

It is surprising that the Polo (B) was going so slow at the time of the collision. One problem with this solution is that the calculated initial speeds are very sensitive to the assumed direction of the Golf (A) prior to the collision. From the damage to the entire front Golf (A), it is probable that the automobile was turned toward the Polo (B) at the time of the collision, as is assumed here. Also on a wet, slick road, this is also probable. Because of its orientation, it is also possible that the driver of the Golf (A) attempting to make the gentle turn to the right skid on the slick roadway and over-corrected to the left, turning the Golf (A) clockwise and entering the lane of the Polo (B), headed in the opposite direction. Perhaps the Polo (B) driver saw this sideways sliding and lane incursion and braked to the slow speed calculated above.

The German energy-based solution concludes that the pre-collision speeds of both cars was

v_{Ai} = 106-120 kph
v_{Bi} = 42-54 kph

Changing the initial, pre-collision velocity direction of the Golf (A) from 22.5° to 17° makes these initial velocities

v_{Ai} = 114 kph
v_{Bi} = 50 kph

which complies with the energy result. The initial direction was assumed as half the heading angle of the Golf (A), which also was assumed from the damage pattern of both vehicles. So to have compliance between both solutions, it is best then to let this parameter float (θ_{Ai}) and then set it based on this compliance. This would mean that the Golf was traveling over the speed limit on a wet roadway in fog after dark, and the driver had been drinking. Certainly that is an imprudent thing to do.

See attached spreadsheet for calculations.

References

Engineering Consultancy Neikes, Dillenburg, in Technische Analyse von Verkehrsunfällen anhand von Beispielen – Band I, GTÜ (Gesellschaft für Technische Überwachung mbH), 2000 Edition, Stuttgart.

Two-car highway accident

mA (Golf)	1110	kg
mB (Polo)	850	kg
mu	0.5	
ThetaAi	22.5	degrees
ThetaBi	180	degrees
PsiAi	45	degrees
PsiBi	180	degrees
PsiAf	523	degrees
PsiBf	368	degrees
TotDeltaPsiA	478	degrees
TotDeltaPsiB	188	degrees

For rolling wheels:

Vehicle A, angle	Sine
45	0.707107
55	0.819152
65	0.906308
75	0.965926
85	0.996195
95	0.996195
105	0.965926
115	0.906308
125	0.819152
135	0.707107
145	0.573576
155	0.422618
165	0.258819
175	0.087156
185	0.087156
195	0.258819
205	0.422618
215	0.573576
225	0.707107
235	0.819152
245	0.906308
255	0.965926
265	0.996195
275	0.996195
285	0.965926
295	0.906308
305	0.819152
315	0.707107
325	0.573576
335	0.422618
345	0.258819

Vehicle B, angle	Sine
0	0
10	0.173648
20	0.34202
30	0.5
40	0.642788
50	0.766044
60	0.866025
70	0.939693
80	0.984808
90	1
100	0.984808
110	0.939693
120	0.866025
130	0.766044
140	0.642788
150	0.5
160	0.34202
170	0.173648
180	1.23E-16
190	0.173648
Average	0.580185

355	0.087156
365	0.087156
375	0.258819
385	0.422618
395	0.573576
405	0.707107
415	0.819152
425	0.906308
435	0.965926
445	0.996195
455	0.996195
465	0.965926
475	0.906308
Average	0.686603

Post-impact angles:

ThetaAf	14	degrees
ThetaBf	150	degrees
dAf	80.62258	m
dBf	7.5	m

Adjustment for guardrail force 10%

Drag factors:

fL	0.55	with adjustment for guardrail force
fUA	0.377632	
fUB	0.319102	
fA	0.420724	
fB	0.434551	

VAf	25.79743	m/sec or	92.87074	kph @	14	degrees
VBf	7.996509	m/sec or	28.78743	kph @	150	degrees

Breaking these into components:

VAfx	90.11208	kph
VAfy	22.46747	kph
VBfx	-24.9306	kph
VBfy	14.39372	kph

From impulse/momentum:

VAiy	33.48968	kph
VAix	80.85124	kph
VAi	87.51275	kph
VBix	-12.8371	kph
VBi	-12.8371	kph