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Contents

Summary

This prestudy investigates the novel idea that drones equipped with lighting capability could be a viable replacement for light poles in rural areas with long cycling distances and a low frequency of cyclists, which we believe will contribute to reduce single bicycle crashes. A drone lighting system may also contribute to an overall increased perceived sense of safety, but the current pre-study is only the first steps toward an implemented service and focuses mainly on how such a solution may affect the behavior and experience of the cyclist and the acceptance of such a system.

The purpose of the pre-study was thus to take the first steps to investigate whether a drone lighting system can be a viable replacement for the traditional lighting infrastructure of bicycle paths and whether it can improve the traffic safety for cyclists on rural bicycle paths. The pre-study aimed to contribute to Safer's vision "All road users travel safely in the road transport system" by investigating novel and possibly cost-effective ways of increasing the safety of cyclists in areas outside the city center.

The prestudy has performed focus group interviews, simplified experience tests with VR-googles allowing subjects to experience the drone lighting system by means of an interactive 360° film of riding the bicycle with and without the drone lighting system. The prestudy has also performed two live tests with the drone lighting system at the bicycle path in Skara.

We have found our studies to be consistent with previous studies, many participants mention that they are afraid biking in darkness, both in terms of being afraid of being assaulted and being in an accident due to darkness. Regarding the drone lighting system's interaction with the cyclist, we have made improvements to the systems abilities which have had a positive effect on the user experience and cyclist behavior.

Another outcome of the prestudy is a new Vinnova funded project called "Förändrade resvanor – hållbar mobilitet" where we besides traffic safety broadened the focus to also include possible health and climate effects on using the drone lighting system by increasing the likelihood to bicycle even in darkness. The project was approved and started during the duration of the pre-study, so the two projects have run in parallel.

Drone Lighting Systems: will it take off

1 Background

In the journey of mobility transformation to more active mobility, such as cycling and walking, a common challenge faced by all municipalities in Sweden is the lengthy Nordic Winter environment. Lack of lighting infrastructure can be a barrier that prevents people from cycling after dark, even with good dedicated bicycle paths. This project, taking the bicycle paths[1] in the Skara municipality as a test case, aims at developing innovative and economically viable solutions with drones for both lighting the bicycle roads as well as providing companion support to improve cycling safety and comfort, thus supporting the changing of travel habits.

The municipality of Skara have proposed the idea that drones equipped with lighting capability could be a viable replacement for light poles in rural areas with long cycling distances and a low frequency of cyclists. Drones have been suggested for several uses, such as delivery, traffic monitoring, rescue, and firefighting (Khan, et al., 2018). Some investigations on using drones to provide lighting have also been done such as by Directline Fleetlights[2] in the UK. While an important and obvious motivation for drone lighting is that it can contribute to a perceived sense of safety, the current pre-study focuses on how such a solution may affect the traffic environment, the behavior of the cyclist and other road users, as well as the acceptance of such a solution.

Darkness is a well-known factor for increasing the risk of accidents for vulnerable road users. Johansson, Wanvik and Elvik (2009) concluded that the risk for cyclists increases by 55% in darkness, compared to daylight. Lighting, for example of bicycle paths, is a costly endeavor, as the light poles are placed at short intervals on relatively long bicycle paths, leading to a high initial investment cost as well as extensive maintenance costs during its life time. Besides the safety of cyclists lighting is important to encourage more active travelling with bicycles, especially during the long and dark winter in Sweden,. Indeed, surveys among the citizens of Skara have indicated that lighting contributes to an increased sense of security and is a common and recurring theme in a survey performed by the Municipality of Skara (Skara Citizen Dialogue, 2020). Schepers and den Brincker (2011) notes that while previous studies have identified road surface factors (ice, road damage) as a major contributor to single-bicycle accidents, the visibility of objects and the road structure also seem to be important factors, and that poor light conditions may also be contributing to an increased risk. They a speculated that older cyclists' reluctance to cycle in darkness might be related to reduced visual performance due to "impairments in ambient vision needed for precise steering" (p. 324) but also to the perceived sense of security as indicated above.

[1] Bicycle path here refers to a lane/road separated from traffic and aimed for cycling (but may be shared with pedestrians).

[2] https://www.directline.com/fleetlights

2 Project set up

2.1 Purpose

We believe that the major impact of drone lighting systems will be to reduce single bicycle crashes (cf. Schepers et al., 2015; Schepers & den Brincker, 2015) by increasing the visibility of the road for the cyclist, but also to some extent reduce the risk of collisions with motorized vehicles by enhancing the visibility of the cyclist. The purpose of the pre-study was thus to take the first steps to investigate whether a drone lighting system could be a viable replacement for the traditional lighting infrastructure of bicycle paths and whether it can improve the traffic safety for cyclists on rural bicycle paths. The pre-study aims to contribute to Safer's vision "All road users travel safely in the road transport system" by investigating novel and possibly cost-effective ways of increasing the safety of cyclists in areas outside the city center.

The project also aimed to support the Safer-related research targets on Road User Behavior as follows:

- A main focus of the pre-study was to investigate how the cyclists' behavior may be affected by drone lighting in comparison to no lighting or traditional lighting. The project also measured several user experience indicators thus contributing to "Define and measure user experience indicators related to safety."
- The pre-study investigated interaction between cyclists and unmanned aerial systems, which contributed to "ensure safe interactions between automated vehicles and other road users, including vulnerable road users".
- The pre-study involved a novel approach involving interactions between drones and cyclists thus contributing to "Develop and evaluate novel interaction principles, including nudging."

2.2 Objectives

In the pre-study application the following objectives were listed.

1. investigating user acceptance and perceived sense of safety,
2. identifying traffic scenarios that may have an impact on safety,
3. draft a proposal of how the traffic scenarios should be tested and analyzed
4. performing a concept based demonstration in relation to the identified traffic scenarios.

There was a slight change in the objectives as objectives 2 and 3 were given less priority since they intended to identify traffic scenarios of relevance on a more general level than we did during the project. This was due to our decision to focus mostly on the type of rural bicycle path that was of interest for the municipality of Skara and that the work on objective 1 and 4 took more time than anticipated. Also, the time and preparation of performing actual tests with the drone lighting system has taken more time than anticipated.

As will be described later, at the time of submitting the application for this pre-study the project team discovered a suitable Vinnova call which could further the investigation of the drone lighting system and we submitted a proposal to that call which was also successful. This allowed us to, together with the Safer funding, do more studies involving

users and more live tests with actual drones as well, with the consequence that the full analyses of that material is still ongoing.

2.3 Project period

2021-08-01 – 2022-08-01

2.4 Partners

-
- University of Skövde
- Jönköping University
- RISE

- Skara Municipality (not member of Safer)

3 Method and activities

One challenge with the drone lighting system is that it is a novel innovation, which means that it is more difficult to predict how users will perceive and interact with the system and it also difficult for potential users to envision how it would be like, hence making it more challenging to elicit user needs and behaviors. However, it is of course possible to overcome these hurdles, e.g., by using VR-googles. In this section we briefly describe the methods used.

3.1 Drone lighting system – brief description

The drone lighting technical solution is based on a commercial drone for DJI, a RISE-developed third party app for controlling DJI drones and a RISE-developed iOS app that publishes the cyclists position. In the background RISE drone system software connects the entities and the drone automatically follows the cyclist (the iOS smart phone).

3.1.1 Drone

The drone used is a DJI Mavic 2 Enterprice Dual equipped with a spotlight payload. It is a versatile commercial drone with a thermal and daylight camera and the possibility to mount payloads such as spotlight, loudspeaker, or beacon light.
The spotlight payload holds two 13W LEDs with reflectors that gives a FOV of 17° and illuminates 11lux @ 30m straight according to the specification.
The drone weighs 975grams and can fly for 22 minutes with the spotlight installed and turned on. The drone supports the mobile SDK which enables third party apps to control it.

The model has reached end of life, but is replaced with a drone with the same or better capabilities. The cost of the drone used in these trials was approximately 35’000kr.

3.2 Software

The solution relies on four softwares:

1. RISE central resource manager
2. RISE DJI-DSS
3. Cyclist mobile application
4. RISE follow stream application

3.2.1 RISE central resource manager, CRM

The task of the CRM is to keep track of all processes and mainly contact info for each process (ip-number and port for initial communication). The CRM also handles ownership of drones. The CRM is a opensource python package developed by RISE and it runs on a server connected to the internet.

3.2.2 RISE DJI-DSS

The RISE-DSS software is a so-called third-party app for controlling DJI drones utilizing the mobile SDK. The app replaces the ordinary DJI Pilot app, but looks similar. The difference to the original app is that it exposes the RISE drone system API to the network, enabling us to control the drone via an application – somewhere on the network.
When the RISE-DSS is launched it registers to the CRM which takes the ownership of the drone and awaits an application to request it.

3.2.3 Cyclist mobile application

The cyclist mobile application registers to the CRM upon start. Once the user taps ‘get drone’ the application starts publishing it position and the CRM launces RISE follow stream application.

3.2.4 RISE follow stream application

The RISE follow stream application requests an available drone with spotlight capability from the CRM. The request is granted, and the spotlight drone is assigned. The application connects to the drone and takes off and starts following the GNSS-stream of the cyclist mobile application.

For the time being, the lamp is not equipped with gimbals which means the only way to adapt the lighting angle is to adapt the drone flying angle. Further improvements to introduce flexibility to change the lighting range and strength are under development.

3.3 Survey on user needs with regard to biking

We have constructed an online survey with the purpose of understanding the habits of the users, e.g. how they would like to use their bicycle, and whether darkness is a hindrance. The survey has so far been sent out to one of our target groups, older adults,

and we have received 32 responses. We are intend to distribute the survey to other target user groups too, as well as more generally, in recent time.

3.4 Focus group studies

We have conducted two focus groups with the user group older adults. The focus groups were carried out at the Skara city hall in June 2022. Each focus group had 3 participants and lasted for two hours.

3.5 VR-google testing

As mentioned above, it may not be easy to imagine the experience of the drone lighting system as it is a novel innovation. To be able to investigate and receive some initial experiences and input to the development of the drone lighting system, we have been using a 365 degree camera that recorded the riding with 1) a bicycle light only, and 2) with the drone lighting system. The video is then used in a VR-headset for mobile phones, which allows the user to look around during the bicycle ride (see **Error! Reference source not found.**). While it is not as immersive as a proper VR-environment where the control and speed of
the bicycle is determined by the person too, we believe that the VR headset does give an impression on the possibilities of the system and how it differs from using only a bicycle light.

For each trial, the participant first saw either the bicycle light only or the drone lighting system movie and immediately after was asked to fill in a questionnaire. The order of the movies was balanced across participants.

Figur 1 VR-google study. Participants experienced either a bikebicycle ride with only bikebicycle lights or with the drone lighting system. After each they answered a questionaire about their experience.

3.6 Drone lighting system trials

We have performed two initial trials with the system on the actual bicycle path in Skara. The first occurred in November 2021. The purpose of the first trial was to 1) test the

current version of the drone lighting system and how it is able to follow the cyclist, 2) get a first impression on how the light is experienced and what of the environment is lit up, and 3) familiarize the project team with the current state of the drone lighting system. In this trial several members of the project team were able to experience the system.

The second trial occurred in March, and the purpose of that test was to investigate the improvements of the system from the first trial and to, in more detail, test different lighting conditions created by the drone lighting system. In this test, one of the project members were subjected to different conditions and was interviewed regarding the experience of the light and drone system.

4 Results and Deliverables

In this section we present the results of the pre-study. We should note that some of the studies mentioned in the methods section is not yet fully complete but are ongoing (and funded by other sources, see Section 4.4).

4.1 Focus groups and user surveys

The first analyses of the material show that darkness is a factor when deciding to travel by bicycle or car. Consistent with previous studies, many participants mention that they are afraid biking in darkness, both in terms of being afraid of being assaulted and being in an accident due to darkness. It is also the case, that the darker months also comes with worse weather which in itself is a factor that affects the likelihood of taking the bicycle. Thus, it is somewhat difficult to fully separate the effects for each of these factors.

4.2 VR-headset testing

A consistent result so far is that participants believe that the drone lighting system is promising and that it provides better lighting conditions. We have also been able to get indications that some feedback from the VR-studies is available on how the participants would like to improve the drone light (such as lighting further ahead and to the sides), but data collection and analysis is ongoing.

Figure 1 Bicycle light only. Filmed from above with a drone.

4.3 Drone trials

In the first drone trial, we noticed that the system had some difficulties following the cyclist and made too large speed adjustments which caused the drone to tilt backwards and forwards together with the light. Since the light is stationary on the drone, this caused the light on the ground to move back and forth which was experienced as disturbing for the cyclists. While the project team is admittingly somewhat biased, everyone that tested cycling with the system had very good experiences with it and it

was at this point that we all were convinced that the drone lighting system is something more than just a bicycle light or stationary light poles.

Figure 2 Drone lighting system, low altitude causing much light on smaller area.

In the secondary test trial, we discovered that the altitude and the amount of light is quite important for the cyclist. Having too strong lighting of the ground caused the cyclist to experience the cycling as scary as there was a sharp edge between light and darkness (see Figure 2). This made objects suddenly appear from darkness to fully perceivable which was experienced with unease. It remains to be tested, whether such lighting could be used to decrease the speed of the cyclist. When we increased the altitude of the drone, creating a more dispersed light cone with lesser strength, the cycling experience was much better (see Figure 3).

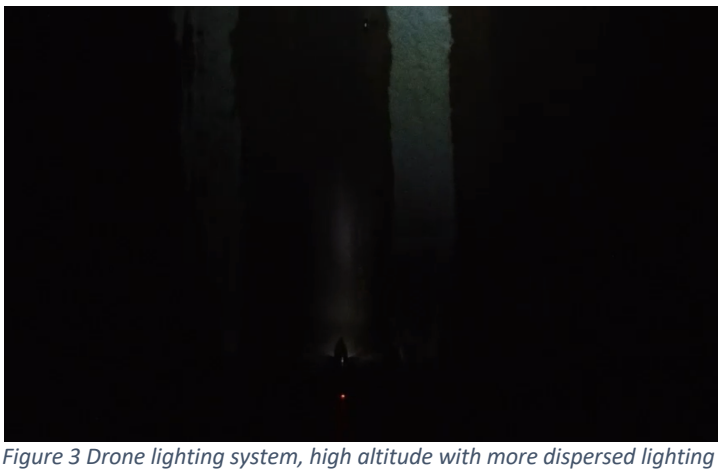

Figure 3 Drone lighting system, high altitude with more dispersed lighting

4.4 Vinnova project : Skara Skyddsängel - *Infrastrukturtjänster on-demand för säkrare, tryggare och bekvämare aktivt resande (2021-10-01 - 2023-09-30)*

In the expected results section of the pre-study proposal it was stated that ". … an additional aim will be to find suitable funding sources for more comprehensive investigations". As it turned out, we could immediately after submitting our pre-study proposal start working on a project proposal to the Vinnova call "Förändrade resvanor – hållbar mobilitet" where we besides traffic safety broadened the focus to also include possible health and climate effects on using the drone lighting system by increasing the likelihood to bicycle even in darkness. The project was approved and started during the duration of the pre-study so the two projects have run in parallel. Thus, one of the expected results of the pre-study was achieved even before the end of the pre-study. The project is also now an associated project with Safer.

5 Conclusions, Lessons Learnt and Next Steps

The drone lighting system is still in its infancy, but the pre-study has further shown that the idea has potential. As discussed in the previous section there are many open questions before a drone lighting system can become an implemented service for municipalities.

There are financial difficulties on providing road lighting in Swedish rural areas, and drones may provide a viable solution. However, challenges must be taken care of before such a system can be introduced including the technical solutions, the acceptance, the physical infrastructure, and regulations, as described in more detail in next section. This project provides experiences, as a first of its kind in Sweden, on using drones for road lighting. Key take aways include:

- Road lighting is important for active travel, and it affects the travel choices between vehicles and cycling,
- Cyclists experienced improved safety perception with better lighting compared with bicycle lighting itself
- Active cyclists welcome new solutions that support their choices, though solution requires further improvement
- Drone solutions are introduced from different perspectives in municipalities and close observation of drone usage is needed to explore the potential for efficient integration.

The prestudy has prepared necessities to gather stakeholders for further research and innovation. The drone systems developed are under further developed and could be used in future tests with improved experiences. The focus group results could be extended to include more diversity such as ages, genders, new residents who move to the resident area recently, etc. We also developed VR environment based on Unreal Enginee which could be further developed for expanded user studies. The results will also support the municipality to evaluate the solution potential for realistic introduction.

5.1 Open questions

During the pre-study, we have realized the limits of the current project as there are many aspects of the drone lighting system that need to be investigated before advancing to higher TRL-levels of the system. To just give a few examples of the open questions:

Drone-perspective

- Is the flight stable enough to keep the light-source stable?
- Is the following ability precise enough to keep the light source at its intended target position?
- How can obstacles be avoided?
- How do current regulations need to be adapted to allow for a drone lighting system in certain environments?

- How should various physical obstacles, such as power lines and trees be handled sufficiently?

Human and lighting-perspective

- How does the lighting of the road change when the altitude of the drone changes?
    - How much area is illuminated at which altitude?
    - What aspects affect the lighting of the road and objects?
    - How is the light spread on the area?
    - How much light is there on the ground and objects?
- What is the difference in illumination/lighting from a regular bicycle lamp?
        - Illuminating objects from above and from the side? Possible examples to test:
            - Reflexes
            - Objects on road
            - Road surface (ice, gravel)
        - Area of illumination
        - Amount of light
- How can drone lighting improve the perception of the road and dangers on the road
    - Detection of road path ahead (e.g. curve, descent, crossing approaching)
    - Detection of objects on the road
    - Detection of ice
- How is the perception/lighting of approaching pedestrian/cyclists changed by the approaching drone?
- How does the drone lighting change gaze behavior, visual attention?

5.2 Possible further experiments

It is practically challenging to perform experiments with the drone lighting system as it requires darkness and also a substantial amount of preparation time and logistics and practical handling of the drones during experiments. Hence, both within the scope of the current pre-study and the larger Vinnova project the amount of experimentation is limited. But we here provide some suggestions for future studies, some of which may be incorporated in the Vinnova project.

5.2.1 Test of detection and visual performance in relation to light

On the bicycle path in Skara, which is relatively straight and with relatively new asphalt, possible hazards are objects on the road, ice patches, or other pedestrians or cyclists. It would be useful to investigate how the drone lighting can be optimized to support detection of these. Experiemental set ups with the following dependent and independent variables would be used and illustrations of the possible set ups are found in Figure 4 and Figure 5.

- Dependent variable: distance to object when identified

- Independent variables:
  - Drone light
    - Present
    - Not present (but bicycle lamp)
  - Drone lighting placement
    - centered,
    - in front of (6m)
    - further ahead of cyclist (12 m)
  - Objects:
    -
    - Cyclist or pedestrian crossing with reflective west
    - Cyclist or pedestrian crossing without reflective west
    - Obstacle (box simulating rock)
    - Ice patch (simulated by Plexiglas or similar)

Speed of the cyclist may be investigated as both an independent and dependent variable.

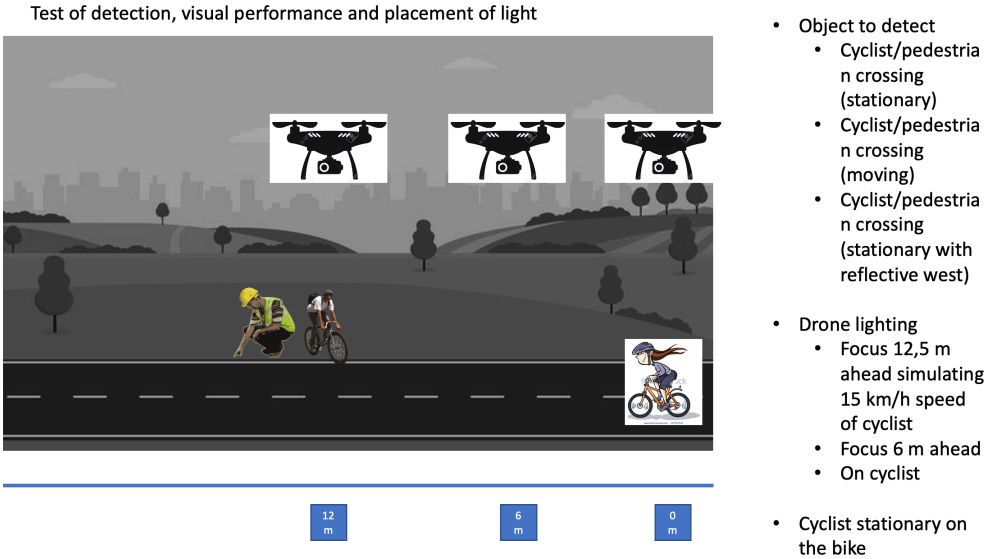

Figure 4 Possible experimental setup 1

Figure 5 Possible experimental setup 2

6 Dissemination and Publications

The drone lighting system was presented at the Kista Mobility Day (May 9). The project was presented both during a panel discussion together with a drone delivery project (panel participants from the pre-study: Henrik Svensson (Högskolan i Skövde), Lei Chen (RISE) and Maria Nordström (Skara)) and at an exhibition area, where we also used the VR-headsets to show the drone lighting system.

The drone lighting system was also presented at the final seminar of the Interreg SMaRT-project. Project representatives consisting of municipality civil servants from Skaraborg and Varberg were attending, as well as two municipalities in Denmark (Hjörring and Aalborg). In addition, representatives from commercial organizations also participated.

We plan to submit at least two publications: 1) a position paper describing the concept and challenges, and 2) a paper describing the results of the project.

7 Acknowledgement

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