Driver behaviour during flashing green before amber

A comparative study

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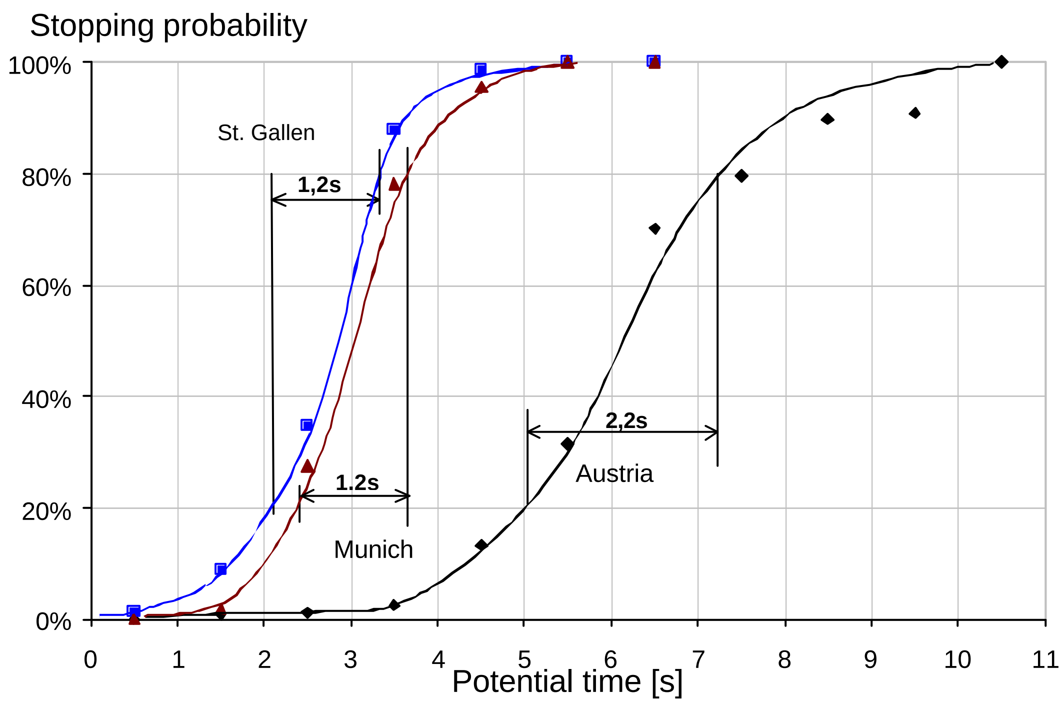
Publication date:
2002-02

Permanent link:
https://doi.org/10.3929/ethz-a-004363243

Originally published in:
Arbeitsberichte Verkehrs- und Raumplanung 105



Driver behaviour during flashing green before amber: A comparative study

Paper submitted for review to *Accident Analysis and Prevention*

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Arbeitsberichte **105**
Verkehrs- und Raumplanung **February 2002**

Fahrerverhalten während Grünblinken vor Gelb: Ein Vergleich

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Februar 2002

Kurzfassung

In diesem Aufsatz werden die Ergebnisse einer umfassenden Untersuchung des Anhalte-Verhaltens von Fahrzeuglenkern an Lichtsignalanlagen mit und ohne Grünblinken vor Gelb vorgestellt und kurz zusammengefasst. Die Videoaufnahmen an zehn lichtsignalgeregelten Kreuzungen in Österreich, der Schweiz und der Bundesrepublik Deutschland wurden mit einem elektronischen Bildbearbeitungssystem speziell ausgewertet.

Die Analyse von rund 5.000 aufgezeichneten Umläufen zeigt, dass bei Grünblinken der Anteil frühzeitiger Stops zunimmt, weil die Fahrzeuglenker die Zeit bis zum Gelbende tendentiell unterschätzen. Darüberhinaus wird die Entscheidungsbreite, also der Bereich mit großer Unsicherheit in der Entscheidung Anhalten oder Durchfahren, stark erhöht. Für die Anhaltewahrscheinlichkeiten mit und ohne Grünblinken wurden diskrete Entscheidungsmodelle geschätzt und die Ergebnisse in einem mikroskopischen Simualtionsprogramm integriert. Die Modellergebnisse zeigen, dass das empirisch beobachtete Entscheidungsverhalten durch die Annäherungsgeschwindigkeit und den Abstand von der Haltelinie sowie deren Zusammenwirken (in Form der potentiellen Zeit bis zum Erreichen der Haltelinie bei gleichbleibender Geschwindigkeit) gut beschrieben werden kann.

Schlagworte

Fahrverhalten, Grünblinken, Gelbüberfahrt, Rotüberfahrt, Anhalten, Entscheidungsmodell, Österreich, Schweiz, Deutschland, Simulation, Lichtsignalsteuerung

Bevorzugter Zitierstil:

Köll, H., M. Bader und K.W. Axhausen (2002) Driver behaviour during flashing green before amber: A comparative study, *Arbeitsberichte Verkehrs- und Raumplanung*, **105**, Institut für Verkehrsplanung und Transportsysteme, ETH Zürich, Zürich.

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February 2002

Abstract

The paper discusses the results of extensive measurements of the stopping behaviour of drivers during signal programmes with and without flashing green before amber. Ten locations in Switzerland, Austria and Germany were recorded with a video camera and analysed using an image-processing system. About 5'000 cycles were documented.

The analysis shows that the flashing green increases the number of early stops, as drivers tend to underestimate the duration of the time to the end of amber. Discrete choice models of the stopping are estimated for inclusion in suitable microsimulation models of traffic flow. The model results show that speed, distance to stop line and their interaction (potential time to the stop line with unchanged speed) explain the stopping process.

Keywords

Driver behaviour, flashing green before amber, stopping, choice model, Austria, Germany, Switzerland, Simulation

Preferred citation style

Köll, H., M. Bader and K.W. Axhausen (2002) Driver behaviour during flashing green before amber: A comparative study, *Arbeitsberichte Verkehrs- und Raumplanung*, **105**, Institut für Verkehrsplanung und Transportsysteme, ETH Zürich, Zürich.

1. The status-quo: Flashing green before amber

The sequence of indications given by a traffic signal varies considerably between countries and sometimes even within countries. The Austrian sequence: Green – Flashing green – Amber – Red – Amber/Red (- Green) can to our knowledge only be found there, in parts of Slovenia (metropolitan Ljubljana), Israel, Jordan and Cuba. Spain employs a Green/Amber indication instead of the flashing green and a number of European countries drop the Amber/Red (France, Italy or Belgium).

The Austrian pedestrian sequence Green – Flashing Green – Red (- Green) is found more often (Netherlands, Poland or Spain). Finland is currently considering the introduction of this sequence.

Austria introduced this sequence in 1969 and gave it final form in 1983 (10. StVO-Novelle[1]):

> "The green light will end with four dark/green light sequences, where each of the dark and illuminated phases last half a second. Flashing green indicates the approaching end of the green light."

All signals had to be converted by the end of 1988. Amber signals the driver to come to a stop before the stop line, unless he/she cannot do so safely given his/her current speed.

The exact reasoning behind the introduction of the flashing green cannot be reconstructed, as the original papers submitted to Parliament do not include any discussions or comments. One reason offered by persons involved at the time was a strong increase in the number of right-angle accidents, which suggest the flashing green as a solution.

Expert opinion in Austria assumes that car drivers generally appreciate the flashing green and that it reduces accident numbers. Still, the flashing green reduces the effectiveness of adaptive traffic control, as it effectively increases the duration of the phase transitions. In addition, the on-going process of European unification raises the issue of a standardisation of the signal sequences in any case.

[1] 10th Supplement of the Road Traffic Regulations

The literature on the effects of a flashing green before amber is very sparse (see Behrendt, 1970, Knoflacher, 1972 and Mahalel and Zaidel, 1985) and generally out-of-date. While there is a larger literature on the driver behaviour during the amber interval it is not directly relevant to the situation at hand or to Austria, therefore no attempt will be made to review it here, but see for example Robertson (1991, 1993).

Against this background the Verkehrssicherheitfonds (Traffic Safety Fund of the Ministry of Transport, Innovation and Technology, Vienna) and a number of other Austrian authorities (Land Upper Austria, Traffic Safety Fund of the Land Tirol, the City of Innsbruck and the City of Salzburg) contracted the authors to analyse the effects of flashing green in a comprehensive manner. The project has three substantive parts:

- Analysis and modelling of driver stopping behaviour in situations with and without flashing green
- Accident analysis of intersections with and without flashing green
- Determination of the effect of flashing green on intersection performance using a suitable simulation model of traffic flow, such as for example VISSIM (PTV, 2001)

This paper will report the results of the first part of the project work (See also Köll, Bader and Axhausen, 2001; Köll, Axhausen and Bader, 2001), while later papers will address the remaining work and the conclusions drawn from it. The paper is organised as follows: the next section describes the data collection method and the data obtained. The frequency of yellow and red running are the focus of the then following section. The final substantive section discusses the stopping behaviour at the different approaches, including the number of unnecessary stops, and finally presents a logit choice model of the stopping behaviour.

2. Data collection and coding

2.1 Locations and observation method

The comparative aims of the project require measurements in both Austria and elsewhere. A total of ten approaches with 23 lanes were selected in Austria, Switzerland and Germany (Table 1). The requirements of the video recording made the selection difficult, as it was necessary to find locations where a steep viewing angle was available, as well as long field of sight. In the case of flashing green (4 seconds) this translate into about 85 m (at 50 km/h approach speed).

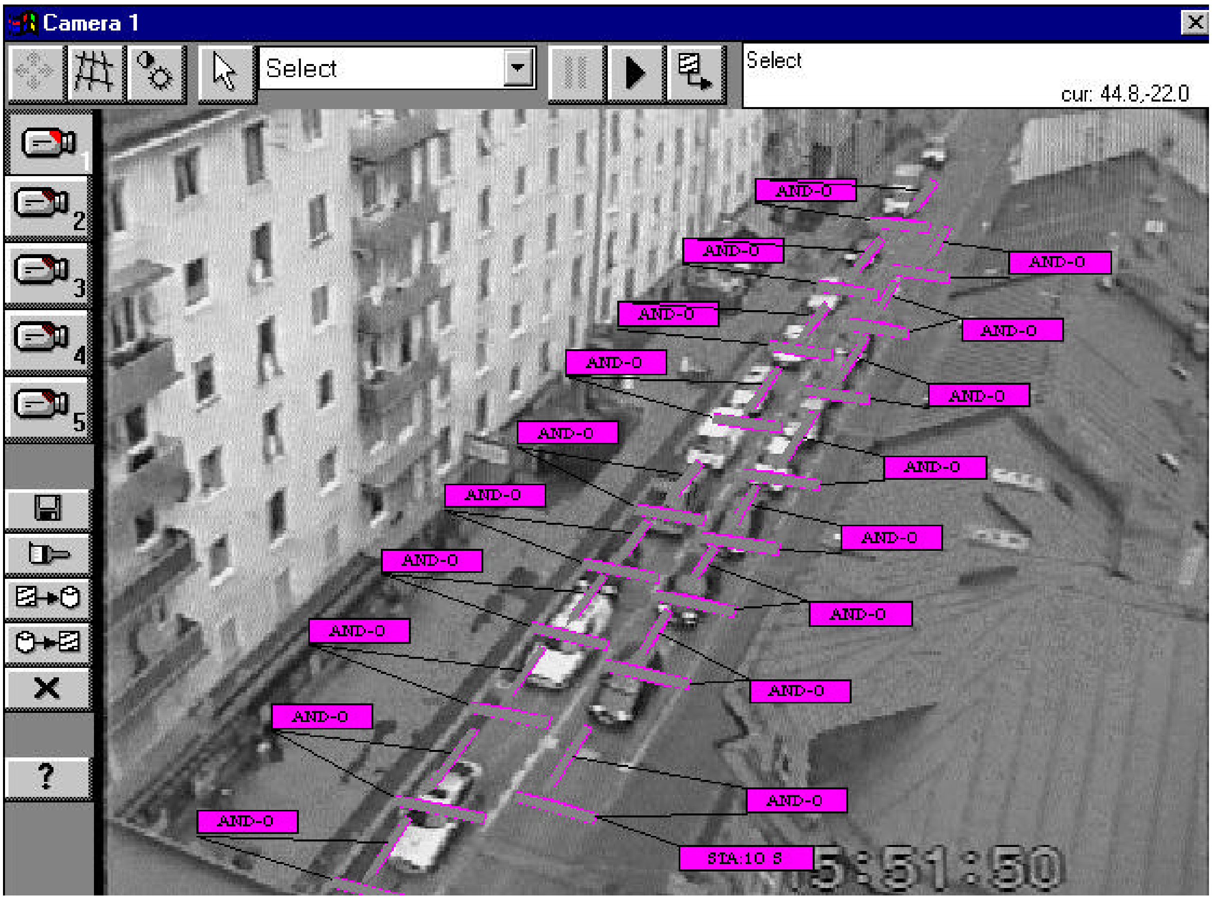
Table 1 Measurement locations

	Lanes	Max. approach speed	Peak load	Amber	Arrival
	[]	[km/h]	[veh/h]	[sec]	
Linz (Austria)					
Salzburger Strasse	4	70	2500	4	Random
Innsbruck (Austria)					
Schützenstrasse	2/2	40	440/830	3	Random
Amraser Seestrasse	2	50	1’560	3	Random
Salzburg (Austria)					
Ignaz Harrer – Strasse	2	50	660	3	Platoon
St. Gallen (Switzerland)					
Rosenberg-Strasse	1	50	920	3	Platoon
Lang Gasse	2	50	1’040	3	Random
Rorschacher Strasse	2	50	930	3	Platoon
St. Leonhard Strasse	2	50	1’700	3	Platoon
Breitfeld	2	60	1’390	3	Random
Munich (Germany)					
Theresien Strasse	2	50	1’300	3	Platoon

The video tapes were analysed using AutoScope 2004 STD (Image Sensing Systems, 1998), which allows the setting of multiple virtual detectors and their logical linking. The approach lanes were covered with up to 10 detectors each (about 5 to 10 m apart) and linked accordingly to obtain the data for a complete tracing of each vehicle (location, time and speed) (Figure 1). The tracing was performed using purpose written software. Equally, further software was written to clean the data generated by Autoscope from spurious or erroneous data.

The signal indications were filmed simultaneously and also analysed using the Autoscope software. In Sankt Gallen the City generously installed special signal heads in two cases to allow this simultaneous recording.

Figure 1 Video image and virtual detectors: Ignaz-Harrer Strasse, Salzburg



Source: Köll, Bader and Axhausen (2001), Figure 2

2.2 Data obtained

A total of 4’997 cycles were observed, of which only 2’661 were relevant, i.e. observed vehicles which had to respond to the start of the amber (flashing green) (Table 2). The low share of relevant cycles in St. Gallen is noticeable. This is due to the adaptive control used throughout in St. Gallen and two approaches with a good co-ordination between intersections.

The average speeds are comparable for the Austrian and the Munich approaches (about 40 km/h), while the speeds are significantly lower in St. Gallen (about 30 km/h). The standard deviations of the speeds have the same order of magnitude in all three cases (ca. 11 km/h).

Table 2 Number of signal cycles observed by country /city

Location	Type of lane Through/right []	Left []	All []	All types []
Austria	1’377	484	-	1’861
St. Gallen, Switzerland	986	818	331	2’133
Munich, Germany	1’003	-	-	1’003
All locations	3’366	1’302	331	4’997

3. Stop line crossings during amber and red

The number of stop line crossings during amber and red gives a first indication of the safety impacts of the different signal sequences. A total of 1’621 crossings during amber (133 during red) were registered. Table 3 shows how these are spread over the duration of the amber by country/city. The approach in Munich stands out with its large number of crossing during red. In Austria the number of crossings decreases with the duration of the amber, while in St. Gallen they are concentrated in the second second. In Munich they are spread equally across the whole duration.

Table 3 Number of stop line crossings during amber and red by country/city

Location	Second of amber				Red
	First []	Second []	Third []	All []	[]
Austria	271	204	79	554	23
St. Gallen	171	199	100	470	18
Munich	186	201	210	597	92
All locations	628	604	389	1’621	133

More interesting is the average number of hazardous crossings per cycle (Table 4). The average number per relevant cycle (with vehicles in a decision situation) is higher for those approaches without the flashing green. The mean varies between 0.31 and 0.70 crossings/relevant cycle (mean 0.46) for the Austrian approaches, but between 0.62 and 1.06 in St. Gallen and Munich (means of 0.83 and 0.97). This trend is more pronounced with the crossings on red (1.90 Austria; 3.18 St. Gallen and 14.94 in Munich [per 100 relevant cycles]).

The Swiss and the Austrian approaches are nearly identical when one considers all observed cycles, which is due to the co-ordination and adaptive signal control implemented in St. Gallen. The experience in Munich remains considerably worse on that metric as well.

The values reported here are comparable to those reported in the literature, for example by Mussa, Newton, Matthias, Sadalla and Burns (1996) for driving simulator experiments and by Behrendt (1970) for a before-and-after study in Germany.

A logit-regression model of the presence or absence of a crossing during amber/red reported in Köll et al. (2001) identifies mean traffic volumes and mean speeds as the main explanatory variables (both positive), but a well visible signal head reduces the number of crossings. As expected the Austrian approaches have a significantly lower number of hazardous crossings.

Table 4 Mean number of stop line crossings per cycle by country /city

Location	Cycle status	Stop line crossings during amber [/cycle]	Stop line crossings during red [/100 cycles]
Austria	Relevant	0.46	1.90
	Total	0.30	1.24
St. Gallen	Relevant	0.83	3.18
	Total	0.33	1.27
Munich	Relevant	0.97	14.94
	Total	0.60	9.17
All locations	Relevant	0.68	5.55
	Total	0.38	3.11

4. Probability to stop during amber

The core question is how the flashing green influences the stopping behaviour at the decision point, i.e. start of amber or start of flashing green. Does it improve the ability of the drivers to judge the begin of red ? Does it encourage early stopping and therefore a loss of effective green (capacity) ? This section will report the empirical results, but will not include an assessment of any of the effects observed, as these have to be seen in the larger context of the safety performance of the signal programmes with flashing green.

4.1 Stopping probability as a function of potential time to the stop line

Malahel and Zaidel (1985) have suggested potential time, i.e. the time to the stop line if the driver continues with unchanged speed from the first possible decision point (start of amber/start of flashing green). Table 5 gives the observed stopping probabilities by country/city.

Table 5 Observed stopping probabilities [%] as a function of potential time by country/city

Potential time	Austria	St. Gallen	Munich
< 1 s	0	1	0
1-2 s	1	9	2
2-3 s	1	35	28
3-4 s	3	88	78
4-5 s	13	99	96
5-6 s	32	100	100
6-7 s	70	100	100
7-8 s	80	100	100
8-9 s	90	100	100
9-10 s	91	-	-
> 10 s	100	-	-

Source: Köll, Axhausen and Bader (2001) Table 2

The table shows that the drivers in Austria tend to stop earlier. Some 3% stop already during the period covered by the flashing green and 70 to 80% by end of the amber (7-8 s period is included due to the one approach in Linz with a four second amber duration). In Germany and Switzerland this share is only about half as large (28 and 35% during the 2-3 s potential green interval). This response leads to a longer interval during which a following car driver cannot be sure, how the car driver in front will decide. The estimated duration between 20% and 80% probability of stopping is about a second longer in Austria in comparison with Munich and St.Gallen (Figure 2).

4.2 Potential time differences

The difference between the potential time of a car to the stop line at the decision point and the actual duration until the end of amber is a measurement which is comparable for both types of signal sequence. A negative difference (time to end of amber – potential time) indicates a crossing during red, i.e. indicates that the driver should stop. Equally a positive difference indicates that the driver could safely cross and should do so. Actually drivers underestimate the time to the end of amber and a substantial share stop even with positive potential time differences (Figure 3).

In Austria, ignoring the location in Linz due to its 4 sec amber duration, we observe 12 crossings with negative potential time difference compared to 110 stop decisions with positive differences. This ratio of 1.0 : 9.2 shows the strength of that underestimation. In Linz it was even more pronounced. In St. Gallen the ratio was 1.0 : 5.5 and in Munich 1.0 : 1.8 indicating the same trend, but much less pronounced.

Figure 2 Stopping probability as a function of potential time by country/city

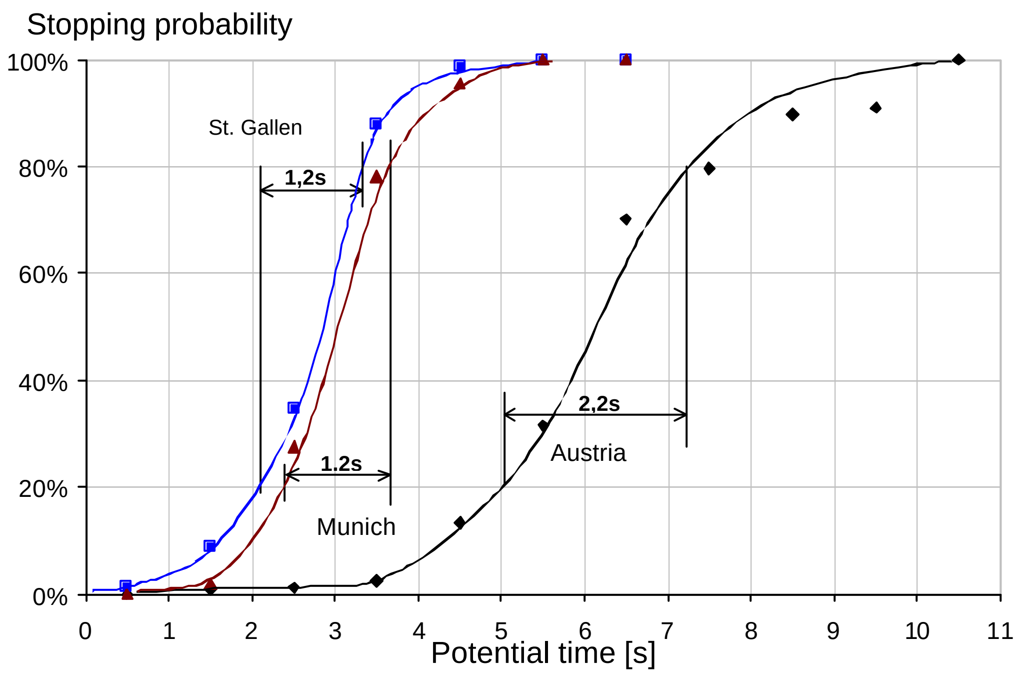
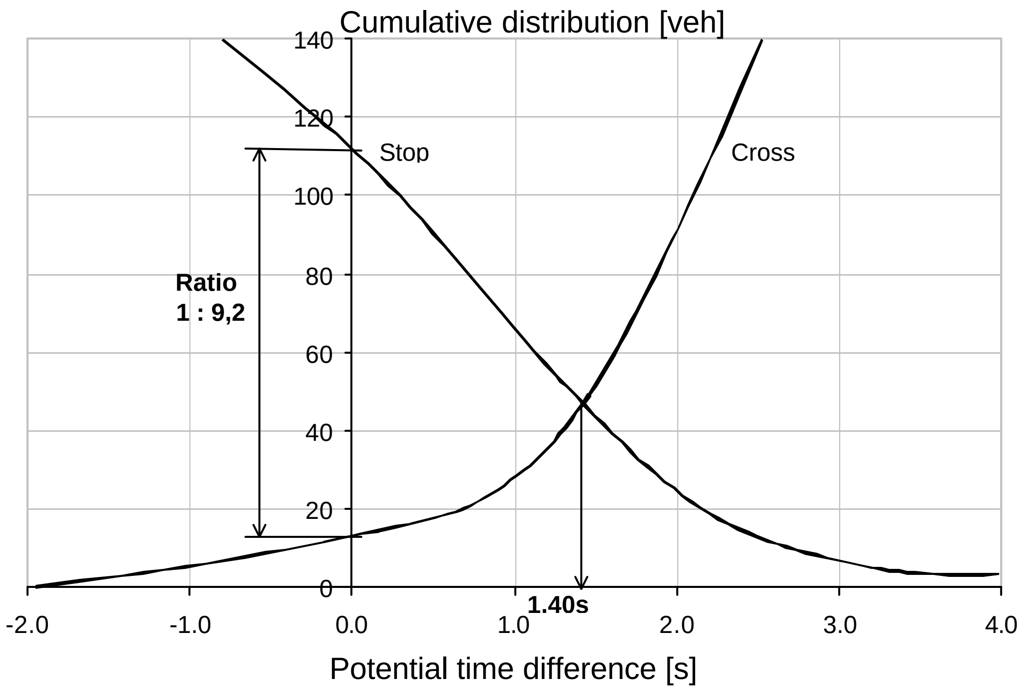


Figure 3 Distribution of potential time differences by decision (stop/cross) (Austria without the location in Linz)



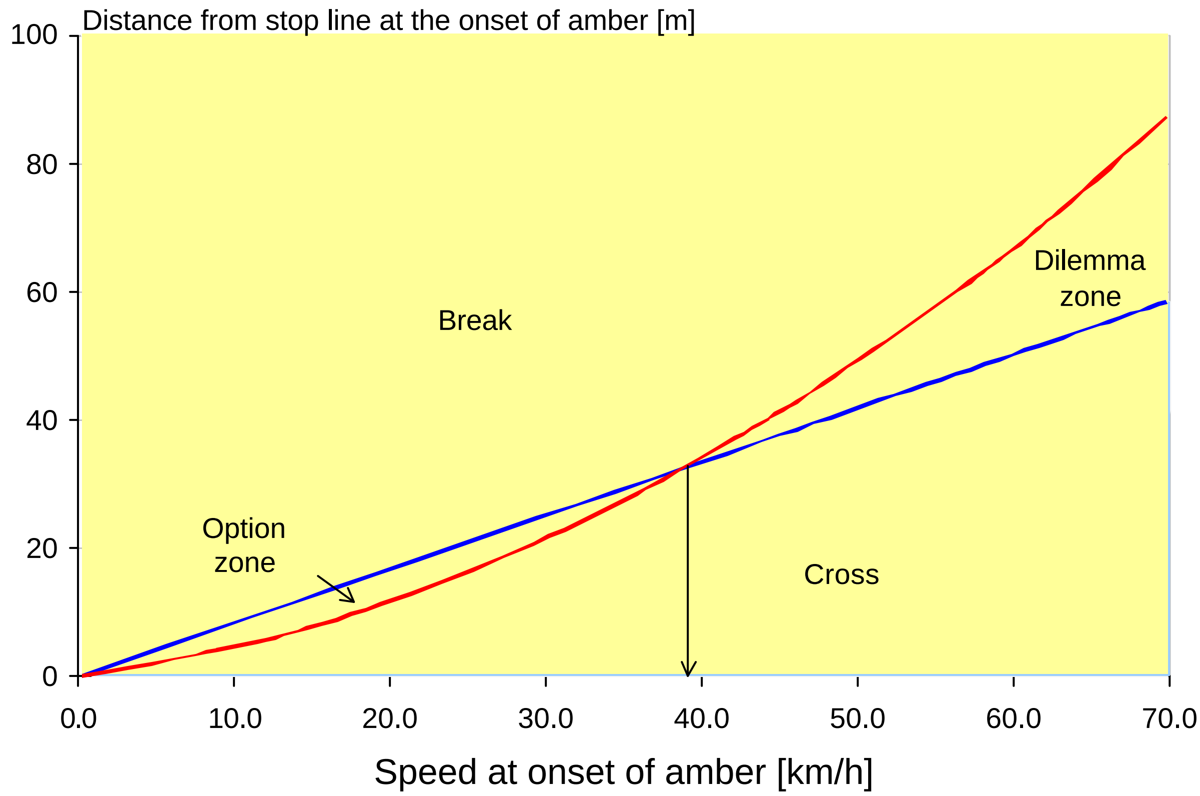
4.3 Number of non-rule compliant decisions

The rules of the road (Strassenverkehrsordnung) stipulate that a driver has to stop during amber, unless this is not safely possible. In this case, the driver has to proceed. This rule allows to define two types of non-rule compliant decisions in the case without flashing green:

- Drivers who cross although they could have safely stopped (assuming a normal reaction time and braking rate) (yellow area in Figure 4).
- Drivers who stop in spite of their inability to do so using a normal braking rate (blue area in Figure 4), while they could safely cross.

Drivers in the dilemma zone, where they can neither safely stop nor safely cross, cannot be allocated to either category.

Figure 4 Decision zones for signal programmes without flashing green and 3 sec amber



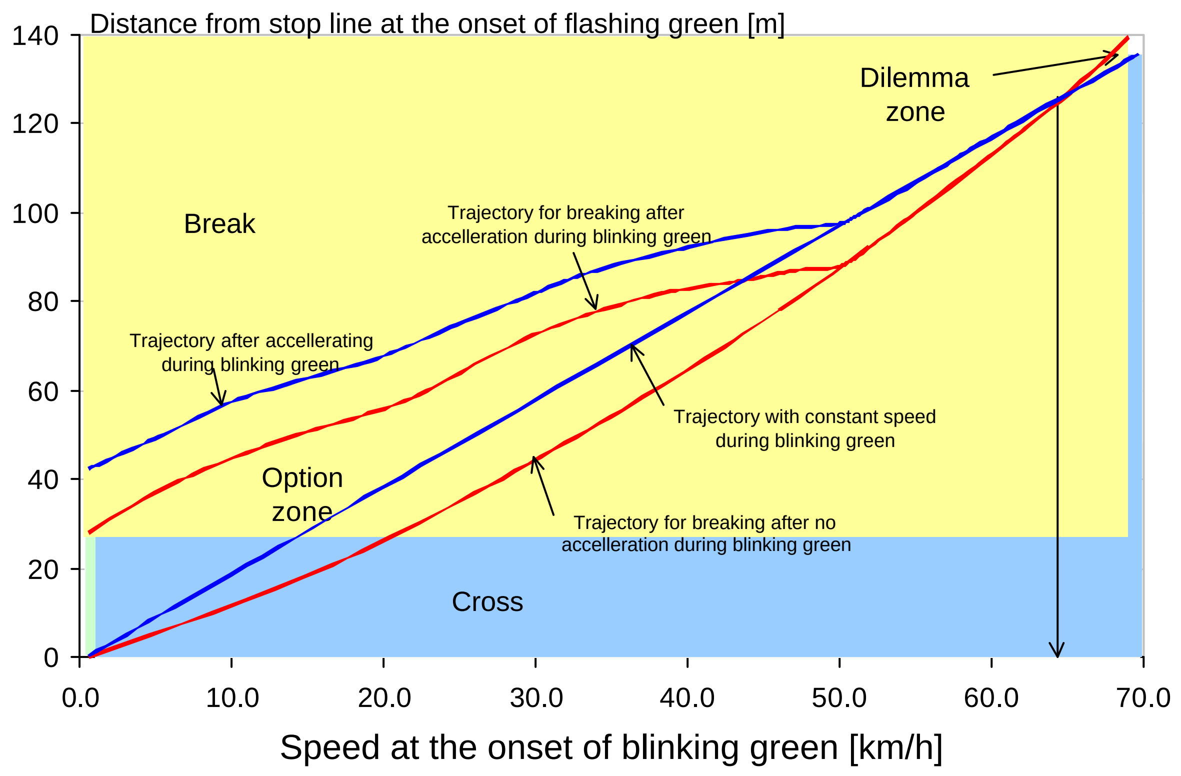
Source: Köll, Axhausen and Bader (2001), Figure 4

The definition is less clear cut for the Austrian case, as the decision point is the start of the flashing green. Clearly non-compliant are the following cases:

- Drivers who cross, although they could have safely stopped at the start of amber after accelerating to the speed limit during the flashing green after a reaction time (yellow area in Figure 5).
- Drivers who stop, although they could have safely crossed at the start of amber after continuing with constant speed during the flashing green (blue area in Figure 5).

In addition to the dilemma zone, there is a second area, where it is impossible to determine if a crossing is rule compliant or not (green area in Figure 5). The status depends on the assumption about the acceleration during the flashing green (see also Liu, Herman and Gazis, 1996). In the Austrian case one could observe a wide range of accelerations and decelerations, but generally accelerations. Using a restrictive interpretation of not allowing for acceleration during the flashing green then all crossings of drivers in the green area are non-compliant. Allowing for acceleration, the crossings are compliant. The stops of drivers in the green area are compliant (safe stop after cruising with constant speed during the flashing amber).

Figure 5 Decision zones for signal programmes with 4 sec flashing green and 3 sec amber (50 km/h maximum permissible approach speed)



Source: Köll, Axhausen and Bader (2001), Figure 5

In Austria a large number of non-compliant stops can be observed (Table 6). A disproportionate number of drivers stop, although a safe crossing would have been possible. The share of non-compliant crossings ranges from zero to 11% of all crossings.

In the Munich case a worrying number of drivers were observed in the dilemma zone, which is due to the high approach speeds driven there. Looking at Figure 4 and Figure 5 one can see, why this does not occur in Austria and St. Gallen. In Austria the dilemma zone can only be reached with speeds well beyond the legal limit. In St. Gallen the generally low speeds avoid the dilemma zone as well.

Table 6 Share of non-compliant decisions of observed decisions by country/city

Country/City	Stopping decisions		Crossing decisions	
	Share non-compliant [%]	Number in dilemma zone	Share non-compliant [%]	Number in dilemma zone
Austria				
Not allowing acceleration	32	0	6	0
Allowing acceleration	32	0	0	0
St. Gallen	14	1	11	0
Munich	23	44	4	18

4.4 Choice models

At the decision point the driver has to prepare for stopping or crossing. It is therefore possible to use the discrete choice framework (see Ben-Akiva and Lerman, 1985) to identify the factors influencing that choice among those potentially relevant. The presence of the flashing green makes the estimation of joint models for all observed approaches undesirable, as the range of behaviours is much greater there. Table 7 presents therefore separate models for these two subsamples. In addition, there are two types of models: one including the interaction term potential time and others not. For both subsamples, the inclusion of the interaction term improved model fit. In the Austrian case, a squared potential time term was necessary to capture the long period implied by the flashing green. Models using the potential time difference did not perform well.

The parameter estimates have the expected signs. The main variables (speed, distance and its interaction term potential time) are all significant. Of the other variables describing the choice situation only one is significant: a signal head on an overhead gantry. The interpretation of this variable is difficult, as the sign switches between the two subsamples. In addition, this variable could describe a location specific effect. Further measurements would be required to confirm this effect.

The model fits are high. The rho squares relative to the log likelihood at the optimal constants range from 0.39 to 0.61.

None of the estimated location specific constants were significant. This indicates that the results are stable and should be transferable to other locations. Equally, the overall amount of traffic during the cycle (mean time gap) had no significant impact. This is an unexpected result, as one would have assumed that large traffic volumes lead to a reduction in the probability to stop.

Table 7 Logit choice model of the decision to stop

	Austria (With flashing green)		St. Gallen/Munich (without flashing green)	
Without potential time	Parameter	Significance	Parameter	Significance
Constant	-2.238	***	0.668	**
Distance at decision point [m]	0.084	***	0.254	***
Speed at decision point [km/h]	-0.087	***	-0.224	***
Mean time gap [sec]	0.001		0.000	
Off turn lane	0.358		0.166	
Signal head on overhead gantry	-0.295	**	0.530	**
Parking along the approach	-0.014		0.187	
$\rho(\text{Constant})^2$	0.39		0.57	
With potential time				
Constant	-4.209	***	-5.371	***
Distance at decision point [m]	-		-	
Speed at decision point [km/h]	-		-0.034	***
Potential time [sec]	-0.135	***	2.377	***
Potential time^2 [sec^2]	0.131	***	-	
$\rho(\text{Constant})^2$	0.41		0.58	
N	2049		1678	

***: $\alpha < 0.01$; **: $\alpha < 0.05$;

5. Conclusions and outlook

The flashing green in Austria is associated with a substantial increase of early stops, i.e. non-compliance with the rules of the road. It also produces a large option zone, where drivers can both safely stop and cross. The dilemma zone, on the other hand, is minimised. This large option zone generates a period of uncertainty, where a driver following cannot easily predict, if the car in front will stop or cross.

The choice models highlighted the expected influence of speed, distance and potential time at the decision point (start of amber/flashing green). Higher speeds and lower distances to the stop line reduce the likelihood to stop. No other variable had a significant impact or an impact, which could be separated from the specific measurement locations.

The early stops should reduce the likelihood of right-angle collisions, in particular as the intergreen times are not adjusted to account for the effects of the flashing green. Still, the longer and larger option zone could lead to an increased number of rear end collisions. Mahalel and Zaidel (1985), Behrendt (1970) and Knoflacher (1972) made similar suggestions. This will be tested using a sample of 100 intersections in Austria, Germany and Switzerland for which detailed accident, traffic and traffic control data have been collected.

The micro simulation model VISSIM (PTV, 2001) has been adjusted to allow an explicit modelling of the stopping probabilities. This capability will be used to analyse the impact of a change in signalling sequence for a number of traffic actuated intersections in various Austrian cities. These experiments plus experiments with standard intersection formats will form the basis of a comprehensive assessment of the benefits and costs of the flashing green element of the current Austrian signal sequence.

6. Acknowledgements

The authors thank the Verkehrssicherheitfonds (Traffic Safety Fund of the Ministry of Transport, Innovation and Technology, Vienna) and the Land Upper Austria, the Traffic Safety Fund of the Land Tirol, the City of Innsbruck and the City of Salzburg for their financial support. Mr. Hunziker and Mr. Tschumper (City of St. Gallen, Switzerland) and Mr. Kaufmann (City of Innsbruck, Austria) provided support during the data collection, which is gratefully acknowledged.

Mr. Wöginger performed a large part of the data coding.

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