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SLUTRAPPORT
Final Report

Project title:
Energieffektiviseringens påverkan på trafiksäkerhet – analys och utvärdering av IT-lösningar inom väg- och gatubelysning

Project title: Traffic Safety and Energy Efficiency of Future Street Lighting

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Contents:

Summary:

Street lighting systems are very important in terms of traffic safety and energy saving. For the purpose of energy saving, new technologies of street lighting have been developed last decade and implemented in several cities worldwide. The most common of new technologies, with most potential of energy saving, are Light Emission Diodes (LED) and Adaptive Lighting Systems (ALS). The impact of these new technologies on road accidents is not well examined yet. This project attempted to evaluate the traffic safety impact of these technologies on road users, mainly drivers and pedestrians.

The study covered four stages:

1. Literature review by making a survey on how new road lighting systems were evolved and used in Sweden and internationally, in addition how effective these technologies are?.

2. Making a survey among interesting methods and indicators that can be applied in the study for traffic safety evaluation.

3. In order to have a general idea of how LED and adaptive road lighting systems are used in Sweden, interviews with delegates responsible for installation of street and road lighting in five different municipalities/cities in Sweden were carried out. The delegates were all recruited through their membership of the BOB group (Purchaser of Public Lighting group) and were only interviewed if they had stated that they had either LED or adaptive road lighting in their municipality. The interviewees were (Stadsbyggnadskontoret, Sundsvall), (Trafikkontoret, Göteborg), (Trafikverket, Kalmar), (Trafikkontoret, Stockholm) and (Tekniska Nämndens Stab, Västerås). The telephone interviews were carried out during April and May 2013.

4. Field study with a purpose to study the impact of energy efficient light sources on detection distance, i.e. traffic safety. In order to do so, a new method for studying detection distance was investigated within the project. This was done in a field test in a real traffic environment including two unsignalized pedestrian crossings with different road lighting. For car drivers in Sweden, it is required by law to give way at unsignalized pedestrian crossings. The study was conducted as a field study with driving in real night-time traffic on streets with public lighting in November 2013.

The results of the project:

Stages 1 and 2 are explained in;

- The attached paper, which was published at the Journal of Traffic and Logistics Engineering, Volume 2, No. 3.
- The Master Thesis work: Traffic Safety Evaluation of Future Road Lighting Systems, by Michael Dully: http://liu.diva-portal.org/smash/get/diva2:667217/FULLTEXT01.pdf

Stages 3 and 4 are explained in the attached final report.

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The Impact of New Street Lighting Technologies on Traffic Safety

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***Abstract*—Street lighting systems are very important in terms of traffic safety and energy saving. For the purpose of energy saving, new technologies of street lighting have been developed last decade and implemented in several cities worldwide. The most common of new technologies, with most potential of energy saving, are Light Emission Diodes (LED) and Adaptive Lighting Systems (ALS). The impact of these new technologies on road accidents is not well examined yet. This study attempts to evaluate the traffic safety impact and traffic risk of these technologies on road users, mainly drivers and pedestrians. Since the new lighting technologies have been recently tested and applied, the safety impact of them on road users could not be evaluated through direct measures of traffic safety e.g. before/after accident rates. Therefore, this study aims to create a new conceptual framework by introducing some indirect safety measures (e.g. speeding profile, behavior adaptation, traffic conflict, jerky driving and visibility of pedestrians) and presenting relevant performance indicators for future experimental design.**

***Index Terms*—street lighting, night traffic, traffic safety, LED, adaptive lighting systems**

I. Introduction

Road accidents are a major problem worldwide, especially in low and middle income countries. The accident rates and severity index, in terms of fatal and serious injuries, are almost 2-3 times higher at night traffic than in daylight despite that only about 20% of traffic flow takes place at night. Keck [1] found that 80% of the vehicle miles driven in 1988 in US were in the hours of daylight but more than half of the fatalities occurred during the night hours.

Street lighting has been proved as an effective counter-measure to prevent road traffic accidents and severities in both rural and urban roads. A meta-analysis study [2] conducted based on 48 studies in 13 countries to evaluate the effects of providing lighting on previously unlit roads. The overall results on all types of accidents, road users and road types show a reduction of fatal accidents and injury by 60% and damage only accidents by 15% due to roadway lighting.

The total electricity consumption of a street lighting in a city is very high, and it accounts between 10-40% of the total electricity bill. Therefore, many countries worldwide are increasingly interested in applying new technologies of street lightings for the purpose of reducing energy consumption costs.

A wide range of new lighting technologies are developed, tested and implemented in road networks. There are mainly two approaches to save energy from street lighting either to use energy efficient lamps as Light Emission Diodes (LED) or to dim lamps on streets at low or no traffic as Adaptive/Smart Lighting Systems (ALS).

To date the main focus has been given on the reduction of energy consumption of road lighting systems while the traffic safety impacts are not well examined.

The aim of this study is to make a survey among literature and performance indicators those can be used for making an evaluation study of the new road lighting solutions in terms of their impact on traffic safety.

II. The Effect of Street Lighting on Traffic Accidents

The main reason of accidents rate at night (darkness) is due mainly to the lack of visibility, which as a result led to difficulties with detecting obstacles and estimating distances. Visual performance in night-time driving is very complex as relates to several visual elements (uniformity, contrast, color, etc.) and several factors related to (human vision, visual targets, weather, vertical illumination (road lighting), horizontal illumination (vehicle headlights), signals, etc.) [3].

Some other reasons for accidents at night/darkness are due to more presence of animals, wet road surfaces, snow, fog, fatigue, drunken drivers/pedestrians, young drivers, high speed, etc.

A closer look in literature studies (e.g. [4], [3] and [5] indicates that there is a greater risk at traffic night, which means greater effect of street lighting, for specific target groups of road users and conditions:

- Pedestrians than for vehicle occupants.
- Rear-end and single collisions than for frontal or side collisions.
- Rural roads than urban roads.
- Rainy than dry weather.
- Elderly pedestrians, young and inexperienced drivers than in daylight weekend.

The Swiss annual statistical report [6] shows that the number of pedestrian fatalities at night is 60 to 70% higher and has a 212% increase of the kilometer risk factor.

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The U.S. pedestrian accident report investigated data from 1997 to 2006 and found that within the time period from 6 p.m. to 6 a.m. 66% of the pedestrian fatalities occurred [7].

A British study [8] used an indicator for the relationship between one fatal collision and 100 collisions based on the British road accident data from 1996 to 2004. It could be shown that the severity of night-time accidents is 2 to 3 times higher than during daytime. A comparison with statistics from Greece, where injury rates are dramatically different, shows nearly the same relationship between night-time and daytime accidents.

The CIE conducted 1992 a meta-analyses of 62 lighting and accident studies from 15 countries. 85% of the results allocate street light as a beneficial countermeasure. Depending on the class of road and the used accident classification the results show reductions of between 13% and 75%, with an overall reduction of 30% [9].

A study of [4] analyzed injury accidents and property damage accidents in Dutch road traffic during the period 1987–2006. An odds ratio of accident rates was used to estimate the effect on roadway lighting on different road types. In total the effect on all roads was -49% on fatal and -46% on injury accidents. The study estimated the road lighting reduction on motorways to be a 49 percent during darkness.

A study at rural intersection [10] showed that street lighting has also similar impact on safety at intersections. In total, the effect of street lighting was 25-50 percent reduction of night accidents at intersections.

However, despite the fact that roadway lighting has a positive effect on accident rates and number of fatal and severe accidents, it was noticed that drivers adopt their driving behavior after the installation of roadway lighting. Studies (e.g. [11]) showed that due to the improved visibility on the roads it the speed increases and concentration level decreases. This can be explained with Risk Compensation Theory. On one hand reducing luminance levels leads to a reduction in perceived speed, while on the other hand when the perceived speed decrease the driving speed increases.

III. New Street Lighting Technoligies – Advantages and Concerns

Street lighting technologies are evolving rapidly. Our focus in this paper is on two main new technologies in terms of LED lamps and ALS.

LED is a modern technology with a high energy-saving potential. The energy consumed by the LED is less than half of the traditional lamp's energy. According to RCI [12], LEDs have also several other advantages over traditional lighting technologies in terms of longer life period, small size, no emissions, directional light toward target, lower maintenance cost, control options of lighting levels, no dangerous metals, etc. Despite of its advantages, LED technology in street lighting, as an early technology, has in other hand some challenges and problems in terms of high initial costs, inconsistent color, glare, inconvenient for animals due to blue light color. However, due to the many advantages, cities worldwide are increasingly replacing traditional lamps (e.g. mercury vapor lamps, high pressure sodium lamps, metal halide lamps) with LEDs.

ALS is increasingly used in many developed countries. It aims to change lighting levels to suit automatically the existing traffic situation, weather, traffic density and speed. It uses two-ways wireless communication, control and monitoring of the level of lighting system. Luminaire locations can be controlled remotely according to their GPS locations. Studies (e.g. E-street project [13]) showed that it is possible to reduce the energy consumption and maintenance costs for road and street lighting up to approximately 60% via ALS.

In April 2007 the city of Gothenburg in Sweden started to install ALS for road lighting in the district of Tuve and Högsbo. Five years later 20 sites with in total approximately 1800 lamps were implemented. The estimation today is that the average energy consumption per luminaire is reduced to 45-50%.

Additionally, in Sweden, LEDs have been introduced as guide lights in the median of motorways as an alternative to conventional road lighting. Further, many cities in Sweden, have replaced to a large scale the older lamps with LEDs.

IV. Methodology Design – Surrogate Measures

Due to fact that LEDs and ASL are recently installed or tested on some road sections in Sweden and accordingly the number of accidents is yet too small for a before-and-after study, the safety impact of these systems on drivers and Vulnerable Road Users (VRUs) could not be evaluated through direct measures of traffic safety. Further surrogate measures can be applied in evaluating traffic safety measures on the basis of observing none or near-accident events [14].

This study suggests basically four surrogate approaches to evaluate the LED and ALS safety impact.

A. Average Speed and Safety

Average speed or speeding profile can be considered a surrogate measure for safety. Solomon [15] provided some curves displaying the relationship between running speed of vehicles during night-time and day-time with accident probability in terms of accident involvement rate. The curve suggests that "the greater the variation in speed of any vehicle from the average speed of all traffic, the greater its chance of being involved in a accident".

The average speed of traffic can either be measured as a Time Mean Speed (TMS) where the speed is measured at a specific cross section within a certain time period or a Space Mean Speed (SMS) where the average speed is measured of all vehicles on a specific road section.

B. Traffic Conflict Technique (TCT)

One of the biggest problems to analyze driving behavior at accidents is that accidents are rare events and are therefore also associated with random variation. Traffic conflict studies can provide surrogate measures of traffic safety when accident rates are not available. A conflict is defined as: "an observable situation in which two or more road users approach each other in time and space to such an extent that there is risk of collision if their movements remain unchanged" [16].

There is, however, still some debate regarding the connection between conflict measures and accident predictions [17]. The most common indicators in traffic conflict are Time-to-Collision (TTC) and Post-Encroachment Time (PET). Some researchers have indicated that TTC or PET is the surrogate measure of safety. Some research indicates Deceleration Rate (DR) as the primary indicator of severity instead of TTC or PET [18].

C. Naturalistic and Jerky Driving

One of the newest and widespread research methods to observe road users' every day driving behavior is naturalistic driving. Such observations take place during ordinary everyday driving situation, preferably in the own vehicle of the driver, which gets updated with various instruments. Different sensors collect precise vehicle kinematic data (speed, acceleration/deceleration, direction, and position), driver behavior and performance (eye, head and hand maneuvers) or external conditions like characteristics of the road, traffic or weather situation. Since accident situations are rare and random events it is hard to get real data how the driver behaved shortly before the accident.

During the last years a lot of field operational tests (FOT) have been conducted in the United States, Asia and Europe. For example US programs as 100-Car study, 250-Truck study or Strategic Highway Research Program (SHRP2). European projects are TeleFOT, 2BeSafe NDS, INTERACTION, SAFER and the biggest one euroFOT.

According to [19], it is possible to collect data (Acceleration/Deceleration Profile) in order to study jerky driving, and they actually showed how the amount of critical jerks is directly related to the risk of being involved in an accident. Hence, analyzing jerks can be an efficient way for detecting safety critical driving behavior, also called "accident proneness". Jerky driving has also been associated with the tendency to commit driving violations. A study [20] analyzed the relationship between behavioral characteristics and involvement in traffic accidents. The unit used for measuring jerks is the rate of change of acceleration or "jerk rate" (m/s3).

D. Visibility of Pedestrians by Drivers

In Sweden, the duty for motor vehicle drivers to give way at unsignalized pedestrian crossings was initiated in May 2000. The main aim was not to increase traffic safety but to increase accessibility for pedestrians. At a pedestrian crossing, it is very important that a pedestrian who wants to cross the road is seen by a motor vehicle driver approaching the pedestrian crossing. Hence, a relevant question will be discussed in future field study: When and where does a driver look for information when approaching a pedestrian crossing?

In the middle of September 2013, a new camera system will be installed in a car at VTI (the Swedish National Road and Transport Research Institute). The camera system enables eye tracking through video recordings of the road ahead and of the driver's eye movements. This will make it possible to determine where the driver has looked, and driver behavior for instance when approaching a pedestrian crossing with different light levels and systems.

The unsignalized pedestrian crossings will be chosen in order to be visible without other interfering objects. The variables included in the study will be: Dependent variables: detection distance; and independent variables: type of road lighting (LED vs high pressure sodium) and luminance at the pedestrian crossing.

V. Discussion

Based on the selected technique for evaluation of safety (surrogate safety measures), relevant data should be collected. Choice of time period (dry weather) and its length for data collection is a matter, which needs to be taken into consideration carefully. Depending on the selected surrogate safety measure, the experiment setup requires equipment, safety indicators and criteria, which are summarized in Table I.

TABLE I. Experiment Design for Indirect Safety Evaluation of New Street lighting Technologies

Indirect Safety Measure	Indicators/ Experiment Design and Equipment
Safety and Speed	***Indicators:*** Individual/ Average Speed of the traffic flow ***Experiment Design*** Calculating individual speed of the motorist vehicles passing the designated section of the road for evaluating the deviation from mean operating speed. The variation in speed of any vehicle from the average speed of all traffic in both before/after field study will be used as a measure of safety evaluation. Calculating TMS and SMS. Consideration: The length of the road sectors as well as the number of sites should be discussed carefully. ***Equipment:*** • CCTV-Camera • Vehicle Re-Identification Systems (VRIS) • Floating Car Data (FCD) • Applications via Smart Phones e.g. accelerometer, etc.
Traffic Conflict Technique	***Indicators:*** TTC or PET ***Experiment Design*** Calculating TTC or PET for a specific type of conflict (for example, rear-end conflict) and comparing the result for the before/after study. The higher values of TTC or PET indicate the higher level of safety. Consideration: the number and types of selected intersection are important and could help to generalize the result. The type of the camera system, the installation height, location, angle, period of recording etc. needs to be discussed further. Implementation of automated video analyser will facilitate the process of data analysis. ***Equipment:*** • CCTV-Camera • Automated Video Analyzer
Jerky driving	***Indicators:*** Jerk Profile/Jerk Rate ***Experiment Design*** Installing a number of GPS loggers in designated vehicles, and obtaining speed, acceleration and

Indirect Safety Measure	Indicators/ Experiment Design and Equipment
	corresponding jerk profile of the vehicles. The higher Jerk rate (m/s3) indicates the lower level of safety. Consideration: The location and length of the road sectors as well as the number of sites should be discussed carefully. The number of selected vehicles for installation of on-board units (OBU), the type of GPS loggers, the characteristics of the drivers (i.e. age, gender etc), the period of data collection should be based on the experiment design. ***Equipment:*** • Floating Car Data (FCD) using GPS traces • Vehicle Re-Identification Systems (VRIS)
Eye tracking of drivers	***Indicators:*** Dependent variables: Gaze behavior, detection distance; and Independent variables: Type of road lighting (LED?, high pressure sodium?) and luminance at the pedestrian crossing ***Experiment Design*** The unsignalized pedestrian crossings should be chosen in order to be visible without other interfering objects. ***Equipment:*** Eye tracking through video recordings of the road ahead and of the driver's eye movements.

VI. Conclusions

While new street lighting technologies offers a wide range of unique potential benefits (mainly in terms of energy saving), it is necessary to evaluate the safety impact of this technology on road users. One potential approach for evaluating the safety impacts of them versus conventional road lighting systems is to conduct a before/after study. In order to have a direct comparison between the two technologies, it is necessary to conduct the before/after study in a same section of road or motorways or intersection. Conducting the before/after study in a same section of the designated road, will help to have a control on the local factors (i.e. geometric design, traffic volume) which may also contribute to the level of safety. However, since the new generation of street/road lighting is an early technology, the number of accidents is yet too small for a before-and-after study. Therefore, it is necessary to implement surrogate safety measures. Three main approaches in terms of average speed, traffic conflict and Jerkiness are suggested for evaluating the safety impacts of the new street lighting technologies. The naturalistic driving data has potential in comparing driving behavior in segments of the road with and without LEDs and ALS, but one of the main concerns of this approach is the access of data according to GPS locations. It is also necessary to conduct a controlled field study in a large scale in order to minimize the impact of other external influential factors.

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Ghazwan. Al-Haji, Associate Professor at Linköping University in Sweden, is a qualified Transport Engineering, Traffic Safety, Road User Behaviour, Energy Efficiency and Intelligent Transport System (ITS) expert with research, teaching and work experience. These qualifications included quantitative and qualitative assessment of traffic safety and ITS development at micro and macro level, transport benchmarking, development of national traffic safety action plans and evaluation of their effects, distribution of responsibilities among the key professionals and agencies that are responsible for transport and traffic safety in a country, capacity building, and development of networking at national, regional and international level for sharing the good practices and know-how in transport, traffic safety and ITS. Dr. Al-Haji has engaged in a considerable number of research and overseas consulting activities in Southeast Asia, South African countries, Middle East, and Russia. Has worked closely with international bodies such as the Asian Development Bank and the European Commission.

Ghazwan has a good standing experience regarding international cooperation and coordination in higher education e.g. curriculum, accreditation and institutional development. He participated in different international conferences and workshops. Has taught three master courses in Road Traffic Safety and Traffic Planning at the department of science and technology, Linköping University for several years. His PhD research "RSDI" is the first approach worldwide to measure road safety achievements in a country or big city in a simple quantitative value, which was acknowledged internationally.

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Impact of Energy Efficiency on Road Safety – Analysis and Inventory of IT Solutions for Road Lighting

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Final report

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FINDING A BETTER WAY

Acknowledgements

In the field test, acknowledgements go to Carina Fors (VTI), for handling the eye tracking equipment, to Jonas Ihlström and Jonna Nyberg (both VTI) for acting as pedestrians, to Harry Sörensen (VTI) for preparing the car, to Christer Ahlström (VTI) for data acquisition, to S-O Lundkvist (VTI) for advice, to Statoil Gamla Övägen, for letting us use their electricity and of course to the participants who made the field test possible.

Table of contents

1 Evaluating a new method in the field

The purpose of this project is to study the impact of energy efficient light sources on detection distance, i.e. traffic safety. In order to do so, a new method for studying detection distance was investigated within the project. This was done in a field test in a real traffic environment including two unsignalized pedestrian crossings with different road lighting. For car drivers in Sweden, it is required by law to give way at unsignalized pedestrian crossings.

1.1 Method

The study was conducted as a field study with driving in real night-time traffic on streets with public lighting in November 2013.

1.1.1 Equipment

Eye tracking equipment from SmartEye that had been installed in a Volvo V70 was used in the field test. Also, a VBox continuously registering e.g. GPS position, speed and brakings of the car was used. A GPS with verbal information about a predefined road stretch consisting of a number of subgoals was used by the participants. Mobile phones were handled, mostly for simultaneous communication between the test leaders and the extra pedestrians via sms.

1.1.2 Test route

The road stretch driven was a route in the city of Norrköping, Sweden, which contained several unsignalized pedestrian crossings. However, only two were part of the study: One with LED lighting and one with high pressure sodium (HPS) lighting. These two crossings were passed twice on the route. **Fel! Hittar inte referenskälla.** shows the road stretch used in the field study.

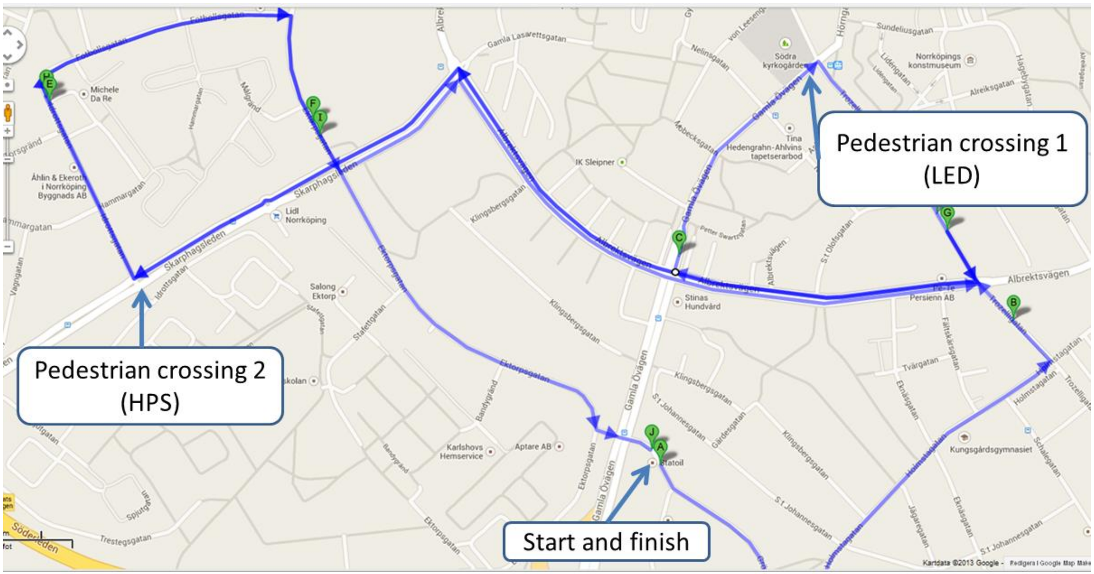

Figure 1. The test route used in the field study.

It can be noted that both unsignalized pedestrian crossings that were part of the study involved a right-turn in connection to the crossing. Figure 2 shows photos of the two crossings.

Figure 2. The unsignalized pedestrian crossings included in the field study, where pedestrian crossing 1 is lighted by LED, whereas pedestrian crossing 2 has HPS lighting.

The illuminance at the pedestrian crossing was measured with a lux meter in three transverse spots, resulting in a mean value of 27 lux for the LED crossing (pedestrian crossing 1) and 21 lux for the HPS crossing (pedestrian crossing 2).

1.1.3 Participants

Four drivers, whereof one female and three males, were recruited for the experiment through convenience sampling, with three persons who registered their interest to participate in a field study through the VTI website, and one person through personal contacts. All of them were living in Norrköping and none of them stated that they wore glasses when driving. They were 35-43 years old and had had their driving license for 17-25 years. Considering the past 12 months they estimated their mileage to 4 000-25 000 km and their total driving in urban areas to 60-80 %.

1.1.4 Procedure

The participants were contacted through phone calls and via e-mail with information about the study, the meeting place and the individual time slot for their participation. All four participants drove the car during the same night in November 2013 and each time slot given was 1 hour, beginning at 7 pm for the first participant and ending at 11 pm for the last.

When arriving at the meeting place, the participant was met by a test leader and given written as well as verbal information about their task in the study. After having potential questions answered, he or she was asked to fill out a form for informed consent.

The participants were instructed that they should drive a predetermined route as specified on a map and according to a verbal-only GPS. The map could be studied in advance, but not during the driving. It was also explained to them that the eye tracking system would be tested by night and that they should drive as they normally would have done. Nothing about pedestrian crossings was said in the instruction. Once the participant was installed in the driver seat, the eye tracking system was prepared for the specific driver by a second test leader.

During the whole trial, the first test leader was positioned in the back seat of the car behind the driver. The road stretch started with a training track, lasting for about 2 minutes, in order for the drivers to acquaint themselves with the car, the GPS and the test situation. During this part of the trial, the driver was allowed to communicate with the test leader. After the training, the driver was told to stop and asked if everything was okay. If so, the driver was told not to communicate with the test leader unless there was uncertainty about the route, but pretend that he or she was alone in the car and start the main test. The drivers drove a road stretch including several unsignalized pedestrian crossings. At one pedestrian crossing with LED lighting (the LED crossing) and one with high pressure sodium lighting (the HPS crossing), a dark clothed extra pedestrian was positioned, unknown to the driver. At specified positions before the LED and HPS crossings, the test leader in the back seat texted the extra pedestrians in order for them to be positioned and ready. When the participant driver approached the crossing, the pedestrian started to walk towards the pedestrian crossing from the left to the right as if he or she intended to cross the road. If the driver stopped to give way, the pedestrian crossed. The same two pedestrian crossings were approached twice. The whole run, from start to end, lasted for approximately 23 minutes.

Having driven the whole route, the drivers were back at the starting point. There they were asked to fill out a form on background information as well as the remuneration form, after which they were thanked for their participation and could go home. The drivers received a taxable amount of 400 SEK for their participation.

1.1.5 Data analysis

After the field test, merging of eye tracking data and video files was carried out, followed by manual scanning of the video files with included eye tracking information for each participant. The aim was to define the first time the driver observed the pedestrian for each approach to the included pedestrian crossings. Having stated this particular time, the GPS coordinates and vehicle speed were collected from the VBox. The GPS position for the current pedestrian crossing was looked up in google maps, enabling calculation of distance to crossing from first observation of pedestrian.

Time to collision, TTC, was calculated using the following formula:

$$TTC = \frac{s}{v},$$

where s denotes the distance from the vehicle to the pedestrian crossing at the moment when the driver observes the pedestrian for the first time and v is the momentary vehicle speed at the same time.

Since the GPS coordinates were missing for two out of four pedestrian crossings for the last participant, pictures of the missing cases were compared with pictures of the non-missing cases to make a best estimation of the distance to the crossing.

1.2 Results

It should be emphasized that this is a very limited study and that to know about the real effects of different lighting, the same, or at least similar pedestrian crossings should be used. Also, due to communication problems, the extra pedestrian at the first trial with the HPS crossing (HPS1) was standing still for participant 2 and was missing for participant 3. However, the results from this field study are described in Figure 3 and Figure 4 in terms of estimated time to collision and distance from first glance at pedestrian, respectively.

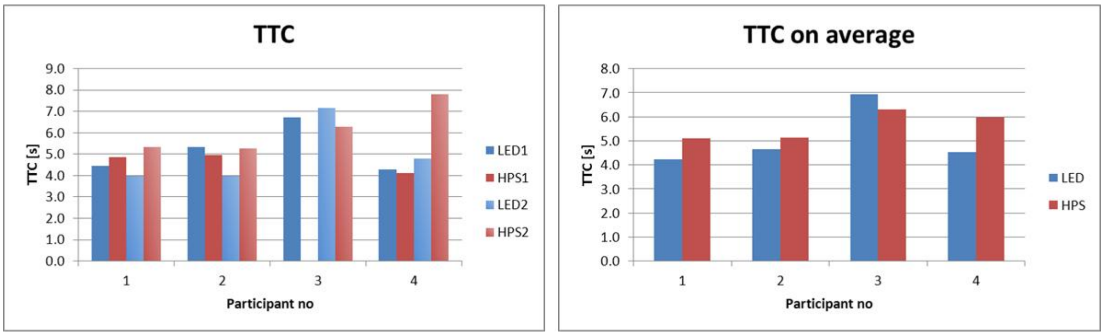

Figure 3. Time to collision, TTC, for each participant driver and pedestrian crossing for each separate trial (left) and on average (right). Note that there is missing data for participant no 3, HPS1.

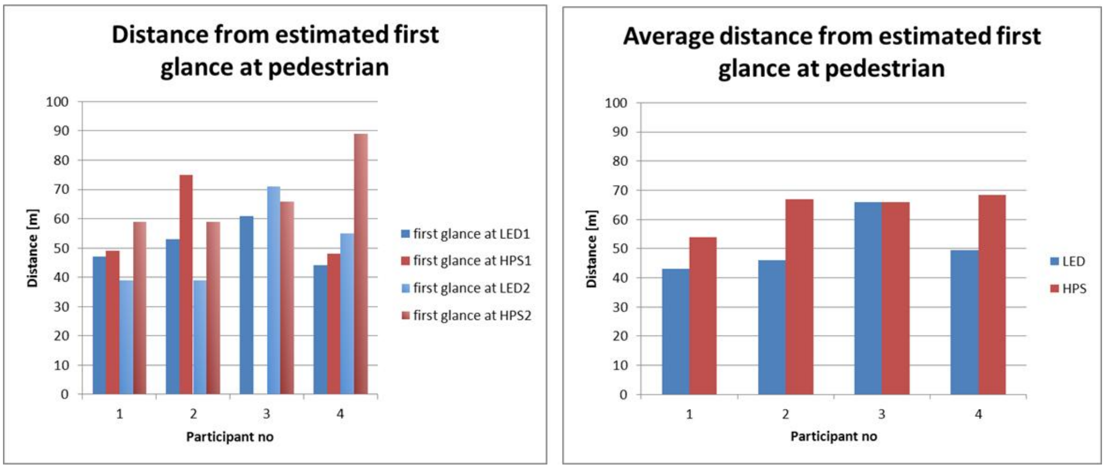

Figure 4. Distance from estimated first glance at pedestrian for each participant driver and pedestrian crossing for each separate trial (left) and on average (right). Note that there is missing data for participant no 3, HPS1.

1.3 Experiences of the method used

Equipment

- The GPS coordinates were only collected for two out of four crossings for one of the participants. A solution is probably to make sure that the cables for collection of the GPS data are ok and to wait a little bit longer before letting the participant drive.
- Reflections in the picture by the camera flashes made it hard to see the details of the video file.
- There were problems with the calibration of the eye tracking system. This could be seen on the video files since the blue "dot" in the file, corresponding to driver gaze, was often not on the pedestrian but near his or her head. (Figure 5 shows examples of snapshots from the video files.) Additionally, the driver gaze given by the eye tracking system seemed to be "jumpy".
- At one occasion, the text message sent by the test leader in the car was not received by the extra pedestrian it concerned due to problems in the mobile traffic, with the result that the pedestrian was not positioned at the crossing.

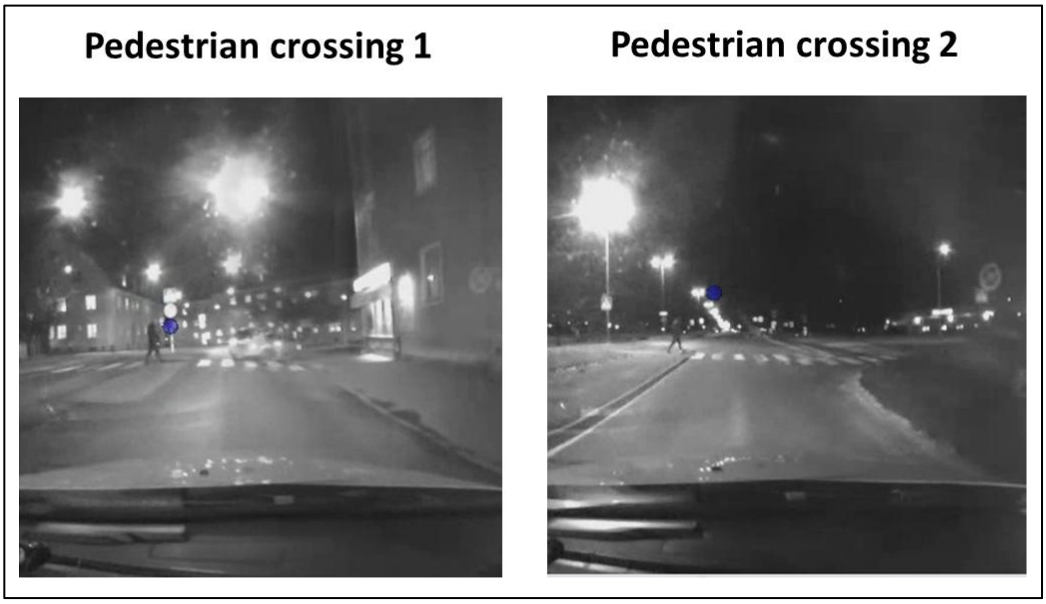

Figure 5. Snapshot examples from the video files at the pedestrian crossings. The images have been cropped for clarity.

Test route and participants

- There were parked cars close to the LED crossing, leading to a maximum distance at which the pedestrian at that crossing in reality could be seen before he walked towards the crossing. The same condition was not true for the HPS crossing. A solution for this is to minimize the differences of crossing by using very similar or even the same crossing with different light sources.
- Although the participants had been trained in driving with the GPS before the actual trial, three out of four participants deviated from the specified route and had to be instructed by the test leader in the car to get on track again during the trial. A solution might be to increase both the length and the difficulty of the training route.

Procedure

- Uncertainty of which car was the experiment car from the pedestrian point of view: At one occasion a pedestrian (at the HPS crossing) mistook the experiment car for another car and stood still on the traffic island instead of intending to cross. At another occasion the pedestrian (at the HPS crossing) mistook another car for the experiment car and crossed the road, discovered the mistake when the experiment car came directly after, crossed back and then again over from left to right. To avoid these situations, the experiment car should be more distinct and easier to discern.
- None of the participants seemed to recognize the pedestrians, despite repeated exposure. The participants did not mention that there was something odd with the experiment.

Data analysis

- Manual scanning of the video files afterwards might be time-consuming and can lead to subjectiveness concerning whether the pedestrian was registered by the driver or not. A small comparison carried out at VTI showed that the difference between two different persons subjective estimations on this data was typically 0-2 seconds, corresponding to about 0-22 meter distance to the pedestrian.
- It is not certain that the driver experiences and notices the pedestrian although the eye tracking marks that the pedestrian is in sight.

1.4 Conclusion

First it has to be stated that from this very limited study, no conclusions about the relationship between type of light source and detection distance can be drawn.

Overall, the method concerning procedure worked quite well in the field, although there is potential for improvement. Since one of the pedestrians was “hidden” behind parked cars while the other could be discerned from farther away, the results concerning light sources in this test cannot, as previously stated, be trusted. More refined tests of the method with a large number of participants should be carried out before conclusions or implications about use of light sources at pedestrian crossings could be made. The eye tracking equipment used had some flaws, why other eye tracking systems would be of interest to test in night-time driving, to try to avoid gaze jumpiness and to achieve better quality of the video files. However, this field test was carried out as a first step to test a method for measuring the impact of energy efficiency in new ways. In that sense, the field test has been a success, while it has led to new and useful experiences for future research.

2 Installation of LED and adaptive road lighting systems in Sweden

In order to have a general idea of how LED and adaptive road lighting systems are used in Sweden, interviews with delegates responsible for installation of street and road lighting in five different municipalities/cities in Sweden were carried out. The delegates were all recruited through their membership of the BOB group (Purchaser of Public Lighting group) and were only interviewed if they had stated that they had either LED or adaptive road lighting in their municipality. The interviewees were Johnas Norberg (Stadsbyggnadskontoret, Sundsvall), Ingemar Johansson (Trafikkontoret, Göteborg), Joakim Frank (Trafikverket, Kalmar), Anders Hedlund (Trafikkontoret, Stockholm) and Erik Pavoson (Tekniska Nämndens Stab, Västerås). The telephone interviews were carried out during April and May 2013.

The following chapter will show summarized results of the interviews, whereas more extensive interview answers can be found in Annex 1.

Installation of LED systems

In summary, installation of LED systems was initialized between 2006 and 2012 in the cities. The sizes of the systems are 300 to 5000 luminaires, partly depending on the size of the city and the installation continues.

Installation of adaptive road lighting systems

In sum, four out of the five cities included in the survey have installed adaptive lighting systems. This was initialized between 2006 and 2013 and the number of systems is between 200 and 3000, with Gothenburg in the lead. It should, however, be noted that the term adaptive is problematic since it is sometimes used for adjustment according to the calendar and time of day, and sometimes not.

Motive of installing and or upgrading to new systems

Four cities mention saving energy as a main motivation for the installation. Replacing mercury and an interest in new technology were also common reasons to upgrade.

Criteria for choice of locations for new lighting systems

The places for the new lighting systems were mainly chosen where there was a need to replace old systems or where there was a reconstruction of roads. In Gothenburg and Kalmar tests were carried out in specific areas according to defined projects.

Vulnerable road users' exposure to new lighting systems

Of the cities included in this study, four mention that pedestrians are bicyclists are exposed to the systems. The majority have also installed or started installation of LED lights on paths for cyclists and pedestrians.

Evaluation of effectiveness of new lighting systems

All cities expect a major decrease in energy consumption, but only Gothenburg has evaluated its installations so far, resulting in an energy saving of about 55-60 % at the first installations.

Challenges experienced regarding installation and operation of new lighting systems

In cities where adaptive systems have been installed some various problems are mentioned. These mainly have to do with installation and adjustments. Also a higher demand of knowledge for people involved is mentioned since there are so many alternatives when buying the systems.

Speed limit and traffic volume at chosen locations for new lighting systems

The systems have been installed on roads with speed limits from 30-90 km and traffic volumes vary between 500-17000 vehicles per day.

Road accident statistics before and after treatments

Statistics about road accidents before and after treatments were not at hand in any of the cities. However, accident statistics after installation on the first sites in Gothenburg were available.

Additional comments from the interviewees

A general concern is the increasing demand of knowledge when buying systems, since there are so many alternatives and there is no standardization. The fact that the systems are expensive and it is uncertain how long they will last is also mentioned.

Annex 1 – Extensive Results from the Telephone Interviews

Answers are presented after each question and for each city respectively.

1) Has your municipality/city installed LED road lighting systems? If yes, when was it installed? What is the size of the new system (e.g number/percentage of new luminaires)?

Sundsvall

Yes, the first LED system was installed three years ago and we continue with new installations every year. Today we have 300-400 luminaires.

Gothenburg

Yes, we are installing continuously and have around 700-800 units. The next step will be to install 200 more this year.

Kalmar

Yes, installed in 2011-2012 as a part of the project LED- Light in Public Space.

Stockholm

Yes, we installed in 2011 or 2012. Including only lighting systems that should be used in reality (excluding test systems) there are approximately 5000 luminaires replacing metal halogen on small streets. They are all in the western and southern parts and not in the central parts of the city and most of the units are luminaires from Philips.

Västerås

Yes, installation started in fall 2012. Totally there are 200 luminaires, whereof 120 are placed in a small residential area (Billsta) and 80 are placed along a large link (Norrleden).

2) Has your municipality/city installed adaptive road lighting systems to dim the light when there is no or less traffic? If yes, when was it installed? What was the size of the new system?

Sundsvall

No, not yet, however we are looking into this.

Gothenburg

Yes, we lead this trend in Sweden and installed the first system in 2006. Today we have around 3000 adaptive road lighting systems and in the later installations most parts are adaptive. We regulate the systems according to certain times calculated from statistics both of traffic flow on the streets and type of traffic on the streets. Regarding bicyclists and pedestrians we think more about safety and security and dim the light later at night (eg. 12 pm instead of 9 pm).

Kalmar

There is an adaptive lighting system adjustment according to the calendar and time of day, however the interviewee does not consider this as an adaptive system. The lighting system on the bridge to Öland is adaptive and controlled by driving speed, friction, weather and wind (when snowing or raining light levels are increased). This is an ongoing installation and the steps used are 0.3; 0.5; 0.65 and 0.8 cd were 0.8 cd is comparable to previous settings. The complete bridge includes 360 luminaires, however including parts before and after the bridge results in change of totally 412 luminaires.

Stockholm

Yes, this is integrated in the luminaries, installed at the same time, who are all controlled individually. The system consists of around 1000 luminaires. There is automatic dimming at nighttime leading to a power decrease of 30%.

Västerås

Yes we have a system called StarSense from Philips, controlled by radio communication and preprogrammed dimming cycles. The light is dimmed approximately 20% at 9-10 pm, 30% more after another couple of hours resulting in 50% of normal power during the night. The system was installed at the start of this year, however some parts are still missing. In total, there are 200 luminaires. 18 of these are controlled by presence and placed in Önsta and Gryta in north Västerås, on a bicycle path leading to a residential area. 250 luminaires will be installed in Hamre this year.

3) What was the motivation behind the installation/upgrading of the new systems (e.g. replacing mercury lamps, energy saving, maintenance and operation costs, safety, etc)

Sundsvall

The main aim was to try out new technology and decrease the energy consumption. Mercury lamps had already been replaced, so that was not critical for us.

Gothenburg

To replace mercury and make the systems more effective. This will be completed within next year and is a part of the community zero vision for pollution. Decreased maintenance costs follow as a result.

Kalmar

The existing luminaires were worn out after 22 years and so were the cables from 1972. The control system was a minor cost in this context. There was also an interest to try out new technology and see if it would work. The control system is a part of a project introduced by The Swedish Transport Administration, New Light (aiming to find the most energy efficient way of illuminating our roads and nationally coordinate tests of new technology, http://www.trafikverket.se/nyttljus)

Stockholm

Saving energy was the main aim and also to increase the life of the luminaires. Energy consumption has decreased with 19%.

Västerås

The aim with the presence controlled lighting was to try it out. LED has been installed to replace mercury and to save energy.

4) What was the criteria for the choice of locations where the new lighting systems have been implemented (e.g. in urban roads, rural roads, highways, intersections, etc.). Can you provide a simple map on these locations!

Sundsvall

Installations have been made in association with reconstruction of roads. We work with the whole road and every aspect at the same time. Bruksgatan, Vasagatan, Appelbergsvägen, Västra vägen, Sivsjövägen, Lasarettsvägen, Granlöholmsvägen, Hulivägen, Trafikgatan, Bygatan. This might sound more than it is, since some stretches are quite short.

Gothenburg

We started with a first test to see how it worked (see video from Naturvårdsverket). This was made on Tuvevägen and Högsboleden which include industrial areas, housing areas and city streets. Today the systems are installed in many various areas, however mainly on roads and streets. On Gammelstadsvägen there are 180-190 LED luminaires with control. Some have been installed in Majorna, on Tagenevägen, Valebergsvägen, Vinnarhult, Valhallavägen, Wadmansgatan (a whole block), Övre Salgatan on a new 3 km long bus road, around Heden. We don't have so many systems on cycle or walking paths yet but this will come. A complete control system has been installed in Backa, which is an area exposed to violence. 1000 units have been installed and 400 more will be added during this year.

Kalmar

The plan for LED- Light in Public Space is to do a test installation of LED lights on cyclist and walking paths as well as in roundabouts. The project is led by "Serviceförvaltningen" in Kalmar (http://www.kalmar.se/t/page.aspx?id=42160). Adaptive lighting is localized to the Öland bridge.

Stockholm

According to the needs to change luminaires. (Örby, Hässelby are dimmed at night time). Unfortunately there is no map of the roads included.

Västerås

Places where it was necessary to replace the mercury luminaires, Billsta and Norrleden. (See the attached file for a map.)

5) Have pedestrians and bicyclists been exposed/tested to the new lighting systems?

Sundsvall

Yes, some small initial tests with equipment from different manufacturers were made on roads dedicated for pedestrians and cyclists. At the moment we focus a lot on pedestrians and bicyclists by placing the walking and cycling path next to the road and replacing the high luminaires with lower luminaires.

Gothenburg

Yes, some tests were made on luminaires from Holland which weren't very expensive and fully integrated. Otherwise they are often very expensive. We are working on an installation for bicyclists and pedestrians along road 190 from Large to Gråbo.

Kalmar

I am not sure in Kalmar. However, there are places were pedestrians and cyclists have been exposed/tested to the new lighting systems (Nytt Ljus Kalix/ New Light Kalix was mentioned).

Stockholm

Yes, around 2010 LED light was installed on test paths for bicyclists and pedestrians along Drottningsholmsvägen towards Alvik. Initial tests with light distribution were made to illuminate the area around the bicyclist.

Västerås

Yes. ActiveLight bollards have been tested previously on a 3 km long cyclist path, where three bollards are lit according to where you bike. However, this was no lighting for security. Now "real" presence controlled road lighting is tested on the same road stretch which is now lit with LumiMotion. There is a camera on each pole communicating with the luminaires. Three luminaires are lit to full effect when presence is detected. After one minute, they go back to the basic light level of 20%. This road lighting has existed for two years (2011-2012). We have tested the systems ourselves and talked to cyclists regarding the presence control. LED is very specific and does not give any surrounding light, which can decrease security. However, it gives better light than the old mercury lamps and the people are very pleased.

6) Has the effectiveness of the new lighting system been evaluated? What variables were used for evaluation? What were the major results?

Sundsvall

We have no statistics regarding this, however the energy consumption has decreased. We expect to see possible decreases in maintenance costs within 10-15 years.

Gothenburg

The first installations have been evaluated and can be downloaded from Esolis webpage. This evaluation showed an energy saving of 61-62% on Tuvevägen and 56% on Högsboleden.

Kalmar

Calculations suggest a decrease of 100 000 kWh/year (from previously 160 000 kWh/year). The change from sodium to LED saves 70 000 kWh/year and the other decrease is due to the control system. Thus a decrease of 30-40% is expected.

Stockholm

Calculations only are available from the supplier's product information. Replacing old technology should save 2 GWh/year.

Västerås

A major decrease in energy consumption follows the shift from mercury to LED (from 200 W to 20-30 W). According to the suppliers there will also be saving on maintenance.

7) Were there any major problems/challenges regarding the installation and operation of the new lighting systems?

Sundsvall

There were no challenges since the installation of LED is no different compared to normal installation. Difficulties might arise once we start with adaptive systems.

Gothenburg

No problems or challenges with the systems, however with the installation and with maintenance personnel worried about their jobs as they now work with replacing bulbs.

Kalmar

There are quite many problems with adjustments according to function demands. Fat tests (factory acceptance tests) lead to problems from the suppliers' point of view (there is no knowledge of sat tests, site acceptance tests, yet).

Stockholm

Standardized calculations for straight roads are not applicable for turning spaces since the light can be glaring due to curves or level differences. This problem is more apparent with LED since the lens technology involves a more direct light.

Västerås

Everything is new, which increases the demand on our contractors. More knowledge is also required from the people ordering the systems. The infinite possibilities lead to immensity if all light units (26 000 in Västerås) should be specifically controlled. Due to the fast development, it is not possible to buy one luminaire and believe that this specific type will remain in the assortment next year.

8) What is the speed limit and traffic volume in the chosen locations? Was there any change of speed and traffic volume before/after treatment?

Sundsvall

Roads with speed limits from 30 to 70 km/hour and traffic volumes from 500-10000 vehicles per day. There has been an increase in the volume on the bicycle roads, however this might also be due to new asphalt.

Gothenburg

Roads with speed limits of 50 or 70 km/hour. Changes in traffic volumes have to do with taxes.

Kalmar

On the Öland bridge driving speed varies between 50-90 km/h with 15 000-17 000 vehicles per day. At the most there have been 32 000 vehicles on one day (always maximum on 15th of July).

Stockholm

LED has mainly been installed on streets with speed limits of 50 km/h, however also on a few with 30 km/h.

Västerås

The speed limit in Billsta and Hamre is 40 km/h, on Norrleden (link) it is 70 km/h.

9) Are there any statistics record about road accidents before/after treatments?

Sundsvall

No

Gothenburg

Yes, there are accident statistics from Högsboleden and Tuvevägen (see the attached files).

Kalmar

No

Stockholm

Not that we know of.

Västerås

No

10) Please feel free to add any additional comments.

Sundsvall

LED is definitely the future, however it will be interesting to see if they hold as long as promised. Warranty is given and varies from 2 to 10 years.

Gothenburg

It is all about intelligent cities and intelligent systems calculating the most efficient lighting. Sometimes people complain, however after making some small adjustments people are happy again.

Kalmar

It is important to know what one would like to buy, regarding LED and control units. There are no standardized ways of defining these things, leading to higher demands of knowledge for the customer. The products in the luminaires are not standardized and until they are the customers will be unsure and LED will not be a success.

Stockholm

We are interested but also skeptical. Since LED is twice as expensive as metal halogen when it comes to replacing mercury, LED is not installed automatically any more. Today we have 30 000 mercury lamps left to replace and also by choosing metal halogen there would be an energy saving of 40 %. Another reflection is the focus on adaptive control, which has higher demands on maintenance if something breaks down. We have around 1100 electricity centrals. A request is standardization of the products in the luminaires, as well as of the communication between the electricity central and the luminaire, to avoid dependence on one specific manufacturer.

Västerås

The systems are good and there are many possibilities. However one cannot have 15 different systems.