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Red-light crossing, crossing time and attitudes to crossing with intelligent green light for pedestrians

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International Co-operation on
Theories and Concepts in Traffic Safety

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ABSTRACT: *In order to increase mobility and promote modal shift to walking, intersections in the city of Aarhus, Denmark, have been equipped with intelligent management of green light for pedestrians. This allows adjustment of green time based on radar detection of pedestrians in the crossing and prolongation of the green time for the pedestrians if required. The effect is examined in a before/after study of a two-stage pedestrian crossing with a centre refuge island in an intersection of four-lane roads. The data consists of responses from an on-site questionnaire including 72+53 individuals and 266+318 hours of video registration of the pedestrian crossing in the before and after study, respectively. The study includes the pedestrians' experiences, the measured time of crossing and the share of pedestrians crossing at red light. The analyses of video recordings are carried out with the video analysing software RUBA. The share of pedestrians who often or frequently only reached the refuge island before red light decreased from 42% to 13%. Video data show that the pedestrians reduced their crossing at red light from 44% to 16% in the remote lane, while the percentage remained virtually unchanged on the closest lane with 16%. The mean crossing time was also reduced by 5 and 6 seconds in- and outside of the peak hour period, respectively. The reductions in mean crossing time were not statistically significant.*

KEYWORDS: *Traffic Safety, Red-light crossing, Video detection, Advanced traffic management*

1. INTRODUCTION

Traffic signals were an essential tool in organising and operating traffic in intersections prior from the intro-

duction of cars, and numbers have increased over time (Ross 2016). The main purposes of traffic signals are to keep the traffic moving and prevent accidents (History.com Staff 2009, Høye et al. 2012).

Despite reduced car ownership among millennials in many urban areas, the traffic volume seems to be growing again after the financial crisis has ended in most countries. This has resulted in increased congestion levels, and in most cases, this issue cannot be solved by establishing more roads as space in urban areas is limited. Hence, in order to ensure the best possible accessibility, more efficient use of the road infrastructure and/or a modal shift to less space-consuming modes such as walking or biking are needed. More efficient use of the existing infrastructure requires a change in the operation of the traffic light installations; this will increase capacity, particularly for motorised road users. This development is ongoing with e.g. Adaptive Traffic Control Systems, which are more advanced and agile than previous systems (Stevanovic, 2010; Hunter et al., 2012; Agerholm et al. 2013).

The facilitation of a modal shift to sustainable modes, including more pedestrians, requires that the conditions for this group of road users are improved. This may involve an improved experience of accessibility or experienced safety and security for this group. This leads to an increased demand for traffic signals that accommodate the needs of soft road users as well as throughput needs (Sanders et al, 2011, Keegan, O'Mahony, 2003, De Winne, 2006).

A couple of studies report the effects of such traffic signal improvements, but also state that pedestrians are likely to cross at red light if the waiting time is too long or seems absurd. Hamed (2001) found that pedestrians are more likely to cross at red light when walking from the refuge island than when walking to it. Keegan and O'Mahony found that around 33% crossed at red light because it seemed safe, and 52%

because they felt impatient or hated to wait (2003). A reduction in waiting time is essential for soft modes; waiting time is perceived as up to three times more valuable than travel time, and hence of great importance and probably part of the explanation for the significant share of pedestrians crossing at red light (Bruzelius, 1979, Levinson et al., 2004)

In order to improve the actual and perceived mobility of pedestrians and cars in the urban road network, the Municipality of Aarhus has implemented a new signal system in selected intersections. The changes to the system include green light for pedestrians, based on radar detections in real time.

This paper reports the results of a before/after study of one of these intersections. The focus of the paper is to report on pedestrian behaviour, experience and travel time when crossing the intersection. The intersection in question is the junction of *Christian X's Vej* and *Ringvej Syd* and it is located at 571935, 6219191 (ETRS89 UTM32N). The intersection is surrounded by a high school, industrial and service premises and town houses, so this is not an intersection used much by pedestrians out shopping etc. (see figure 1).

The intersection studied is equipped with improved signal programmes and extensive coordination between intersections. During day-light hours, the signal is coordinated with four other intersections, using different programmes for peak hours to improve the traffic flow. In the night and evening, the signal is completely traffic-controlled, with an all-red waiting position for periods with no traffic. At all times, pedestrians wishing to cross must press a but-

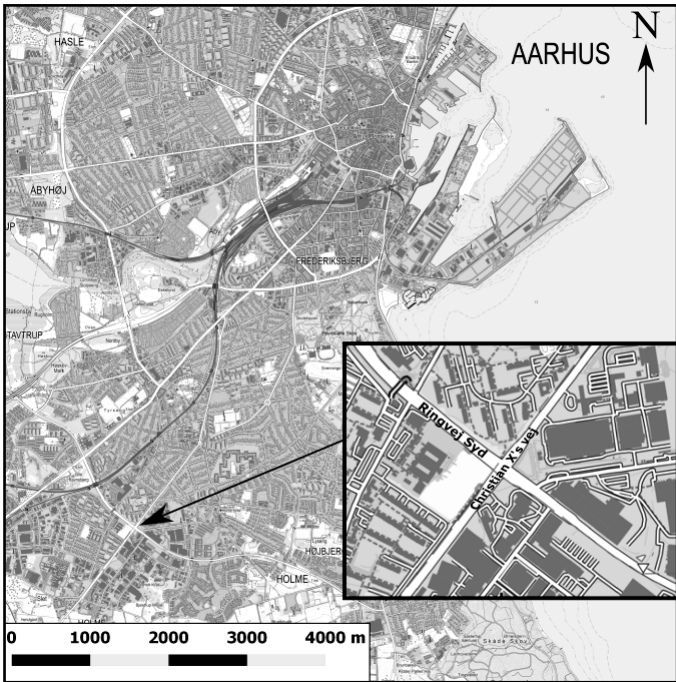


Figure 1. Map of Aarhus, Denmark, and the location of the intersection of Christian X's Vej and Ringvej Syd.

ton on the signal stand. A green light is not provided simultaneously for pedestrians moving in both directions in the pedestrian crossing; lights are adapted to the need, and are coordinated with the overall traffic management programme. Table 1 shows an overview of the signal groups and the circulation times in the different programmes.

The new signal system, which came into operation during the first week of October 2016, utilises a radar to estimate the pedestrian's time of arrival at

Table 1. Signal groups and description of when they are used.

		Peak hours 120 seconds circulation time	Off-peak hours 66 seconds circulation time	Evening/night 80 seconds circulation time
Group 1 (Ringvej Syd)		Mandatory	Mandatory	Traffic controlled
Group 2 (extra green light for turning traffic)		Traffic controlled	Disabled	Traffic controlled
Group 3 (Chr. X's Vej)		Mandatory	Mandatory	Traffic controlled
Group 4 (extra green light for turning traffic)		Mandatory	Disabled	Traffic controlled

approximately one meter past the refuge island. If the estimated crossing time is longer than the minimum green time and shorter than the maximum green time, the traffic management programme will allot additional green time up to the maximum green time, allowing the pedestrian to pass the refuge island during green light time. When the pedestrian has passed the refuge island, the signal shifts to red light, unless another pedestrian is crossing and is within the time limit for additional green time. The radar recalculates the arrival time every 200 ms.

Since pedestrians walk at different speeds, a fixed green light time means that some pedestrians will be caught on the refuge island, while others will make the entire crossing well within the time. Using the radar to change the green light time depending on the pedestrian, the signal system minimises the share of people who are caught on the refuge island, while at the same time minimising the green light time for pedestrians. The time saved can then be used to improve the flow of car traffic.

1.1 Research Question

Aarhus Municipality is interested in further improvements for soft road users in their transport network. In order to evaluate the effect of the new signal system on pedestrians, the following research question was asked:

“How does intelligent green light for pedestrians affect their crossing time, crossing at red light and general experience?”

The remaining part of the paper includes a description of the selected method, a presentation of the data, our analyses and results, and our conclusion.

2. METHOD AND DATA

Our data consist of video recordings from the south-west zebra crossing in the intersection between *Christian X's Vej* and *Ringvej Syd* and from short roadside questionnaires among users of the pedestrian crossings.

2.1 Questionnaires

Short questionnaires were distributed among pedestrians who used the studied crossing. This was done by student assistants who afterwards typed in the answers on tablets. The format and content of the ques-

tionnaire were based on experience from a large-scale collection of driving and parking behaviour data conducted in 2012 (Agerholm, Madsen 2013). A short pre-test involving five students and two traffic experts was carried out, followed by minor adjustments of the questionnaire. 72 individuals answered the questionnaires before the implementation of the new signals and 53 individuals answered after the implementation. The questionnaire included questions regarding gender and age as well as questions about the pedestrians' experiences while using this particular zebra crossing (user frequency, waiting time, crossing at red light, waiting frequency on the refuge island, security and estimated crossing time). The questionnaire answers provided by pedestrians using the pedestrian crossing were registered on tablets during the afternoons of 20 September and 5 December, in the before and after period respectively.

2.2 Video recordings

The aim was to acquire a minimum of two weeks of video recordings during before and after periods, respectively. However, technical problems caused the recording periods to be extended in order to secure sufficient data. Recording before the implementation of the new signal was conducted on 2 to 19 September 2016. The recording after the implementation was conducted on 3 to 24 November 2016.

The camera recorded from 05:00 to 21:00 on all days including weekends. For two reasons, it was decided not to record outside this time period. Firstly, the number of pedestrians crossing between 21:00 and 05:00 was assumed to be very small, so the result would have been only a few additional crossings. Secondly, this would have reduced the battery capacity of the cameras. The video recordings included a total of 266 hours of recording for the before-period and 318 hours for the after-period.

The camera was placed facing the zebra-crossing of *Christian X's Vej* from the south-western corner of the intersection. The camera placement and the camera view appear in figure 2.

The computer programme Road User Behaviour Analysis (RUBA) was used to process the video data. RUBA is a video analysis tool, which can set up detectors that activate when a pedestrian enters a specific part of the frame (Bahnsen et al., 2014 and Tønning et al., 2017). Every activation is registered in a log file with a time stamp. Each video clip corresponding to the entry in the log file was then manually reviewed



Figure 2. Camera placement and view. *Christian X's Vej is the road running from north-east to south-west.*

to remove false positives and to count if more than one pedestrian crossed during the activation time. The manual review also registered if the pedestrian crossed during red light.

Since the pedestrian lights are not synchronized for both directions, it is not possible to determine if pedestrians walking towards the camera were crossing during red light. Thus only the pedestrians walking in the direction shown on figure 3 were counted. Area 1 is the part of the crossing from the pavement to the refuge island, while Area 2 is the part of the crossing from the refuge island to the other side of *Christian X's Vej*.



Figure 3. Crossing areas on Christian X's Vej used for the red-light analysis.

The crossing time was measured manually by reviewing a sample of the video data. Departure and arrival positions were defined, and the time it took for

pedestrians to walk between the two positions was registered. This was done for the peak hours 07:00 to 09:00 and 14:00 to 17:00 and for off-peak hours 09:00 to 14:00 on 7 September and 9 November during the before and after periods, respectively. During the before period, 128 people crossed during peak hours and 48 during off-peak hours. For the after period, the numbers were 120 and 44, respectively.

The crossing times measured includes waiting time from when pedestrians arrive at the crossing. This was done since the waiting time is an important part of the pedestrians' experience. The aim was not to register the time spent by pedestrians who began crossing when the traffic light changed to green. The reason for this was, that the majority of these pedestrians must be expected to pass the refuge island while the light was still green, but also that such registration would reflect pedestrians' walking speed rather than a possible effect of the signal control system.

2.3 Statistical tests

Statistical tests have been performed on the questionnaire data to determine if the distributions of answers changed from the before period to the after period. Most of the questions offered several answer options, but due to the low number of respondents, some answers amounted to less than five counts. In order to perform a Chi-squared test, some answer options were grouped, causing each group to receive more than five answers. To give an example, four options were given for answering the question "Do you often wait for a green light", i.e. yes/no/not sure/blank. In order to run a chi-squared test, a minimum of five subjects

must have ticked each of the five options, which did not apply to “not sure” and “blank”. Therefore, these answers have been added to the “no” answers, causing some information to be lost as it was no longer possible to distinguish between no/not sure/blank. However, it was now possible to run a chi-squared test.

For some of the questions, for instance those concerning waiting time at the intersection and the measuring of crossing time, it was inexpedient to combine response options; in a chi-squared test this would result in the categories 0–30, 30–60 and 60–180. We therefore used Fisher’s exact test, as this test is able to handle answer options with less than five answers.

In addition, the crossing time distributions were tested using Fisher’s exact test, and the mean crossing time was tested using a t-test.

3. RESULTS

3.1 Pedestrians’ Experiences

The questionnaire results, presented in table 2, show that the share of pedestrians who always/often only

reach the refuge island was reduced statistically significantly from 42% to 13%. Also, there tends to be a statistically significantly reduced share of pedestrians (from 18% to 6%), who stated that they always or often need to wait for a green light on the refuge island ($p < 0.10$). This shows that pedestrians experience the passability of the pedestrian crossing to have improved and that they experience less waiting time at a red light while crossing. Moreover, this indicates that the share of pedestrians who often need to wait for a green light was reduced from 74 to 66%; that several pedestrians experienced that they had enough time to cross during green light (32% to 45%); and that the feeling of security among the pedestrians when crossing increased from 75% to 78%. However, none of these results were statistically significant.

The pedestrians’ estimated waiting time, collected from the questionnaire data, appears in table 3. The share of pedestrians who stated that their waiting time was above 60 seconds increased from 22% to 30%. However, below 90 seconds, the share is unchanged at 77%. None of the changes are statistically significantly different.

Table 2. Questionnaire data

Question (Answer)	Before	After	p-value	Significant on the 5% level
Do you often need to wait for green light? (yes)	74%	66%	0.8717	
Do you have sufficient time to cross during green light? (yes)	32%	45%	0.1820	
How often have you only reached the refuge island when the signal changes to red light? (always/often)	42%	13%	0.0012	*
How often do you have to wait on the refuge island? (always/often)	18%	6%	0.0567	
Do you feel safe when crossing the intersection? (always/mostly)	75%	78%	0.9257	
Number of participants	72	53		

Table 3. Pedestrians’ estimated waiting time.

Estimated waiting time (s)	Before	After	Fisher’s exact test	p-value
0–30	47%	38%	Estimated waiting time	0.7130
31–60	26%	28%		
61–90	4%	11%		
91–120	14%	15%		
120–	4%	4%		
Blank	4%	4%		
Total	100%	100%		
Number of pedestrians	72	53		

3.2 Crossing at red light

The results of the crossing at red light analysis in table 4 show that virtually no change is found for area 1 (the closest lane), while the change for area 2 (the remote lane) is clear. The share of pedestrians who start crossing from the refuge island during a red light is reduced statistically significantly from 44% to 16%. Also, a minor reduction was found in the number of pedestrians managing to cross the entire distance during green light.

It is also worth noting that the share of pedestrians, where the light change to red during crossing at Area 2, has gone up from 24% to 62%. This increase suggests that the new signal system is working as intended, extending the green light until the pedestrians have crossed the refuge island, and then switching to red light if no other pedestrians are about to cross.

3.3 Crossing time

The distribution of the crossing time measured using the video data appears in table 5. This indicates (although not statistically significantly) that the mean crossing time during peak hours and during off-peak

hours was reduced from 68 to 62 seconds and from 51 to 46 seconds, respectively. Also, the share of pedestrians using between 61 and 120 seconds decreased, and both the share using 0 to 30 and that using 31 to 60 seconds increased during peak hours. However, a slight increase was also seen in pedestrians using between 121 and 150 seconds and between 151 and 180 seconds, from 4% to 7% and from 0% to 2%, respectively. These changes are also not statistically significant.

The distribution of crossing time during off-peak hours shows a statistically significant change. Most notably, there are no observations of crossing times longer than 90 seconds in the after period. While the distribution has changed, no statistical evidence suggests that the mean crossing time has changed in the off-peak hours.

DISCUSSION

The share of pedestrians who answered that they were able to cross the street while the light was still

Table 4. Crossing at red light for area 1 and area 2 in the before and after period, respectively.

	Area 1		Area 2		Chi-squared test	p-value
	Before	After	Before	After		
Red light from the start	16.4%	15.8%	43.5%	16.4%	Area 1	0.8441
Change to red light during crossing	0.9%	1.1%	23.6%	62.1%	Area 2	2.20E-16
Green light during the entire crossing	82.7%	83.1%	32.9%	21.6%		
Total	100%	100%	100%	100%		
Number of pedestrians	1,397	1,474	1,397	1,474		

Table 5. Crossing time during peak and off-peak hours, respectively.

	Peak hours		Off-peak hours		Test	p-value
	Before	After	Before	After		
Crossing time (s)						
0–30	15 %	20 %	25 %	34 %	Fisher's exact test	
31–60	28 %	36 %	46 %	30 %	Crossing time during peak hours	0.09582
61–90	27 %	21 %	21 %	36 %	Crossing time during off-peak hours	0.04856
91–120	26 %	15 %	0 %	0 %		
121–150	4 %	7 %	8 %	0 %	Two-tailed t-test of means	
151–180	0 %	2 %	0 %	0 %	Peak hours mean crossing time	0.24325
Total	100 %	100 %	100 %	100 %	Off-peak hours mean crossing time	0.36786
Mean crossing time (s)	67.6	62.25	51.3	45.7		
Number of pedestrians	125	120	48	44		

green increased slightly. The increase was not statistically significant. However, the share who reported that they had to stop at a red light or that the light turned red when they arrived at the refuge island was reduced. This is in line with the video analysis results, which show that the share of pedestrians crossing the most remote lane (area 2) at red light was significantly reduced. The fact that a smaller share of pedestrians have a green light during their entire crossing is well in line with a more efficient traffic management system. The intention is not that all pedestrians should have a green light while crossing the most remote lane; this would result in delays in the next phases of the signal programme, which would reduce accessibility for other traffic flows.

The above meets the idea of the functionality of the new signal control system. In regard to the length of crossing time of pedestrians, the results suggest that the crossing time was reduced by 5 to 6 seconds during and outside of peak hours, even though these results are not statistically significant. Similar uncertainties relate to pedestrians' reported crossing time. It was observed, however, that the share of pedestrians who had to stop in the refuge island due to red light or who experienced that the light turned red before they arrived at the refuge island was reduced; this result is statistically significant.

The development in pedestrians' crossing time and the fact that a larger share of pedestrians have a red light while crossing area 2 are not contradictory; this is rather a consequence of more efficient traffic management. We must also bear in mind that the initiatives taken to improve the traffic management system were aimed at increasing capacity and facilitate the flow of all road users, primarily by ensuring more flexibility and consequently higher capacity. Consequently, all things being equal, the results achieved would have been more significant if the solution had been directed exclusively towards pedestrians at the expense of other road users.

From a traffic safety perspective, we must remember that the share of pedestrians crossing the nearest lane (area 1) at red light did not in fact change. The share who crossed the most remote lane (area 2) at red light before the implementation of the new traffic management system was identical to the present share. It is therefore plausible that this share will cross both lanes at red light and is indifferent to any changes. Crossing at red light probably relates to risky behaviour in general or implies crossing the intersection during periods of small traffic volumes,

when a number of pedestrians would consider waiting for green light meaningless. It is possible that traffic management which to a larger extent adapts the signal control systems to the immediate traffic volume may significantly reduce the share of pedestrians crossing at red light; however a subset of pedestrians will likely remain unaffected, unless the traffic volume increases dramatically, causing safety to be reduced, or the police decide to spend more resources on this area in the future.

5. CONCLUSION

In the outer ring road in Denmark's second largest city, Aarhus, an intersection has been equipped with a traffic management system which, on the basis of radar detection in real time, ensures green light for crossing pedestrians. This initiative is part of the general improvement of the traffic signal management in the overall road network in Greater Aarhus. The aim was to improve the traffic flow for all road users, including pedestrians. The effect of the improved traffic management system in the intersection was evaluated as a before/after study based on questionnaire data collected among pedestrians in the intersection and on video registration of the share of pedestrians crossing the intersection at red light and the crossing time of pedestrians in the intersection. The main results were that the share of pedestrians reporting that they had only reached the refuge island by the time the traffic signal changed to red was reduced from 42% to 13%. The share reporting a change to red light, resulting in waiting time in the refuge island, was reduced from 18% to 6%. The latter result is not statistically significant, however. The video recordings showed a reduction from 44% to 16% in the share of pedestrians crossing the most remote lane at red light. Crossing time in the nearest lane remained unchanged at 16%. On average, the crossing time was reduced from 68 to 62 seconds during peak hours, and from 51 to 46 seconds outside of peak hours. The latter results are not statistically significant, but are supported by the fact that a smaller share of the interviewed pedestrians reported that they had to wait at red light following implementation of the new traffic management system. In other words, their crossing time was reduced.

Our study suggests that advanced traffic management based on real time registration of pedestrians in an intersection reduces the share of pedestrians

crossing the most remote lane at red light. Moreover, it detected a small but not statistically significant reduction in the average time spent by pedestrians on crossing the intersection. Overall, this indicates that the implemented traffic management has a positive impact on both traffic safety and the length of crossing time of pedestrians.

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