Documentation

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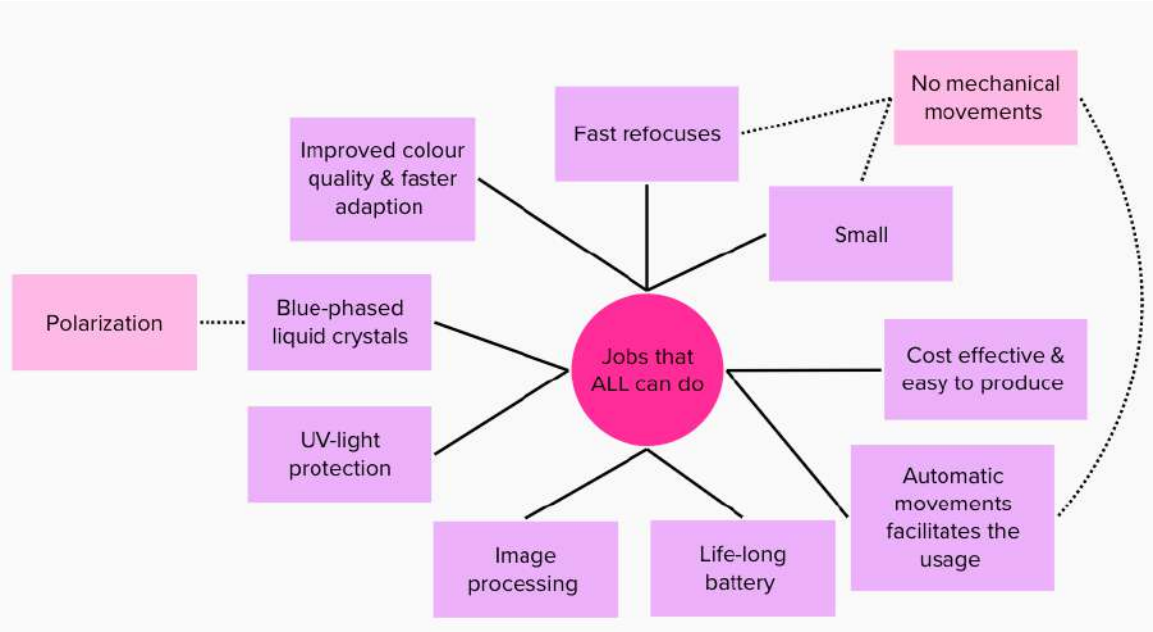
1. Introduction

The following documentation is the result of a five-week project. The mission of this project has been to find potential implementations for the use of the adaptive liquid crystal lens-technology (ALL). The documentation features several different paths that have been discovered during the exploration phase of this project. The initial stepping-stone for these ideas are problems that have been researched to different extents, following a process of identifying jobs to be done in order to solve these problems. In those cases where the solutions have a need for lens-technology, further research is conducted to develop these ideas and consider how the ALL-technology can perform these jobs. Research includes scientific articles, web-pages, as well as more hands-on exploration such as interviews and visiting relevant institutions. The documentation culminates in a final solution which is formulated into a design brief which is then sent to a team for further development.

Brainstorming on the advantages of ALL:

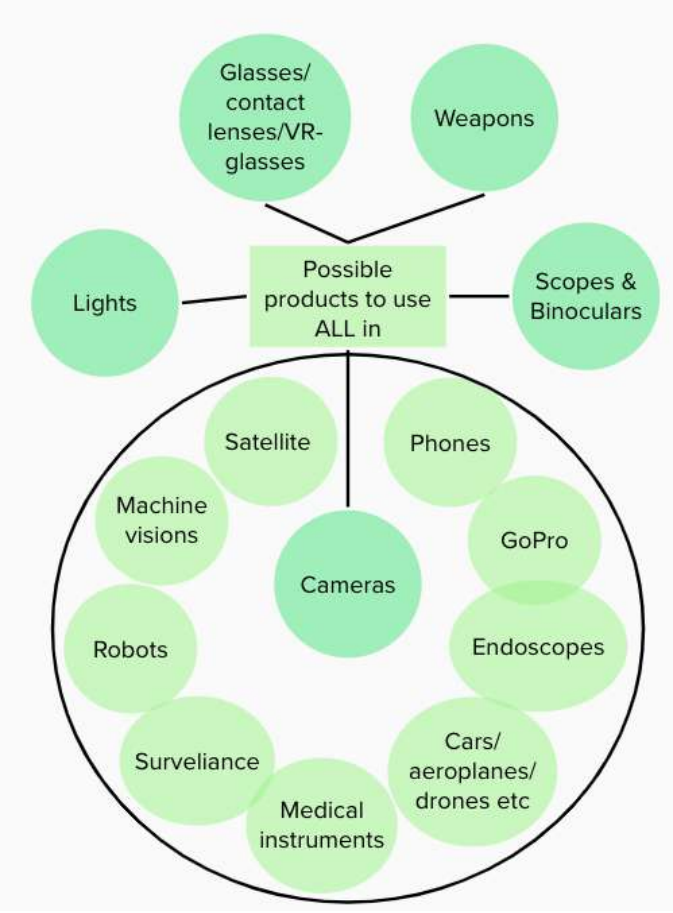


2. Possible applications of ALL

In this chapter we present several different possible areas of application for the ALL-technology. Some of them we abandoned because we did not see any major potential in them, some we had to leave behind because we found more interest and potential in other fields. The ideas explored in this chapter are:

- Virtual reality headsets
- LIDAR
- Seeing Aids
- Smart Windows
- Beamers and Projectors
- Other ideas

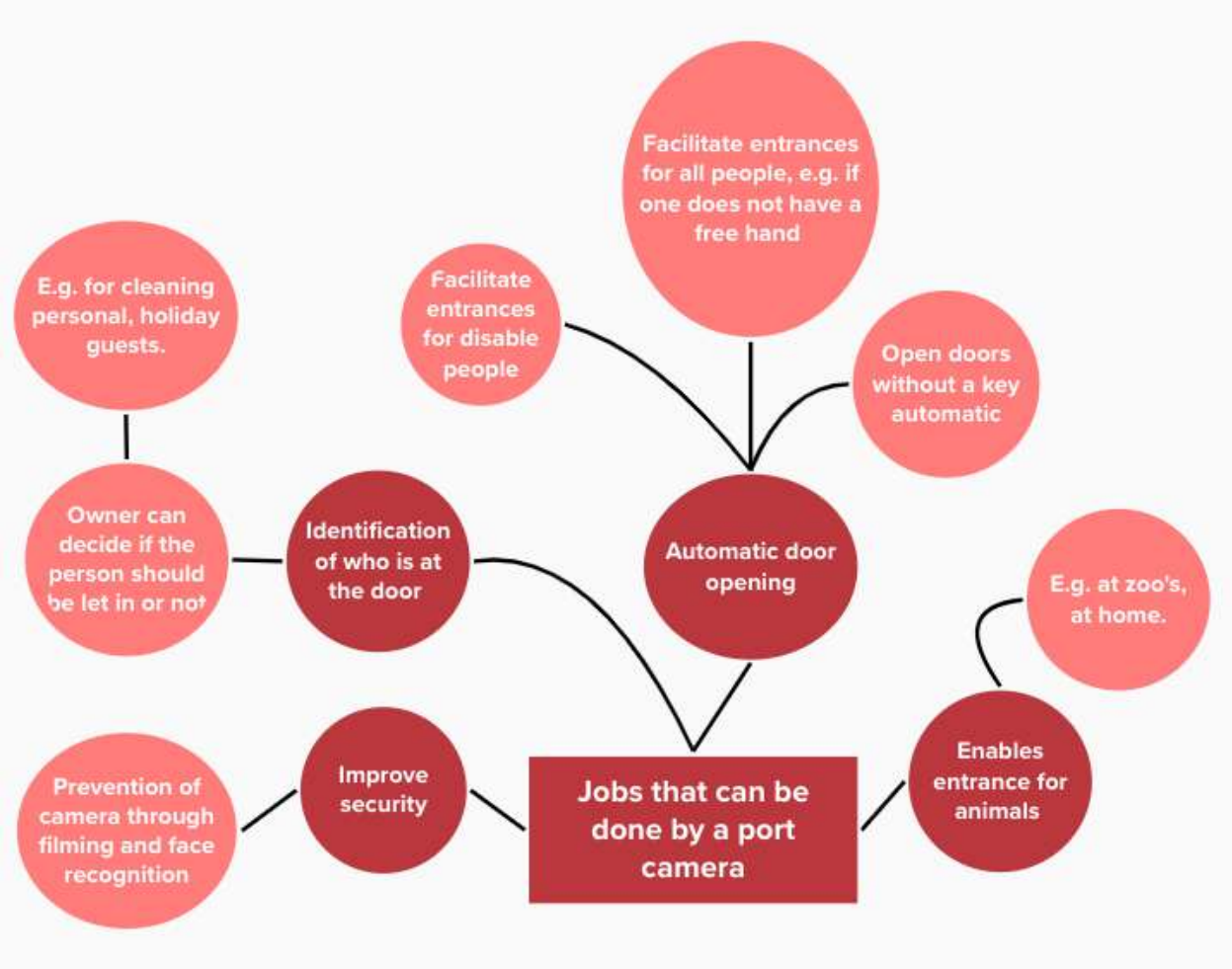
Brainstorming on the potential products that ALL can be used in:



2.1. Port camera, real world recognition, face recognition

Fields of work:

- Research; Traffic monitoring; Animal observation; Criminal identification; Security - entry access; Biometrics;



Since the ALL can provide clear focus, and furthermore, do so quickly, it would be interesting to test its abilities when combining it with a facial-recognition AI. Using the ALL we could innovate contemporary port-cameras to react faster to different faces, which could provide better home-security if a face that is not recognized by the camera can quickly lock the doors. Similarly it could quickly react to a familiar face and unlock, perhaps even open the door.

Problem-definition:

- Not sufficient sharp focus of traditional lenses => less accuracy for real-world recognition. Therefore, higher lens resolution means higher chances to detect the object correctly.
- "it does not directly increase the system's depth of field" (Mascellino, 2022).
- The liquid lens cannot be used by itself, there is a need for multi-element assembly, as the lens alone provides insufficient performance (Edmund, 2022).
- Law enforcement => even if the law could concern the information captured by the lens and not the lens itself, it can affect the market demand => may lead to non-consumption in certain fields.

Field analysis:

- Image recognition requires machine-learning techniques or deep-learning algorithms for extracting features from selected images, also called imagine acknowledgment technology (Fortune business insights, 2019).
- Object detection is a machine-learning approach. R-CNN is an algorithm mostly used for object-detection => accurate and efficient (Fritz, 2022).
- For real-world recognition, Liquid lenses are more efficient for security protocols that are "future-ready" such as iris recognition than traditional lenses.

Recognition:

1. *Humans identification*

Purposes: security, monitoring, entertainment.

Iris recognition - becomes widely spread in biometrics verification, however, there is a need for high resolution and focus to perform this job properly.

2. *Animals observation*

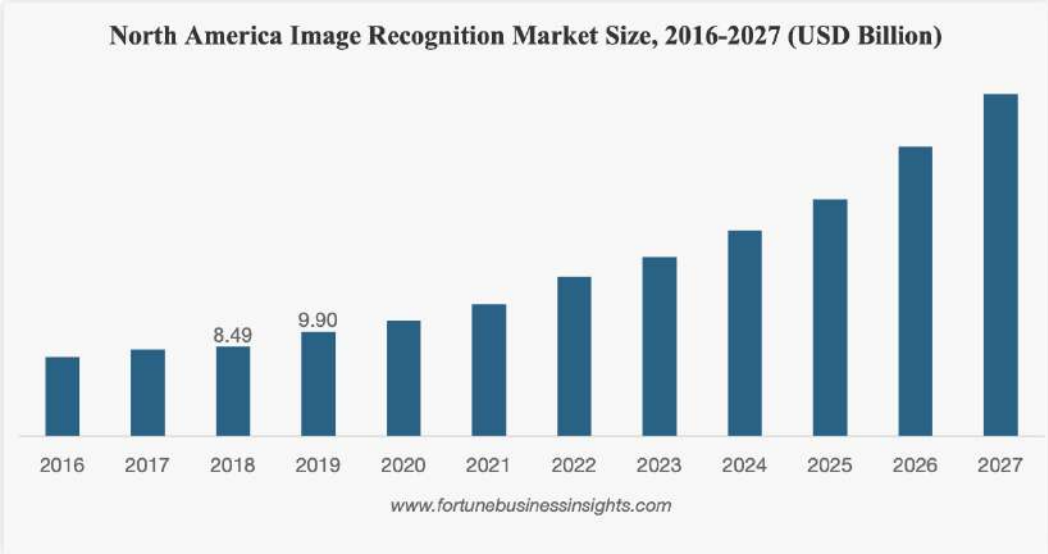
"Purpose: for research reasons, for documentaries, for amateurs and professionals. The need for cameras (miniature in size, soundless, sharp focus) in order not to disturb the animal's routines and not scare them. Ability to analyse animals from far distances, underwater, under extreme environmental circumstances, etc.; Ability to scan areas for animal detection".

3. *Objects detection*

Purposes: research reasons, traffic security, production plants, for people with disabilities, entertainment (Mascellino, 2022).

Market:

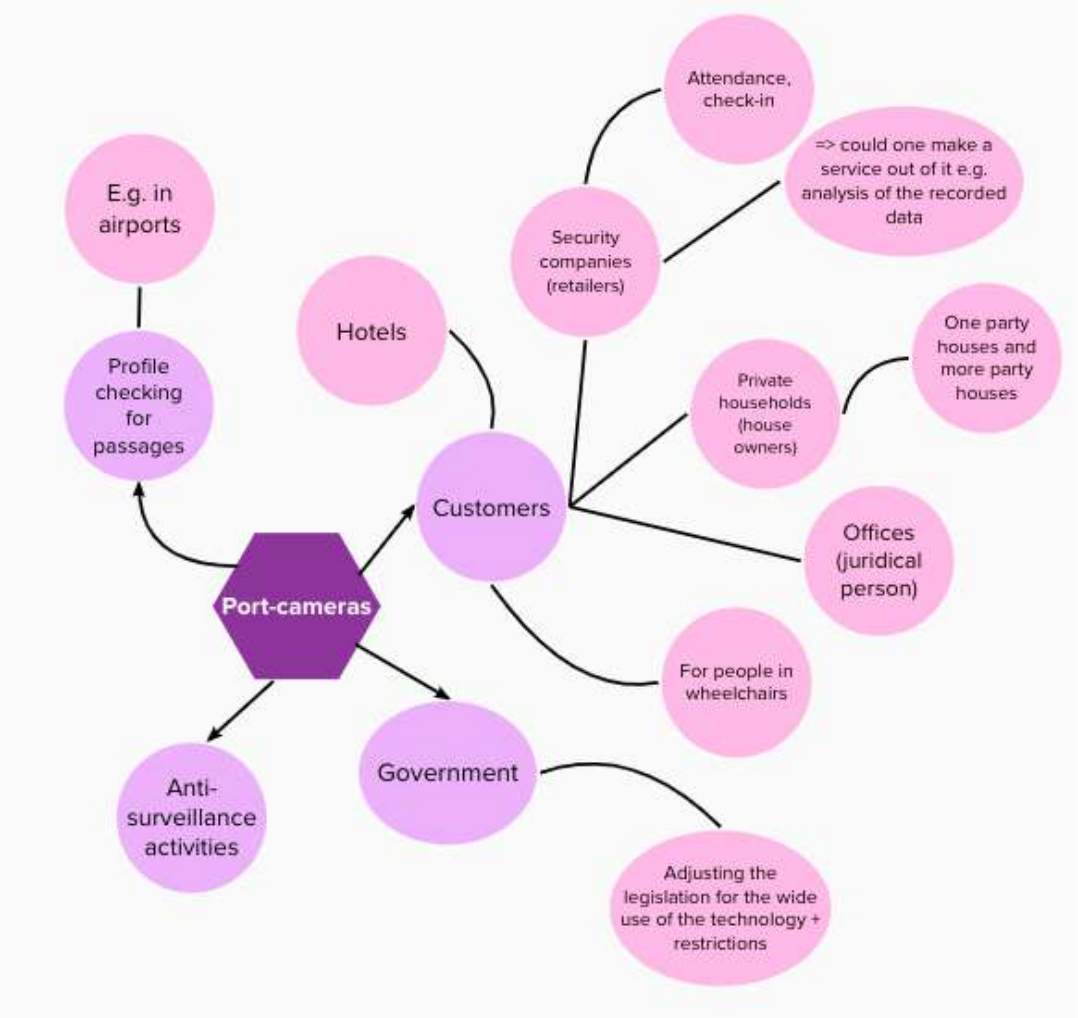
- The global biometrics market is expected to grow by up to 20% from 2017 to 2024 (Novus Light Today, 2021).
- The market size of global image recognition in 2019 - is USD 23.82 billion. By 2027 it is projected to reach USD 86.32 billion (Fortune business insights, 2019).



Source: *Fortune business insights, 2019.*

Stakeholder Map:

https://app.mural.co/invitation/mural/clod20206593/1650365905628?sender=u678d0cab0cff578e8d7e8284&key=f542bec5-c0ad-4ee3-ba1e-f415e8069798

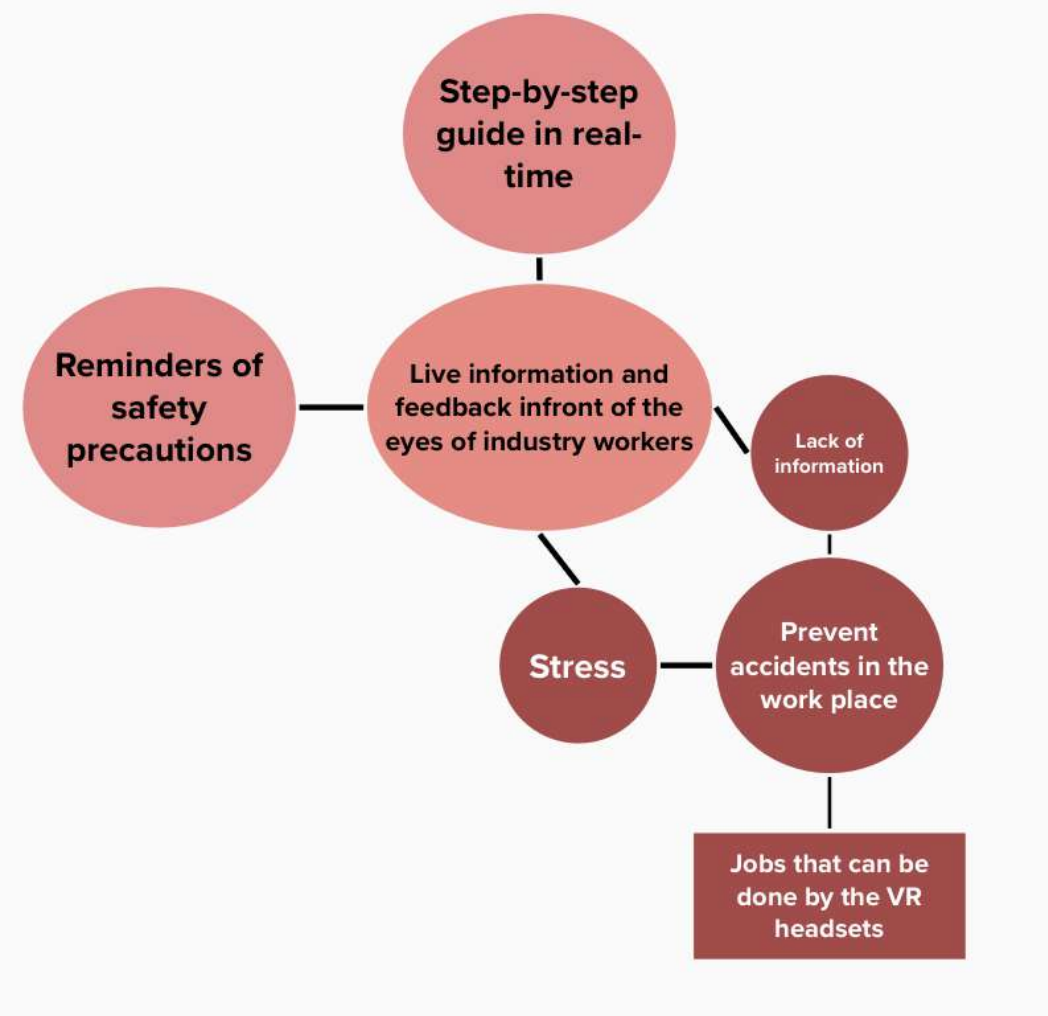


Why we did not continue to develop this idea:

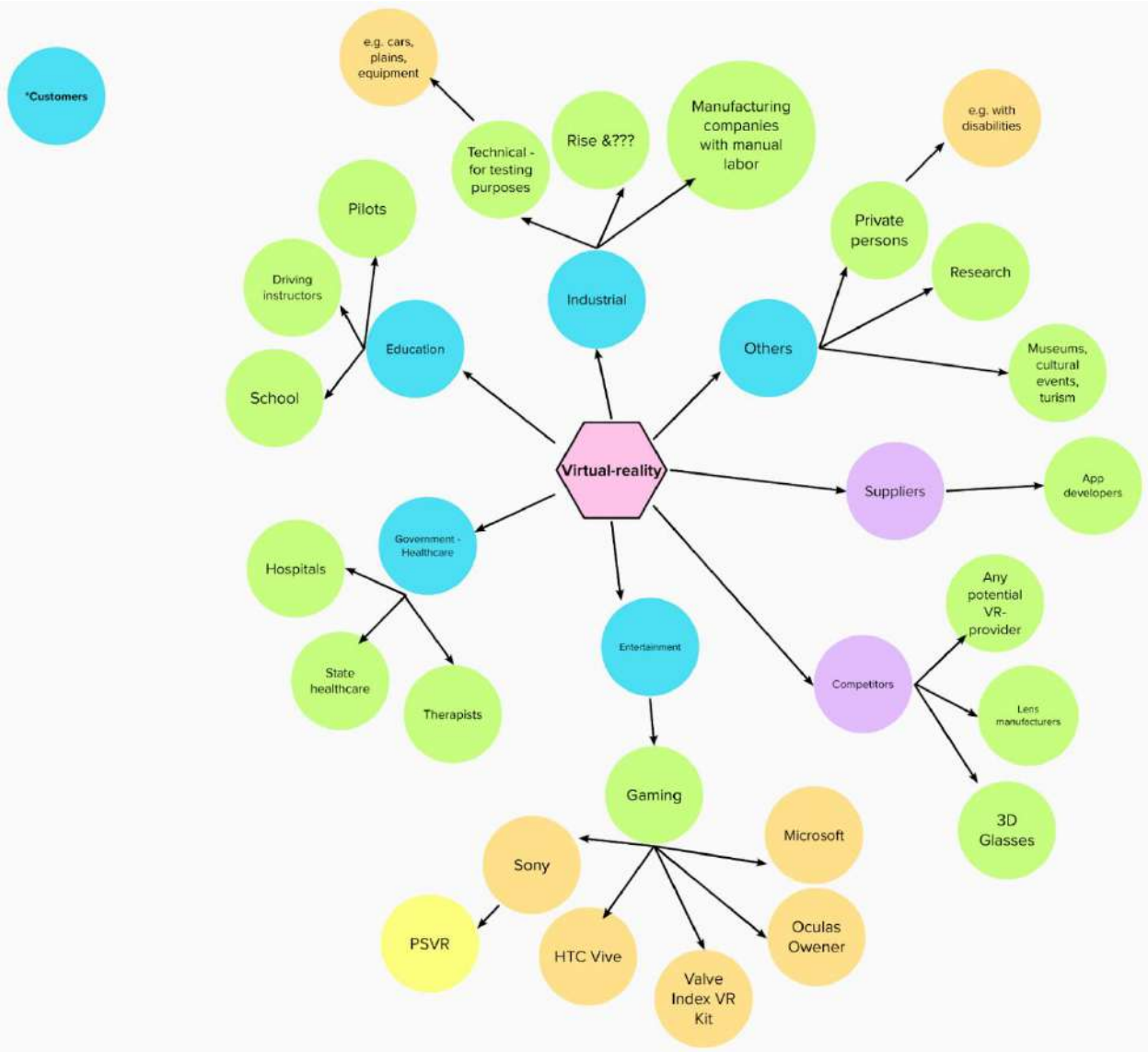
Even if the area is tempting and has great potential for further development, it is already receiving enormous attention from corporations and security institutions. Port-cameras has a growing market. It is already accomplishing most tasks that are immediately interesting. Automatization of door locks and openings could be problematic. For example, if emergency service staff require entry into a house they would need to be able to override the automatic door lock suggested above. Automation is always tricky because it is necessary to program an AI that can predict many different scenarios, as the following commercial will show: https://www.youtube.com/watch?v=6LELq9ZbS8o. Therefore, we considered that there are other more promising ideas that can both be feasible and have a positive impact on the society that we can further develop with ALL.

2.2. VR

Many accidents that occur in industries are consequences of stress which in turn leads to employees trying to perform their duties quickly and missing safety steps. Therefore live feedback on operations is necessary as a reminder of how a job should be done. Such information currently forces the employee to actively search for that information, therefore there is potential in a tool where feedback could appear in front of the employee's eyes during labour. Here we discover a need to provide VR or AR without the expensive construction of prototypes and models e.g. in the construction industry. However, as it currently stands, adoption of such technology is moving slowly due to design problems such as wearing VR-glasses with other glasses, size and weight of existing VR-glasses reduce the comfort



The solution: VR-glasses: in the construction industry where a worker can work comfortably while receiving live feedback. VR can provide value in other areas as well such as entertainment, therapy, and education where there is a need for immersive experiences in a safe environment.



(a) Market Potential

The VR-industry is expected to grow 18% each year from 2021 to 2028 (https://www.grandviewresearch.com/industry-analysis/virtual-reality-vr-market).

Most obviously for the entertainment industry, especially gaming, but also for health, business, education and industrial use (https://ieeexplore.ieee.org/abstract/document/7581705). In the latter

category, the technology is received by scrutiny and criticism to a larger extent (https://www.mdpi.com/2624-6511/3/2/16/htm). However, implementing instructions provided via AR-glasses, instead of computer screens tends to increase productivity and results in manufacturing because this means workers do not have to stop what they are doing to look to a separate screen (https://www.mdpi.com/2624-6511/3/2/16/htm). Looking at other markets, therapy of phobias through exposure, VR has proven to be a powerful tool when there is a sense of presence (immersion) into the virtual world (https://link.springer.com/article/10.1007/s11920-017-0788-4).

The feeling of immersion and being present in a virtual world and in a virtual body are positive factors of VR usage (https://www.mdpi.com/2624-6511/3/2/16/htm).

(b) Problems

The adoption of VR/AR-glasses has been halted for reasons in connection with their design. These reasons include discomfort with regards to wearing the glasses for a long time due to the weight of the glasses, as well as people who wear eyeglasses not being able to (or at least experiencing great discomfort when) wearing VR/AR-glasses. Also, the question of justifying investment into AR is hindered by problems with regard to cost-effectiveness (https://www.mdpi.com/2624-6511/3/2/16/htm). The reason behind a lot of the discomfort associated with VR-glasses is that they are limited in how slim/small they can be, this is partly a consequence of mechanical movement necessary for the ability to adjust focus to some extent (https://gizmodo.com/why-are-vr-headsets-so-bulky-1845109876). Further, increasing the range of focus in VR-glasses to be suitable for users who have different visual impairments would require more lenses, which would cause an even bulkier headset.

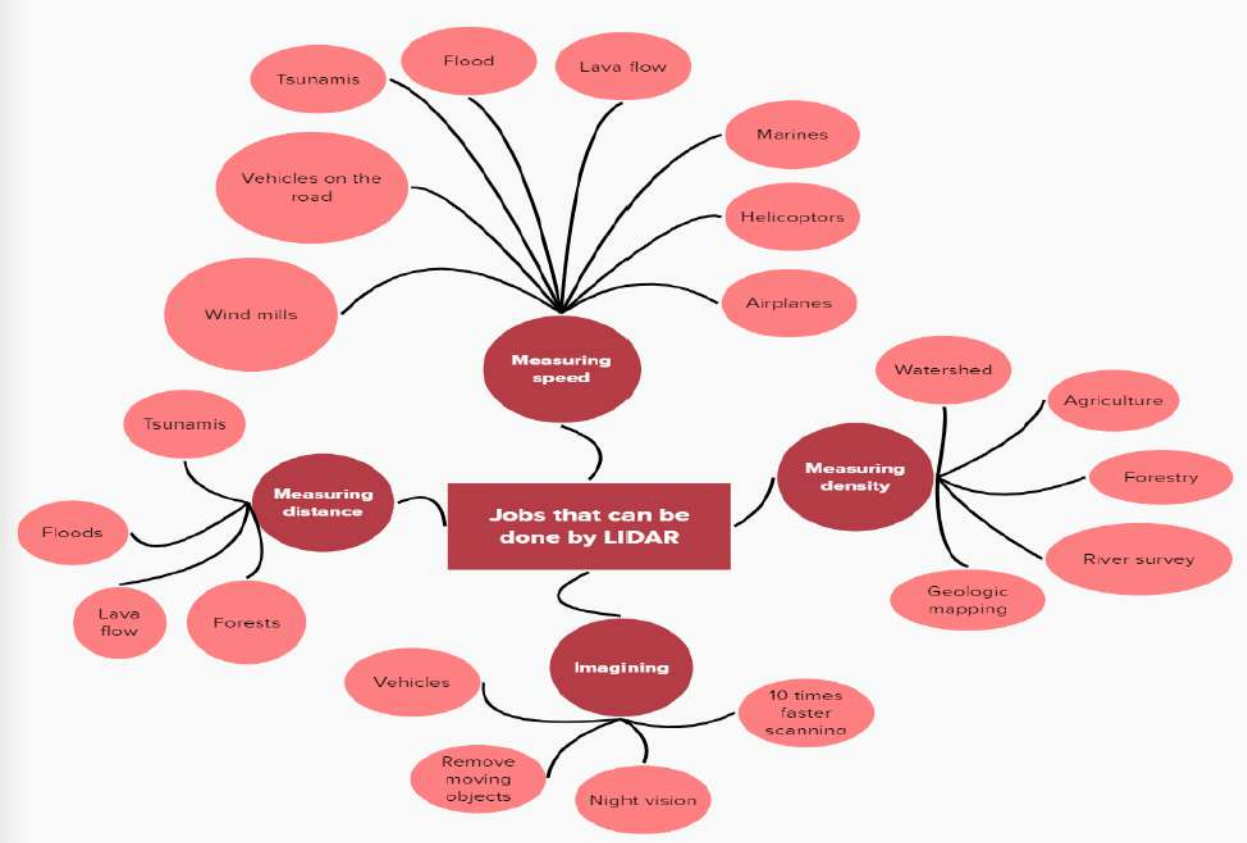
Currently solutions are being tried of implementing AR in industries through specific headsets that can fit with smartphones. This is an attempt at keeping the AR-device small. The solution is accessible as all that is required is to download an app. However, this solution is limited because the phones used are off-shelf commercial phones that are not guaranteed to be equipped with cameras that have the capacity to capture the rapid movements of machinery in industries (https://www.mdpi.com/2624-6511/3/2/16/htm).

Feedback:

- There is potential in VR. He believes problems we had not included such as motion sickness could also be improved using the lenses focusing capacity
- He cautioned us not to assume that the headset would be much smaller/more comfortable as a result of the lens. Factors such as the size of the screen and other hardware necessary could be equally responsible

2.3. LIDAR

Light detection and ranging (LIDAR) technology is laser-based imaging technique for measuring the distances. The technology works by using light beams to sense things/materials by throwing a light beam at the objects and measuring the distances/ranges. It is considered crucial for autonomous vehicles, aerial vehicles reconnaissance and artificially intelligent robots. It principally consists of a specialised GPS receiver, a laser, and a scanner. As it relies on light sources, adaptive liquid crystal lenses are an important part of them.

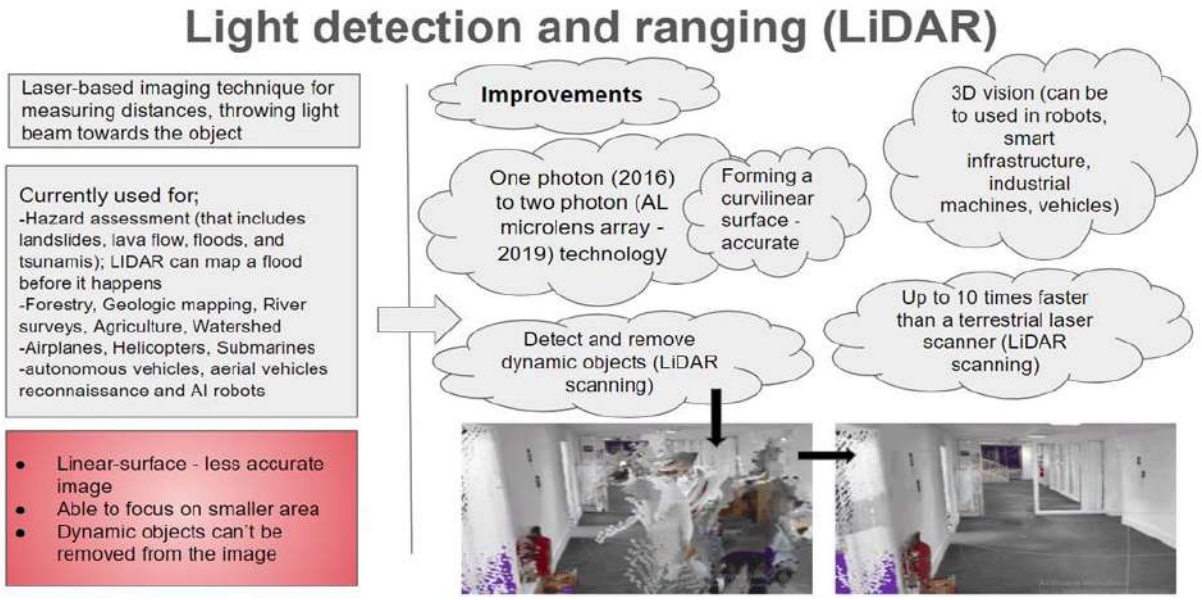


Current market

- Hazard assessment (that includes landslides, lava flow, floods, and tsunamis); LIDAR can map a flood before it happens
- Forestry, Geologic mapping, River surveys, Agriculture, Watershed
- Aeroplanes, Helicopters, Submarines

Improvements/Future prospects

- 3D vision (e.g. to robots, smart infrastructure, industrial machines, vehicles)
- Detect and remove dynamic objects (LiDAR scanning)
- Up to 10 times faster than a terrestrial laser scanner (LiDAR scanning)



LIDAR - In one Photon technology in 2016 – The new Geiger mode and single photon lidar offer a better use of the photons generated by the laser source, resulting in a denser point cloud from the same or a less efficient laser source.

More recent development – Adaptive liquid crystal microlens array enabled by *two-photon* polymerization. "Such a microlens array creates homogeneous electric field distribution and homogeneous-like liquid-crystal alignment, simultaneously. The phase profile and thus the focal

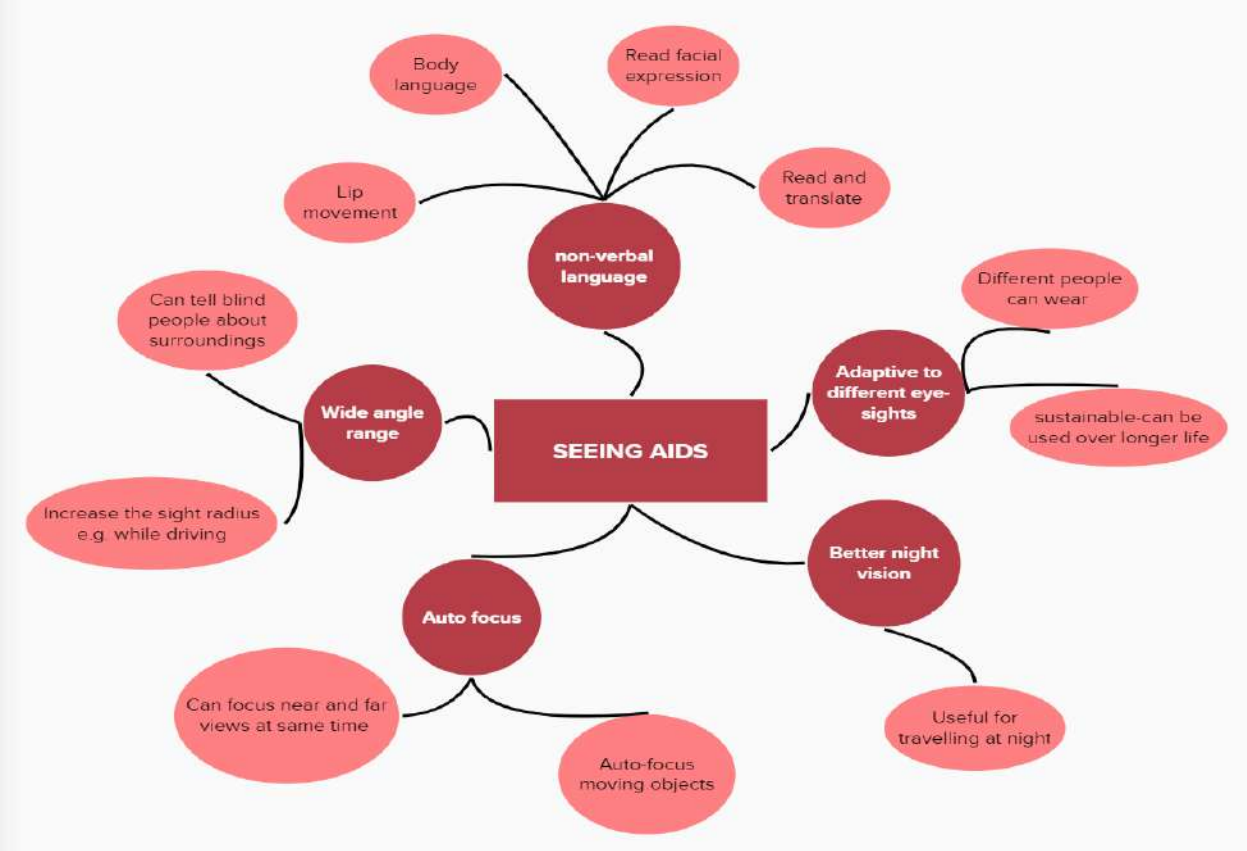
length can be tuned dynamically by the applied voltage. We also further investigate the focusing property and the imaging capability of the fabricated sample. Using the adaptive microlens array as an example, we demonstrate that directly forming a curvilinear surface with liquid-crystal alignment is feasible. In addition to adaptive lenses, this direct-laser writing method is also a powerful tool for making other tunable photonic devices."

He, Z., Lee, Y. H., Chanda, D., & Wu, S. T. (2018). Adaptive liquid crystal microlens array enabled by two-photon polymerization. Optics express, 26(16), 21184-21193

Ready for anything | NavVis VLX 2nd generation

High-performance digital lidar: autonomous vehicles, robotics, industrial a... | Ouster

2.4. Seeing aids



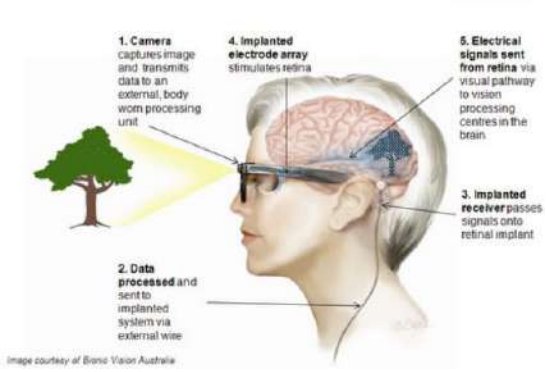
Underlying problems: visual impairments e.g. blindness, short-sightedness, long-sightedness, colour blindness or night blindness limit the ability to perceive (all) visual stimuli, change of sight over time calls for new (expensive) glasses during life → glasses that need to be adapted individually hinder the effective re-use of glasses (unsustainable), visual impairments as crucial constraints in everyday life e.g. in traffic, in the school or in the job especially in less developed countries or when having a low income that prevents from buying high quality seeing aids, some difficulties to interpret visual stimuli in the right way e.g. when having autism, through cultural differences, different languages (when it comes to reading lips), aesthetic issues

- Glasses that "read and translate" non-verbal language (e.g. facial expressions, body language, lip movements) and tell it to the wearer e.g. blind persons, autist, deaf people
- Glasses for blind people that tell them about their surroundings
- Adaptive glasses with several purposes and functions in one pair of glasses e.g. reading, far and near sightedness, sun glasses in one pair of glasses
- Adaptation to different sights over time, more precise adjusted iments of the sight (more precise measurement as well since voltages can be changed slight steps)
- Automatically magnifying glasses e.g. with speech recognition to zoom in and out in contexts where different detailed foci are needed e.g. surgeries, chip manufacturing
- Night vision
- Increase the sight radius e.g. for driving →
- In connection with voice and noise recognition: provide better oversight for deaf people by focussing sight according to the sounds around the person

Existing product:

- Argus II Retinal Prosthesis (https://secondsight.com)

Surgically implanted device that delivers electrical signals to the retina (a camera attached to glasses captures images that are converted into electrical signals) → perception patterns of light are recognized by the brain, through training the users learn to interpret these patterns.



- orcam (https://www.orcam.com/en/about/) device with a camera that is attached to glasses and is able to read texts (3 languages possible), recognizes faces or objects, connected with headphones to tell the person what it sees

- 32northglasses (https://32northglasses.com/#) Sunglasses that can be switched to reading glasses with a possible adaption of the magnification power via app. The glasses are based on liquid crystal technology and cover a range of 0-2 dioptres.
- Photochromic lenses (https://www.essilor.com.au/products/adaptive-photochromic-lenses) carbon-based lenses that react to UV light. The molecules inside the lense change shape and absorb the light which results in the lenses starting to look darker. The more UV rays there are, the darker the lenses become.

Further developments and improvements through ALL:

Improve the image quality and thereby the electrical impulses that are sent to the brain to recognize the patterns → more precise patterns might be possible, maybe even colour recognition possible?

- Adaptive glasses with several purposes and functions in one pair of glasses e.g. reading, far and near sightedness, sun glasses in one pair of glasses

- Adaptation to different sights over time, more precise adjustments of the sight (more precise measurement as well since voltages can be changed in slight steps)
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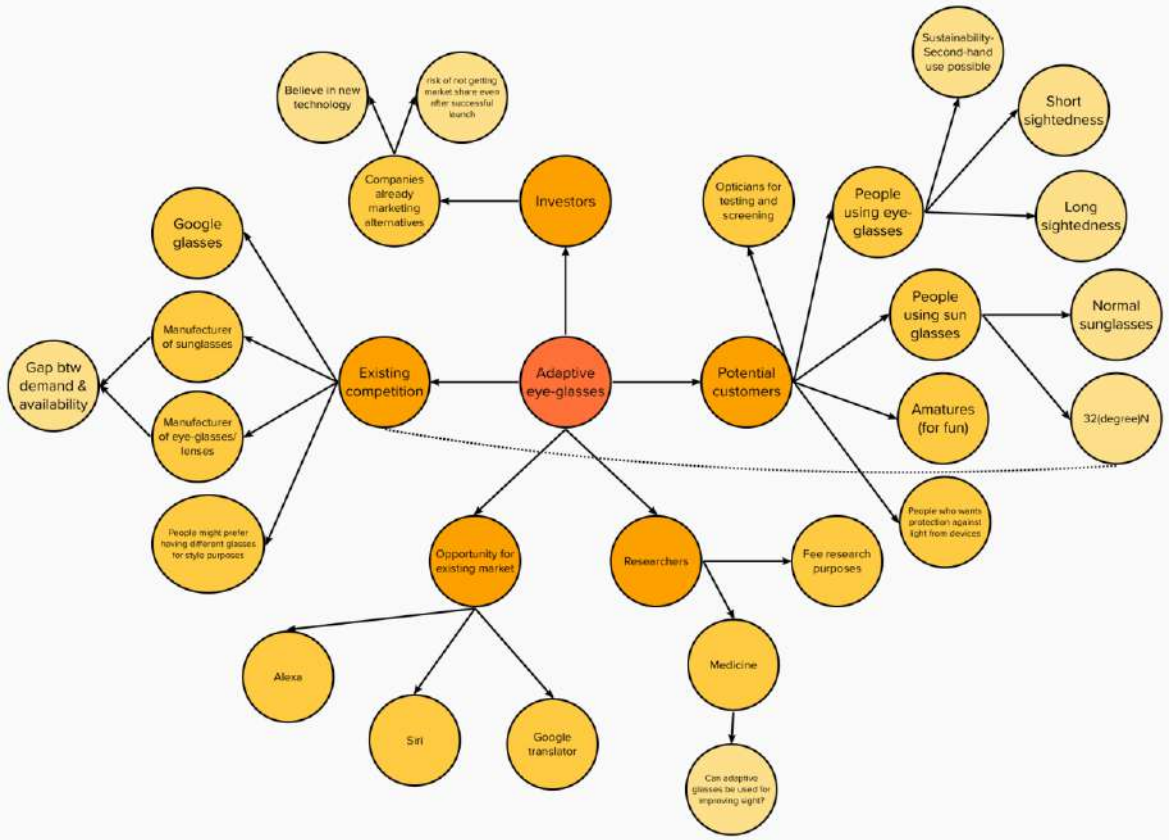


Feedback:

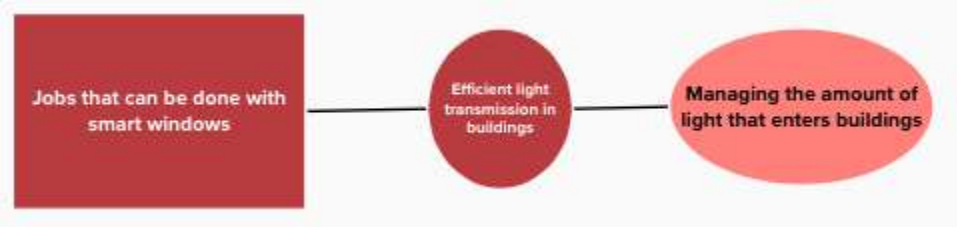
- Have potential, but people may want to change their glasses:
  - Due changing fashion;
  - They get crashed;
  - Glasses cannot be considered (too) expensive anymore → cost efficiency may not be the strongest argument for adaptive eye-glasses

Improve sight	Correct sight	Manipulate light	New lenses for	Adaptive glasses

	impairments	beams that enter the eye	every change in sight and different uses e.g. sunglasses, reading glasses, nearsightedness	with several functions (all in one solution) Improve existing seeing aids → e.g. bionic eye

2.5. Smart Windows

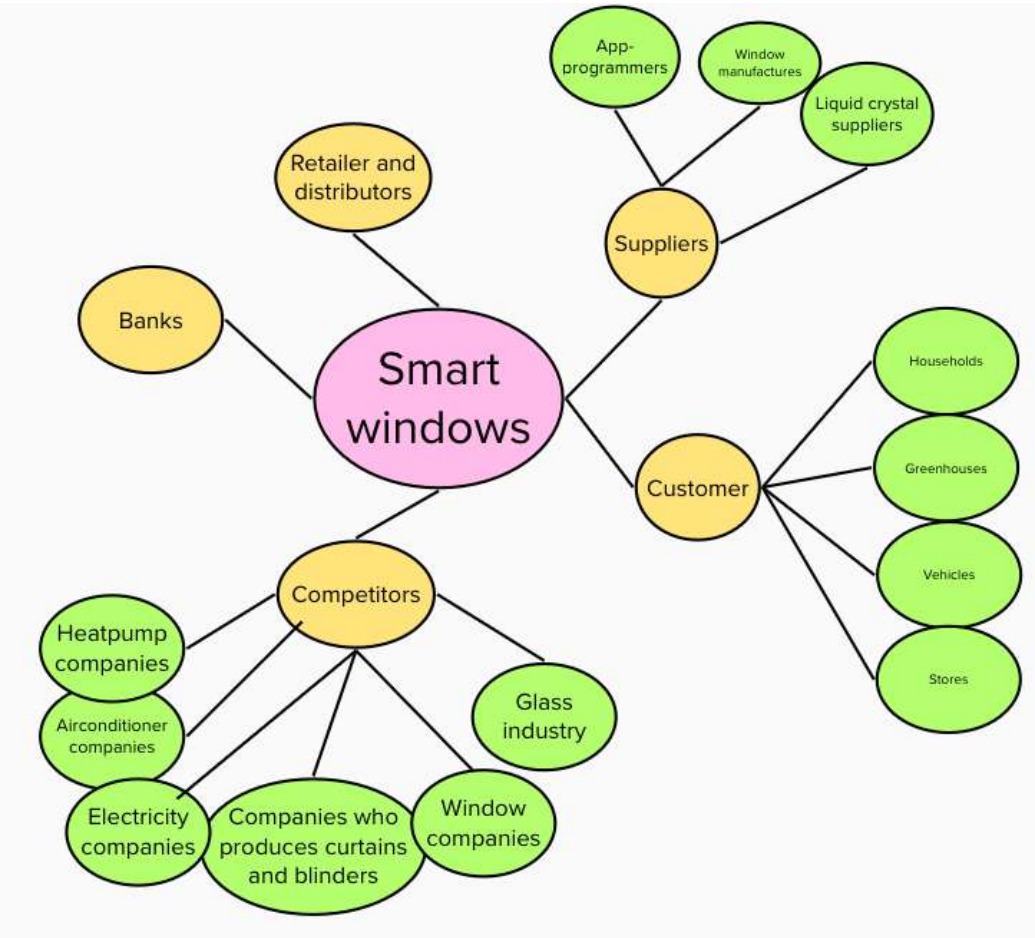
Underlying problem: more extreme climate and weather conditions e.g. very hot and dry summers and long and cold winters, need for the increased and efficient use of renewable energy e.g. sunlight, unstable and extreme weather conditions as a risk for farming. An increase in energy prices also increases the need for households to be more energy-efficient. Heating and cooling are the biggest energy consumers in houses and this creates a need to use the sunlight through windows in an efficient way.



- Automatic dimming of windows e.g. letting more and more light in the room without curtains or jalousies
- Decide on how much light to let in instead of letting too much light in and then cool down the house
- Windows where different areas can have different foci e.g. in Safari Lodges
- Windows where you can look outside but it is not possible to look inside from outside
- Greenhouses: improve efficiency, manipulate the entering sunlight and therewith also the temperature

- Swimming pools: covering them to keep the temperature constant, preventing it from becoming warmer or colder by efficient manipulation of sunlight
- Solar cells: optimise the amount of sunlight that is collected and turned into power

Stakeholder Map:



Two main purposes for using smart windows:

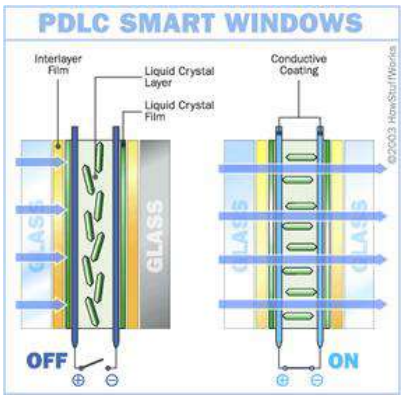
1) Energy conservation

2) Light transmission

How it works:

Depending on the voltage, the crystals arrange themselves in different positions.

The position of the crystals regulates the amount of light and heat passing through. The window can therefore let in different amounts of light/heat and the user can then decide how much light/heat to let in.



Meng et al, "Colour-switchable liquid crystal smart window with multi-layered light-guiding structures," Opt. Express 27, 13098-13107 (2019)
https://opg.optica.org/oe/fulltext.cfm?uri=oe-27-9-13098&id=409304
How do Eyrise Liquid Crystal Smart-glass Windows Work?
The Science Behind Smart Glass

Benefits:

- This can help to save energy since you can reduce the amount of light/heat that comes into the room. Less light in a room will reduce the heat and therefore the need for different cooling procedures, which are very energy-consuming. The other way around more light will increase the heat and therefore reduce the need to heat up buildings.
- Very sustainable since heating and cooling are big energy consumers in households. Also, a future thing since the amount of electricity needed will increase and probably the price as well → People will be willing to have energy-efficient homes.

Limitations with today's smart windows: expensive to make, have inconsistent light-blocking efficiency and are unlikely to be durable in the long term.

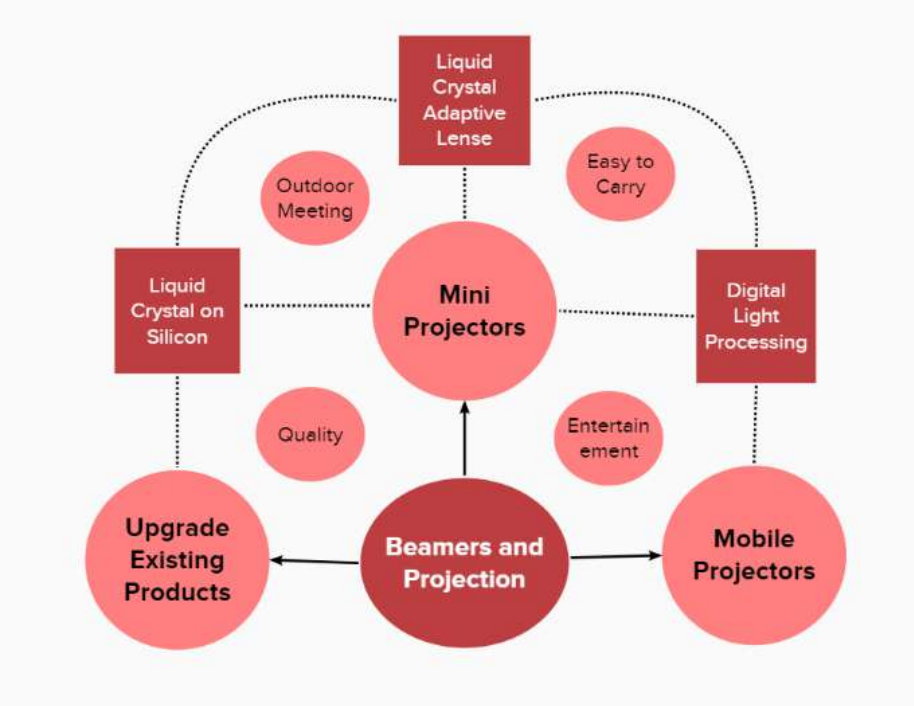
Feedback during first presentation:

- He does not see potential in this since the ALL probably will not fit. There are other technologies they are working with that would have a greater fit than the ALL. He does not believe in this idea due to the ALL-technology.
- This is not possible due to what the ALL lens is doing *right now.*
- However, this idea is very fun and interesting, he thinks.

What		**How (working principle ALL)**	**Value**
product/ solution	**Problems/issues**		
Smart window	more extreme climate and weather conditions → need for the increased and efficient use of sunlight unstable and extreme weather conditions as a risk for farming. increase in energy prices à need for households to be more energy-efficient Heating and cooling are the biggest energy consumers in houses → need to use the sunlight through windows in an optimal way Smart-house - technologization of utilities => Industry 4.0	By deliberately addressing the electrodes in the window the amount of and the way how sunlight enters the building can be determined according to the needs of the customers.	No need for curtains and jalousies to prevent sunlight from entering the building. Sunlight can be efficiently used to determine the temperature in the building.

2.6. Beamers and Projection

Beamers and projectors have significant importance in corporate sectors and educational institutes. The technology is bigger in size and can be more adoptive if size can be reduced with enhanced picture quality. Companies tried to install it in mobile phones but were unable to grab potential markets. Besides, mini projectors are more favourable than having them in the mobile phones.
Why These 'Revolutionary' Phones Failed So Hard (gizmodo.com)



Why are projector phones unable to create an impact in the market?

A. Installing pico projectors in cell phones.
B. Low resolution.
C. Low colour uniformity.
D. Longer projection time
E. Occasionally usage.
F. Portable beamers.
G. Portable beamers provide better compatibility and resolution.
H. Inadaptability by consumers

Why Projector Phones Still Aren't Ready for Prime Time After Almost a Decade « Smartphones :: Gadget Hacks

(LCAL):

The use of adaptive lenses for beaming and projection can enhance the quality and programmable focal length. This programmable focal length allows 3D beam control.

Liquid crystal adaptive lens: beam translation and field meshing - PubMed (nih.gov)

Digital Light Processing (DLD):

DLD has a different process of image projection than liquid crystal display as it operates on the grid of tiny mirrors to reflect the light. The DLD projector consists of small chips of digital micromirror devices and some of these projectors use three DMD chips which makes it an expensive tool. It provides better image uniformity and motion sharpness as compared to liquid crystal display.

Buying a projector or beamer: The basic technical knowledge (allhomecinema.com)

Liquid crystal on silicons: LCoS

LCos are considered the best alternative in the projector industry as it is a combination of DLD and LCD and well-known brands are using this technology for best output of projection. It is an expensive option as compared to LCD and DLD but provides stable output light and contrast. This application is also well known for creating micro displays. Microdisplays are widely being used for big screen televisions, head mounted displays, projectors, and digital cameras. Microdisplays are also handy for portable high resolution displays in mobile phones, wristwatches and pocket projectors.

Liquid crystal on silicon | Nature Photonics

Buying a projector or beamer: The basic technical knowledge (allhomecinema.com)

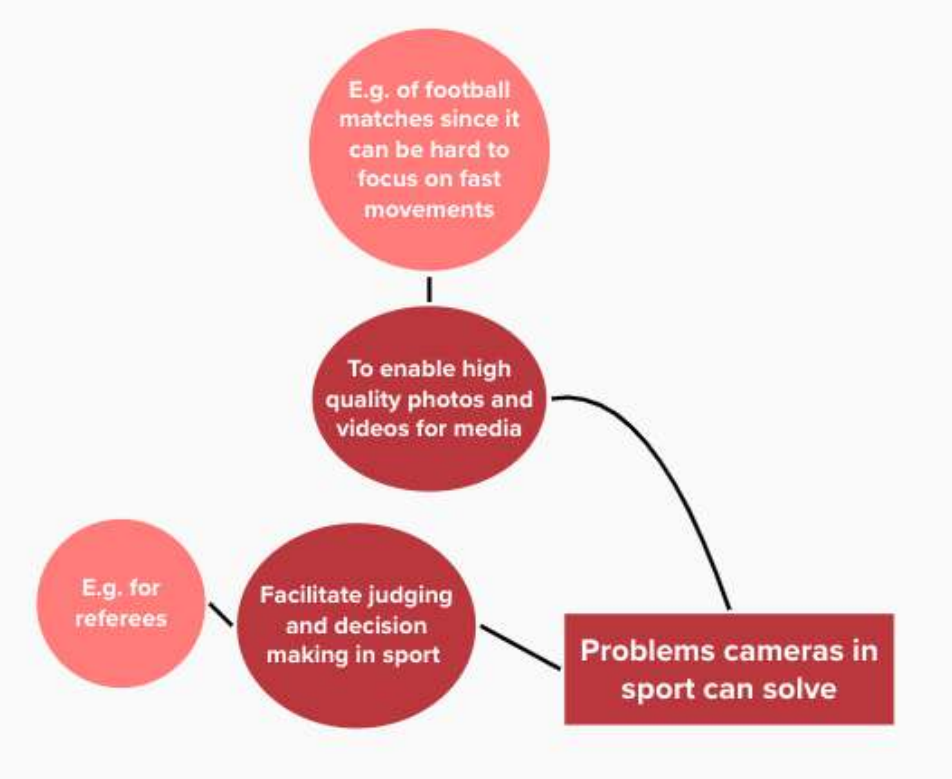
Market Potential:

ALL is in the race to provide a better solution by using existing technology and they have already developed the adaptive crystal lens. The projector is widely used in offices and education institutes. The projectors in the mobile phones have a potential market because cell phones are a necessity. The ALL can make efforts to provide better solutions to make mini projectors in the phone and portable projectors which can provide better resolution at a cheaper price. In the past the projectors

in the fail are not considered as potential products and people are more adaptive to portable projectors. Apart from liquid crystal lens, IALL can make experiments with digital light processing and liquid crystal on silicons as they provide more colour uniformity and better resolution. LCoS are widely used to develop displays and it has potential to capture more market share as they are already being used in cellphones, smart watches and pocket projectors. The already developed adaptive liquid crystal lens is cheaper and provides better quality and focal length. DLD and LCoS also have potential to produce better results and can be adapted to current demands of the market.

2.7. Other ideas

2.7.1. ALL in sports



Cameras are being used in sports to facilitate judging since there are many actions happening at the same time which can make a good overview and therefore make it more difficult to make the right decision. To improve these cameras, ALL can be used since it would make the photos and videos more clear: especially since ALL have the ability to fast refocus on moving objects.

Moreover, we chose to not proceed with this since we saw greater potential within other ideas.

2.7.2. ALL in cooking devices

A camera can be used in cooking devices to see if the food is ready, e.g. to see if the food in an oven is ready, if the noodles are boiled enough etc. This could also be useful when children are cooking since it can be quite dangerous for them: the safety of children when cooking could be favoured by a camera. Additionally, cooking often requires one to be in the kitchen, and observant, but a camera could allow one to leave the kitchen without burning anything. This could also help parents handling small children while cooking.

Cameras may already be used in cooking devices but due to ALL's characteristics, this lens could improve these cameras. However, since we did not see a large potential with this, we chose to not proceed with this idea.

2.7.3. ALL in production plants

Cameras are being used in today's production plants, however, there are obstacles within these regarding the ability to fast refocusing on products but also image resolution. For instance, cameras are used to detect faulty products. To replace today's lens with ALL would solve these obstacles since ALL can fast refocus on moving objects. Too see an example, click on the followed link: https://www.youtube.com/watch?v=K87-xLFI3WM

Moreover, we chose to not proceed with this idea since we saw greater potential with other ideas.

2.7.4. ALL in cameras in wearables

Cameras are already being used in wearables, e.g. policemen usually wear cameras when they are working. For instance, this is useful in violent environments since they can catch criminals through videos and photos. The ALL would enable improved image resolution and fast refocusing on videos since this could be obstacles in, for example, demonstrations where there are a lot of people and often chaotic. Furthermore, cameras with ALL as a lens can also be placed in prisoners' clothes in case they are escaping. Moreover, a camera can be placed on animal necklaces to know where they are.

We chose to not proceed with this since we saw more potential in other ideas. However, the cameras policemen are using could be improved by using the ALL instead.

2.7.5. ALL in photography & film

Cameras that are being used in extreme environments require a certain standard. Examples of extreme environments could be in space or deep in the ocean and it could be dangerous for humans to be there. Therefore, ALL can improve these cameras and enable humans to not be in these extreme environments. For instance, this can also be useful when observing animals in the wild, e.g. detect sharks, tigers, lions etc.

However, we chose to not proceed with this idea.

2.7.6. ALL in webcams

There is some potential in implementing the ALL into webcams because this could improve the focus of the camera independent of what position the user is in. For example, the camera's focus might be thrown off by something going on in the background.

We chose not to proceed with this idea because we were unsure of the ALL's actual contribution to the webcams since the problem might also be addressed by changing the settings of the webcam and felt that there were other, more interesting, paths to explore.

2.7.7. ALL in hunting

Scopes in hunting rifles use lenses to focus on prey. This is essential to ensure that the shot is clean and kills the animal immediately, so that it suffers as little as possible. Altering this focus is usually done by turning a wheel on the scope, this can throw off the hunters aim and is relatively time consuming, which is not ideal as the prey might be spooked and manage to run away before the shot is even fired. Utilising the ALL's ability to quickly focus, one could replace the traditional wheel with a simple button that automatically adjusts the aim to focus on the point of impact.

While we believe there is great potential in this idea, both in scopes and binoculars, we chose to focus our exploration on a different field.

2.7.8. ALL in disability tools

Disable people that cannot move and speak can use devices that enable them to, more or less, communicate their needs and wants. There are devices that can help them to communicate via eye tracking, but perhaps these can be improved? For instance, by making them smaller and more mobile to enhance and disable people's usage of these. ALL is a very small lens and could perhaps help making this device smaller.

We chose to not proceed with this idea since we saw a greater potential within other ideas.

2.8. Final remarks

We categorised our ideas according to the risk level. The risk level is based on:

- Potential of implementing the ALL e.g. existing solutions can be improved by the ALL
- Market potential because of growing markets and customer demands

Categories by Risk level		
High	**Medium**	**Low**
Smart Windows	VR Glasses	Cameras in vehicles
Concentrated solar power	Adaptive eye-glasses	LIDAR
Glasses that "read and translate" non-verbal language	Port cameras	Cameras in wearables (especially for policemen)
Improvement of the bionic eye	Projector/Beamer	Animal photography
Greenhouses	Cameras in traffic	Endoscopes
Improved eye tracking for paraplegics	Magnifying glasses with speech recognition e.g. for surgerists	Hunting rifle
Glasses that "tell" blinds about their surrounding		

3. Ideas for further development

Apart from the ideas presented above and developed in chapter 2, we also thought that the ALL could be applied in the areas of solar panels, traffic and vehicles. We consider these areas highly potential because of the following reasons: highly market potential, implementation potential and potential to address problems on a broad societal level.

In the following we aim to provide an overview over the two topics and how the ALL can be implemented in solutions that help to solve problems we have identified.

3.1. Solar panels

Summary of findings

This chapter introduces our research into solar panels. We found that there is potential in using the ALL-technology to direct sunbeams in concentrated solar power. Currently the solar-panels need to be moved in alignment with sun-light, the ALL might be able to work around this to enable solar panels to gather energy more efficiently.

The lens could provide better ability to produce energy from infrared light which in turn could provide cheaper energy, making solar panels a more attractive choice.

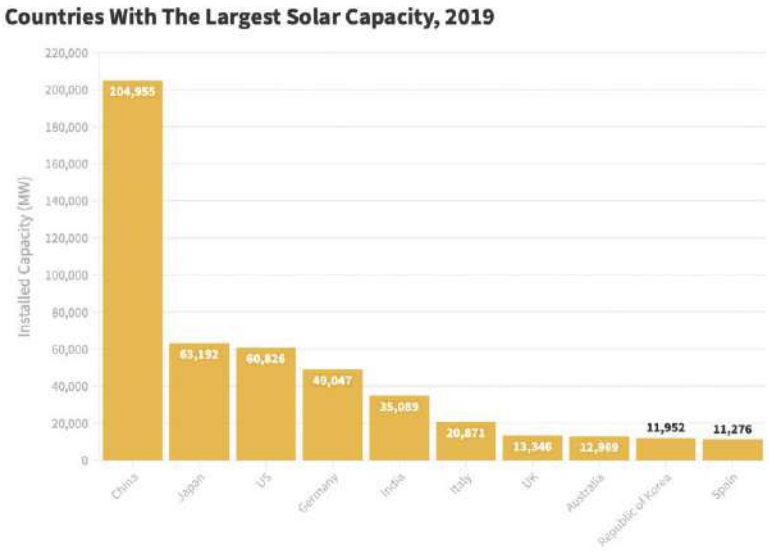
However, one of the main drawbacks of solar energy is the limited storage capacity.

3.1.1. Context and Background Information

The usage of solar panels:

- The efficiency of using solar panels → half of the land that is used for oil and gas, could be replaced with solar panels and that could generate enough power for the whole US. https://sunbadger.com/solar-energy-statistics/
- "The average amount of solar energy consumed per capita was 232 kWh during 2019". https://www.theecoexperts.co.uk/solar-panels/solar-statistics

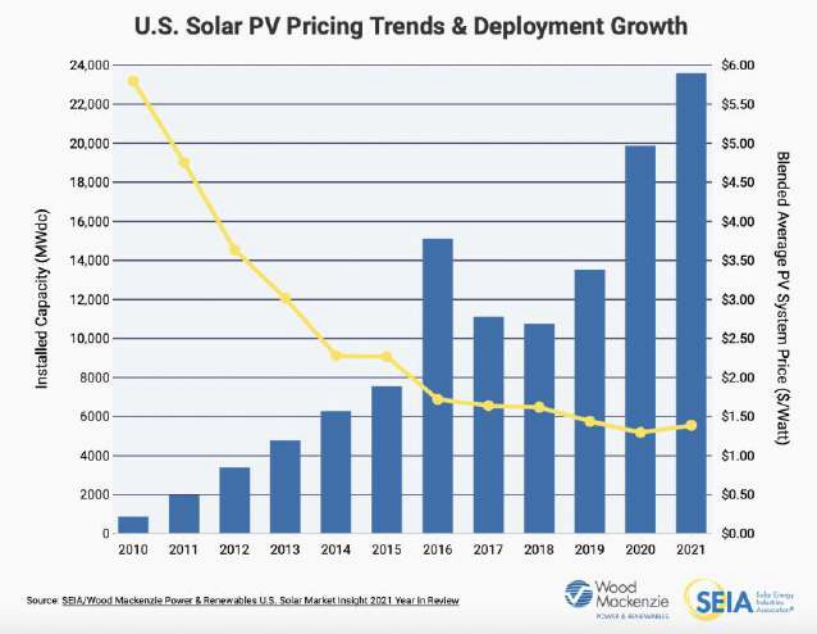
- In 2019, Australia, Japan, Germany, and the United Arab Emirates was the countries that consumed the most solar energy per capita. https://www.theecoexperts.co.uk/solar-panels/solar-statistics. (See diagram below).
- "renewable energy contributed to 29% of electricity generation in 2020 – an increase from 27% in 2019…Hydropower produced over half of the world's renewable energy (57.8%), with wind contributing to 21.4%, and solar 11.4%". https://www.theecoexperts.co.uk/solar-panels/solar-statistics
- "In a recent survey, we found that despite roughly three-quarters of respondents knowing what solar panels are, only 4% of them have purchased panels in the last 12 months." https://www.theecoexperts.co.uk/solar-panels/solar-statistics
- There is a need for cheaper solar panels; "...61% of respondents said they would buy solar panels if money was no object". https://www.theecoexperts.co.uk/solar-panels/solar-statistics
- Likelihood of purchasing solar panels: 76% of Gen Z; 50% of the Silent Generation and 58% of Baby Boomers. https://www.theecoexperts.co.uk/solar-panels/solar-statistics
- "Solar PV accounted for 3.1% of global electricity generation, and it remains the third-largest renewable electricity technology behind hydropower and onshore wind after overtaking bioenergy in 2019". https://www.iea.org/reports/solar-pv
- Solar panels can be placed on solar panel fields, on vehicles (cars, boats), in-house, on buildings, on greenhouses etc.



Source: https://www.seia.org/solar-industry-research-data

Other Statistics and information:

- 90-97% of a decommissioned solar panel's materials can be recycled or sold https://sunbadger.com/solar-energy-statistics/
- The price of solar has fallen over 70% since 2010. https://sunbadger.com/solar-energy-statistics/. Due to the increased installation of solar panels, does the price decrease (see figure below).
- "Since clouds, atmosphere and nighttime are absent in space, satellite-based solar panels would be able to capture and transmit substantially more energy than terrestrial solar panels." https://www.energy.gov/maps/space-based-solar-power
- Solar panels could be highly important to implement due to UN's Development goals: e.g. affordable and clean energy (goal 7), responsible consumption and production (goal 12), climate action (goal 13). https://sdgs.un.org/goals
- Further comments on market potential:
    - "Solar energy is experiencing a boom in Europe…Industry association SolarPower Europe predicts growth accelerating further in the years ahead". https://www.en-former.com/en/why-solar-cell-production-has-resumed-in-europe/
    - "Only 5 to 16% solar panel efficiency has reached till now so there is need for more improvement. So tools are required to increase the efficiency with use of lenses that can emit light in single focal length with higher intensity which can give more power to the plates". IJSES
    - "In the US researchers believed that power produced by solar cells will increase 700% by 2050 thanks to technical improvements but also that the price is steadily decreasing". https://sitn.hms.harvard.edu/flash/2019/future-solar-bright/
- Types of organic materials that can be used in organic photovoltaics: small molecules, polymers, oligomers, dendrimers, organic dyes and liquid crystals. https://www.nature.com/articles/pj2016109



Source: https://www.seia.org/solar-industry-research-data, 2021

Types of solar panels

1. Monocrystalline (Bigger in size and expensive)
2. Polycrystalline (Smaller in size and cheaper)
3. Amorphous Silicon (newer and flexible solar panels instead of plates. More cheaper) (see picture below)
    - High conversion rate, high efficiency output
    - Suitable for charging cell phone and small DC batteries

Some limitations with solar panels:

- On one hand, the device will be less efficient in high-temperatures => the need for a cooling device. On the other hand, however, the device is less susceptible to degradation at more

reasonable operating temperatures. https://cen.acs.org/articles/92/web/2014/11/Liquid-Crystals-Stabilize-Dye-Sensitized.html

- Not possible to use on protected areas such as heritage ones (e.g. on old buildings)

3.1.2 Why ALL in solar panels?

"The lenses can improve solar panels so that they can produce energy from infrared light as well and that is a major improvement since almost half of the solar energy consists of infrared light" https://www.kth.se/om/nyheter/centrala-nyheter/upp-till-25-procent-effektivare-solceller-1.933809

Technical part: how the liquid lens work in solar panels:

- Two layers of LC are used to remove polarisation dependency (polarisation definition: the action of restricting the vibrations of a transverse wave, especially light, wholly or partially to one direction). https://ieeexplore.ieee.org/abstract/document/6330984

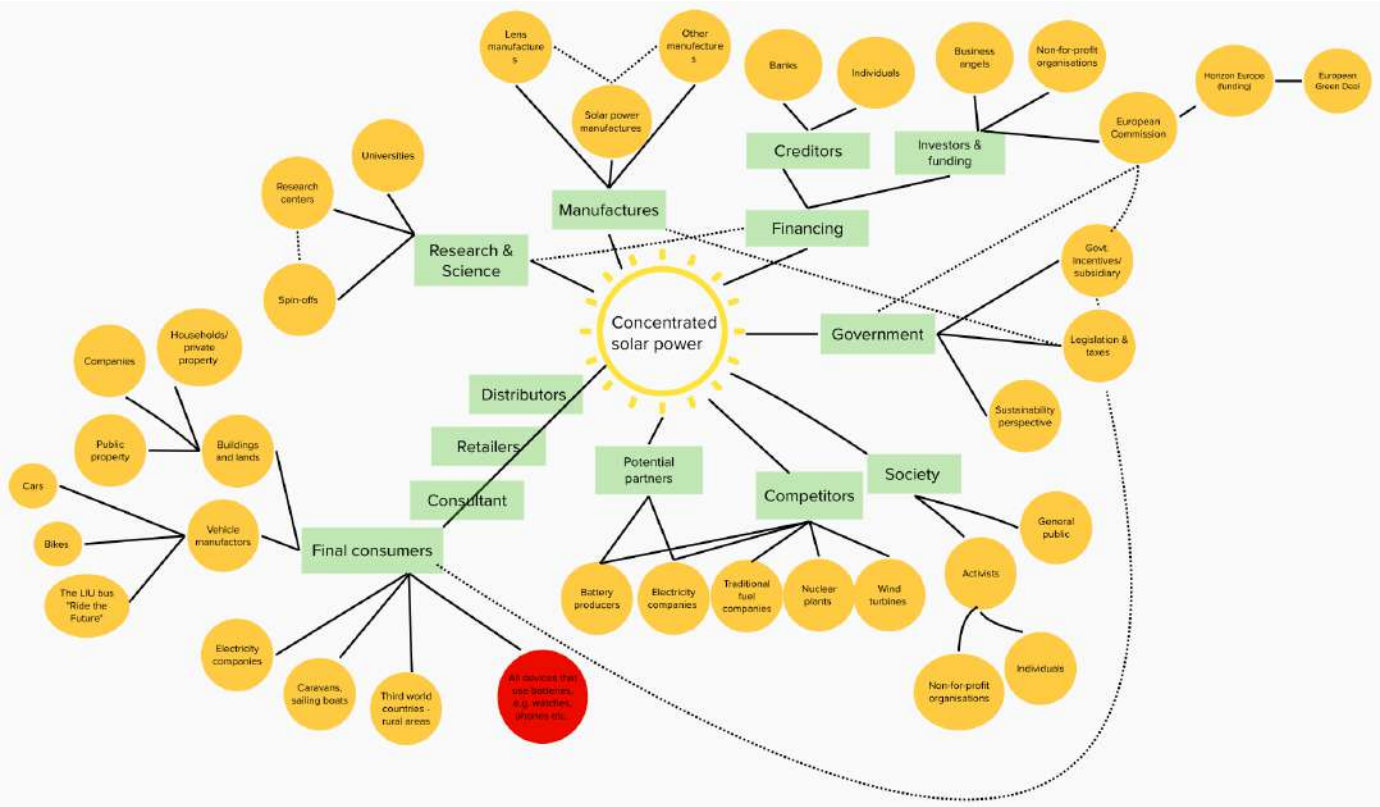
Reasons to develop solar panels with crystal liquid https://www.nature.com/articles/pj2016109; https://www.futurity.org/liquid-crystals-solar-cells-839332/:

- Increasing demand of sustainable energy => pollution-free
- Solve the energy crisis
- Cheaper energy => cost-efficiency
- Better potential comparing with conventional solar panels
- Shaped to fit nearly any surface are

Other reasons to develop today's solar panels, and some problems within these:

- The need to increase the efficiency of the production of solar energy in a sustainable way
- The need to make the consumption more efficient
- The need to allow production and use of energy for everyone and everywhere
- Solar panels' size, weight and costs can be improved and decreased; light reflection; nefficient light absorption
- Currently, solar panels need to be moved according to the sun light → it could be possible that this would no longer be necessary if the ALL would be used
- A lens could shift the focal point of the light

3.1.3. Stakeholders map for solar panels



3.1.4. Interview with an expert on Solar panels; Huotian Zhang (University of Linköping)

Date of interview 2022-04-27

- Concentrated solar power that uses lenses might not increase efficiency compared to the area that it would cover, but since the lens might be cheaper than solar cells that might still be a benefit
- Currently concentrated solar power mainly uses mirrors that do a similar job as the lense would do → it might be that the lense could help to catch sunlight even if the sun is moving but this is not sure since sunlight is a parallel light
- Most common used solar cells that are continuously further developed and improved:
    1) Silicon-based => absorbs light more efficient, are more durable, non-organic;
    2) CIGS => more efficient than silicon-based ones, non-organic;use of several materials (inorganic)

3) Pro-sky => works similar to paper printing - printing of cells.
4) Solar panels with liquid crystal => a new thing.

- Most power comes from solar power.
- Issues: limited capacity of storage, not possible to work during night/cloudy periods, etc. Even batteries can not store the amount of energy generated.
- Solar parks are more efficient, cost-benefit than individual production→ concentrated solar power with the lense would be most feasible here.
- The area and the location of the solar cells are the crucial factors that determine the efficiency of the solar cells.

3.1.5. Final Comment

As for now the main draw-back of solar power is the storage capacity and therefore it might be most important to find a solution for this issue. However, from a scientific perspective the lense might have potential for improving concentrated solar power but the feasibility is not clear. Due to the lack of distinct practicability and because other solutions e.g. mirrors or improvements of current solar cells can be regarded as good solutions in terms of efficiency the use of the lense in the area of solar panels might not be recommendable. Nevertheless, considering that the lense might be cheaper as a solar cell and the possibility that further development of the lense might enable it to catch the parallel sunlight in fixed solar cells even when the sun moves can indicate some potential in this area. To reliably evaluate and continue this path much technical knowledge and expertise would be needed and therefore we would recommend to continue this path only in collaboration with knowledgeable experts.

Other helpful literature within solar panels:

- http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.877.8679&rep=rep1&type=pdf
- US20080190415A1 - Liquid inserted lens and solar panel focusing system - Google Patents
- How Do Solar Panels Work Step-By-Step (Solar Science Explained) (climatebiz.com)
- 0.5W 2V Amorphous Silicon Thin Film Flexible Solar Panel | QSKJ
- *https://www.researchgate.net/profile/Sarah-El-Himer/publication/345216009_Photovoltaic_Concentration_Research_and_Developmen*

t/links/5fbd7fbb92851c933f579d89/Photovoltaic-Concentration-Research-and-Development.pdf?origin=publication_detail

- *https://www.researchgate.net/publication/286341800_Concentrated_photovoltaics_a_case_study/fulltext/56941bc008ae3ad8e33b6224/Concentrated-photovoltaics-a-case-study.pdf?origin=publication_detail*

3.2 Cameras in Vehicles and traffic

Summary of findings

This chapter introduces our research to cameras in traffic. It describes how the situation looks like today and also problems with that and what we consider to be possible solutions are. We found that today there are problems both with the cameras in vehicles and in traffic. The safety of being in traffic is a big issue that is affected by several factors such as driving experience, street conditions or attention of the driver.

Today there is a lot of safety technology that uses cameras and here the ALL could be implemented. Due to the ability to change focus very fast and without mechanical movement it could be beneficial in cars since today one problem is providing a clear picture at high speed.

3.2.1. Context and Background Information

Traffic accidents

- Most traffic accidents happen in low or middle economies but also in developed countries accidents are more likely when having a low socioeconomic status. https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries
- 3% of accidents are caused when sight is obscured, a statistic that shows that men are more likely to be involved in accidents. https://www.iii.org/fact-statistic/facts-statistics-highway-safety
- Most accidents happen on rural roads, followed by urban roads and highways. https://www.itf-oecd.org/sites/default/files/sweden-road-safety.pdf

- In most accidents there is a car involved. https://transport.ec.europa.eu/news/road-safety-european-commission-rewards-effective-initiatives-and-publishes-2020-figures-road-2021-11-18_en
- Young driver´s increased risk of being involved in accidents (reasons: inexperienced, drugs and alcohol, perception of risk, driving at night, not adjusting speed according to situation, use of older cars with fewer safety devices). https://ec.europa.eu/transport/road_safety/system/files/2021-12/ERSO%20thematic%20report%20Novice%20drivers_0.pdf
- Senior´s increased risk to be involved in accidents (reasons: age-related cognitive and physical limitations especially in complex situations e.g. turning left and crossing pedestrians; senior drivers are a greater risk to themselves than to others; peripheral sight and night vision decrease with age; lack of routine. https://ec.europa.eu/transport/road_safety/system/files/2021-07/road_safety_thematic_report_seniors_final_tc_final.pdf
- Fatigue and vehicle technology to deal with it (names some challenges such as system sabotage and confidence in the system; EU regulation to make driver drowsiness and attention warning systems mandatory for all vehicles). https://ec.europa.eu/transport/road_safety/system/files/2021-07/road_safety_thematic_report_fatigue_tc_final.pdf
- The importance of seat belts and child restraints; the role of enforcement of traffic rules e.g. police controls and punishment but also vehicle technology such as ISOFIX, seat belt reminders and seat belt ignition and interlock. https://ec.europa.eu/transport/road_safety/system/files/2022-01/Road%20Safety%20Thematic%20Report%20-%20Seat%20belt%20and%20child%20restraint%20systems.pdf
- Study about blind-spot mirrors in trucks also highlights that the driver must be attentive and looking to the right place at the right time → support of warning systems. https://ec.europa.eu/transport/road_safety/system/files/2021-07/retrofitting_mirrors.pdf

A report that elaborates on the technical feasibility e.g. intervening systems might be impossible to retrofit because of lacking software and vehicle information, but devices with cameras and

visual/audio signals are feasible https://op.europa.eu/o/opportal-service/download-handler?identifier=88be5621-7ebf-11ea-aea8-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part=

Executive summary of the potential of retrofitting advanced driver assisting systems in existing cars https://op.europa.eu/o/opportal-service/download-handler?identifier=72659808-7ec1-11ea-aea8-01aa75ed71a1&format=pdf&language=en&productionSystem=cellar&part= ;

- The Regulation (EU) 2019/2144 makes several ADAS, such as Advanced Emergency Braking (AEB), Intelligent speed assistance (ISA) mandatory from June 2022 in new models and in all new vehicles from June 2024; but what is about existing vehicles (average age of a vehicle is 10 years which means that this technology will only be widespread within this period)?
- The following retrofit ADAS are studied in this report:
    - FCW Forward collision warning, both VEH (vehicles) and PCD (pedestrians and cyclists)
    - LDW Lane departure warning
    - SLI Speed limit information
    - DDR-ADR Advanced driver distraction warning
    - REV Reversing detection
    - TPM Tyre pressure monitoring system
    - VIS-DET Detection and warning of pedestrians and cyclists nearby the front or side of the vehicle
- Based on this analysis, the highest safety benefits could be expected for LDW, SLI, 112 eCall and DDR. The bundle (FCW, SLI and LDW) was estimated to reduce road fatalities by 12.9−27.2% and injury accidents by 8.4−23.4% at 100% penetration, against the baseline in which 0% of vehicles are fitted with ADAS (neither factory-fitted nor retrofitted).

3.2.2. Information about Cameras in Vehicles

Cameras from a safety perspective

- Visual cameras (together with automotive radars) → the most common safety sensors in vehicles. Cameras improve the driving environments, e.g. eliminate blind spots, work as virtual mirrors, provide a better night vision (with infrared sensors). Also emphasise the importance/the usage of LIDAR. https://ieeexplore.ieee.org/abstract/document/7786130/authors.

Automotive cameras consist of image sensors, image processors, camera module, flash memory, printed Circuit Board and camera housing.

"Vehicles equipped with automotive cameras are the best solution for providing safety and reducing accidents". Cameras' usage in vehicles are becoming more common. For instance, the camera's job is to.

- Object detection (e.g. of other traffic participants).
- Ensure that the vehicle is within its lane while driving.
- Enhance the insecurity within the blind spot
- Enhance sigh while parking/reversing

This information is from the sources:

https://www.emergenresearch.com/industry-report/automotive-camera-market.
https://www.emergenresearch.com/industry-report/automotive-camera-market
https://www.analog.com/en/technical-articles/auto-camera-link-tech-challenges-and-solutions.html
https://www.which.co.uk/reviews/new-and-used-cars/article/car-safety-features-explained-aUHSQ6N9iDKr

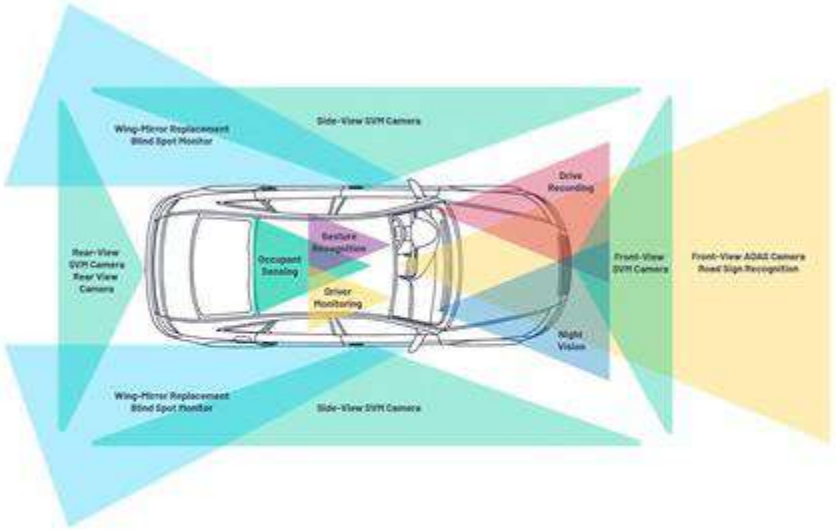


Figure 1. Proliferation of cameras in modern vehicles.

Source: https://www.analog.com/en/technical-articles/auto-camera-link-tech-challenges-and-solutions.html

The camera's Tesla are using

Tesla have highly developed cameras in their cars and the technology they are using can be worth looking into. Find more information at https://www.tesla.com/autopilot

This is basically the goal with automotive cameras; “This system provides a view of the world that a driver alone cannot access, seeing in every direction simultaneously, and on wavelengths that go far beyond the human senses” https://www.tesla.com/autopilot

Camera’s limitations

- Can only provide information about objects within sight → this limitates the automation of vehicles. To overcome this, *wireless communication* can be implemented. https://ieeexplore.ieee.org/abstract/document/7786130/author

3.2.2. Problems that can occur in traffic and possible solutions

In short, problems that can occur in traffic (these are more elaborated below):

- Blind spot
- A lot of moving objects (other traffic participants, animals etc.)
- Weather conditions
- Lack of attention

The table below highlights critical situations that can occur while driving, and what action the driver takes to manage these situations. However, this is only an example of problematic situations and possible solutions. This is also visualised in a journey map, see link: https://app.mural.co/t/clod20206593/m/clod20206593/1650539858770/2a3b53717e155688c271baf91be8394c1dc36678?sender=ue3bf92bebc7a268da5ca2940

Problems	**Solutions**
The driver does not have full visibility because of the blind spots	(a) drive even slower when turning; (b) have always a passenger to help; (c) have a vehicle equipped with a camera that covers blind spots; (d) blind spot mirrors in the car (e) install blind spot mirrors on cross-roads (f) awareness of pedestrians about crossing the street
Losing few seconds if looking too much in one spot => leads to missing “events” from another	(a) issue driving licence only to “responsible and careful” persons;

spot	(b) have a vehicle equipped with a camera that covers blind spots and the whole surrounding; (c) other passengers that can watch out
The driver is already involved in few activities => complex situations that require multitasking and fast perception and decision-making	(a) regular trainings; (b) technical devices that make some of the actions automatically, e.g. cameras and AI (c) self-driving vehicles that lack the human restraints;
Overall problem: Driver can not keep attention to everything and everywhere	Improved attention to the surrounding with a camera All is a solution because: -fast change of focus -> fast detection of people/objects
Overall problem: poor sight due to bad weather conditions	(a) Improved eyesight; e.g. usage of better eyeglasses. (b) Improve the vehicle's different assistance systems (b.1.) Improve the cameras within the vehicle (b.2.) Improve the sensor system within the vehicle
Overall problem; lack of attention.	(a) More restricted laws and enforcement regarding the usage of phones while driving. (b) breaks when long-distance driving (c) driver distraction detection
Driver needs to see back and forth in order to park the car in between two cars. That takes a lot of energy and time, plus a little portion of extra fuel for a longer time.	(a) Sound sensors (b) Camera covering more angles accurately

Occurred problems: car accidents and insecurity of all participants in the traffic e.g. car drivers, cyclists, pedestrians, wild animals; traffic jams, need to ensure that traffic rules are followed, especially in cities: need to decrease the car traffic and make it more efficient (measures like street charges or park and promotion of park and ride parking places), increased use of supporting technologies to make cars safer, in the future: self-driving vehicles that lack the human perception and decision-making abilities

- **Use of cameras in traffic:**
    - Regulation of the traffic → cameras instead of sensors in the ground

- Time specific foci to check for traffic rules like seat belt or child car seat e.g. first focus on driver, then on the other passengers in the car
- Counting people in the car → improve face recognition => for sustainability reasons e.g. when decreasing the number of cars in cities by giving incentives for ride sharing
- Cameras in (self-driving) cars → improve security

3.2.3. The usage of ALL in vehicle cameras

ALL as a potential solution: not necessarily for cameras in new vehicles but especially in devices to be added retroactively

Statistical data indicates that more heavy accidents occur in low or middle-economies and that people with a low socioeconomic status are more likely to be involved in accidents. Apart from other factors, one reason for this is that the vehicles are not equipped with modern safety technology. Moreover, the fact that many young drivers and senior drivers are involved in accidents can, besides other crucial factors, be attributed to the fact that many of them use older cars without safety devices.

The EU regulation 2019/2144 makes some advanced driver assistance systems mandatory for new cars from 2022 respectively 2024 but many cars that are produced earlier, especially cheaper ones, are still not equipped with these devices. Hence, the problem that persons with lower socioeconomic status and older cars are more likely to be endangered in traffic remains.

However, some safety warning technologies can be added to older cars afterwards. This applies especially to devices that use cameras and visual and audio signals because they do not necessarily need to be connected with complicated internal car technology and software. Hence, cameras that use the ALL might have high potential for being the optimal solution. Due to the ability to change focus rapidly, the camera with ALL can observe and analyse the environment and provide similar information as sensors but the camera would probably be easier to mount retrospectively. Moreover, since the lense is so small the camera would be tiny and therefore not be a disturbing new element. The low price of the lens is an additional argument for the ALL because this would

make the product relatively cheap and therefore affordable which is very important since the main target group would be people with lower incomes.

It could be that there will be legal requirements for retrofitment of older vehicles with advanced driver assistance systems. That would make the market even more attractive.

In sum, there are different application areas for cameras in traffic but especially in vehicles they could contribute to more safety and driving comfort.

Emphasised problems within vehicle cameras and how ALL can be relevant within this field:

- Poor image resolution . https://www.edge-ai-vision.com/2015/04/smart-exterior-cameras-enhance-vehicle-safety-security/

· ALL can enhance image resolution significantly, and this will also enhance the camera usage at a high speed (cameras tend to work better at lower speed).

- Improve the detection of pedestrians https://www.edge-ai-vision.com/2015/04/smart-exterior-cameras-enhance-vehicle-safety-security/

· ALL have the ability to quickly refocus on moving objects and can therefore improve the detection of pedestrians and in that sense increase the car's self-braking ability.

- Cameras tend to not withstand poor environmental conditions such as snow, fog and heavy rain https://www.emergenresearch.com/blog/automotive-camera-technological-advancements-and-evolving-product-landscape

· Due to ALL's great image resolution and its ability to quickly refocus, may this be something this lense can improve.

- Cameras within vehicles is not always installed in cheaper cars

· ALL is very cheap to mass-produce and can, therefore, decrease the cost of having a camera in a vehicle.

Wireless communication through the ALL

Wireless communication → can enable information exchange between vehicles (information such as collision warning, do not pass warning, blind intersection warning, red light violation warning). https://ieeexplore.ieee.org/abstract/document/7786130/authors

- By having a suitable carrier frequency, communication in non-line-of-sight condition can be done, e.g. around corners.
- A presence of a communication link with high bandwidth → can enable the exchange of high-rate raw sensor data (is in the article called *fully connected vehicles*). These vehicles can implement powerful active safety applications, e.g. "see through", "bird's eye view".
    - "The shared raw sensor data can independently be processed by each vehicle"
    - "By sharing raw sensor data it becomes possible to implement adaptive platooning or even cloud-driven, fully automated driving"

Different jobs are meant to be done due to the placement of the camera https://ieeexplore.ieee.org/abstract/document/7786130/authors

- Front camera; detect speed limit signs, improve night vision (with infrared sensors)
- Side-rear view cameras; check blind spots and lane departure
- Rearview cameras; prevent backover crashes
- Interior cameras; prevent the driver from dozing off.

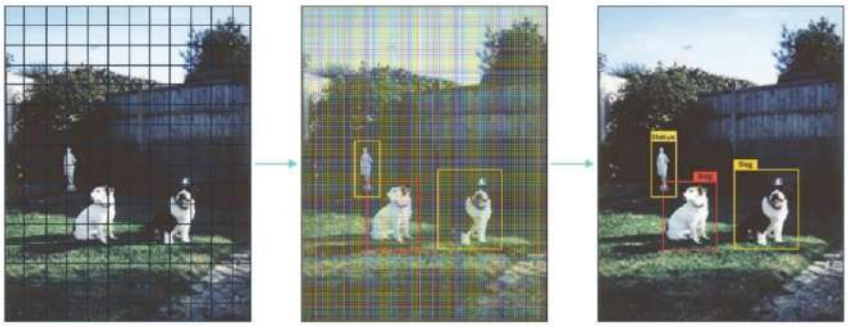
Photonic communication is through light waves (optics) that can send information but not wireless. Light has a wavelength that makes it limited to pass through objects and are therefore transported through fibre.

Wireless communication is through electromagnetic radiation (radio waves) which uses antennas to send and receive the signals.

ALL Application in micro cameras (in cars)

- Durable stability of over 1000 hours under continuous driving in high temperature (85°C). https://opg.optica.org/oe/fulltext.cfm?uri=oe-20-25-27520&id=246322

Machine learning in combination cameras, LiDAR is important in developing autonomous vehicles. Data Annotation to identify street signs, other cars, etc. YOLO (You Only Look Once) algorithm that detects different objects and categories them (Humans, dogs, trees, vehicles) (https://mindy-support.com/news-post/how-machine-learning-in-automotive-makes-self-driving-cars-a-reality/).

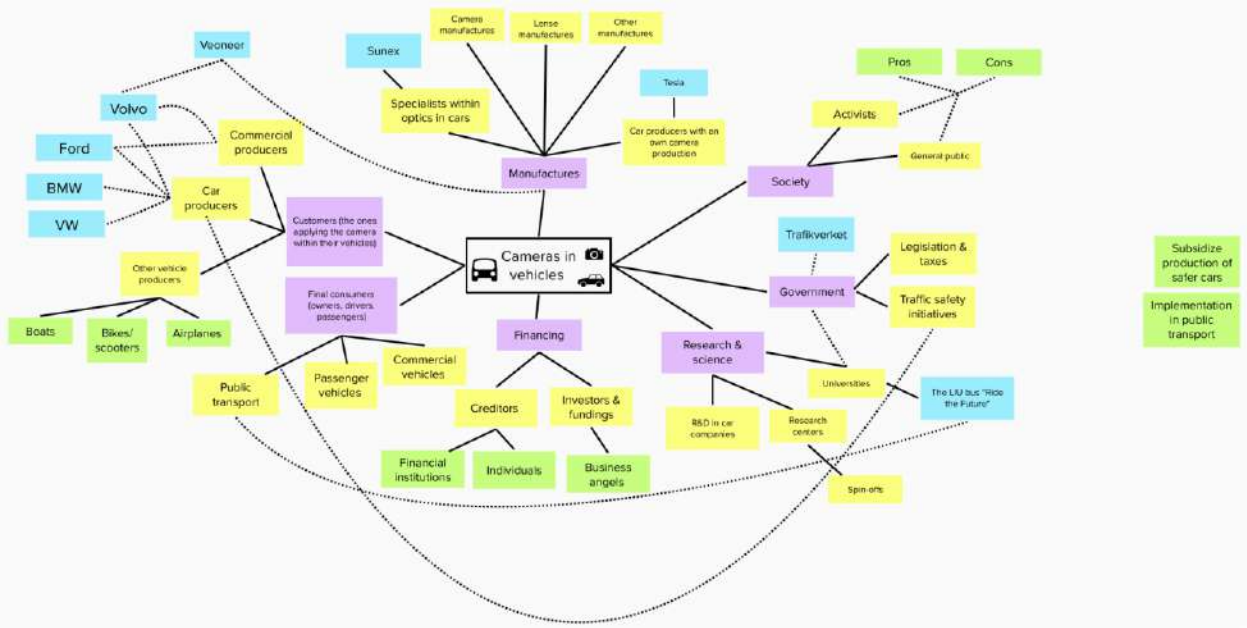


Lidar enables greater possibilities because it gives 3D imagery rather than 2D imagery (as a camera would). But there are issues https://www.mdpi.com/2076-3417/9/19/4093:

- Spatial resolution
- Several sensors with complementary measurements and failure models are necessary to ensure safety and reliability (short and long-range radar and lidar, ultrasound, vision cameras, all in combination).
- Around 20 to 40 sensors per car are required.
- Detection under fog, rain, and snow is difficult.
- Potential interference between different cars' LiDAR systems, each signal needs to be unique

Developing machine learning to understand what objects are a threat and what objects are not, Developing machine learning to react differently to different objects, The influence of weather, Combining long-distance view with broad field view (https://mindy-support.com/news-post/how-machine-learning-in-automotive-makes-self-driving-cars-a-reality/)

Stakeholder map for cameras in vehicles



3.2.3. Market potential

- There is an increasing demand for autonomous vehicles which includes the need for convenient and easy driving https://www.emergenresearch.com/industry-report/automotive-camera-market
- The amount of road accidents is increasing and is expected to support this industry's revenue growth. Additionally, most accidents are due to deficient human behaviour or driver error https://www.emergenresearch.com/industry-report/automotive-camera-market
- Due to Covid-19 and other global factors there is a certain risk of entering this field since the vehicle industry may drop in the near future. This is mainly due to manufacturing problems https://www.emergenresearch.com/blog/automotive-camera-technological-advancements-and-evolving-product-landscape.

-"The market for global automotive cameras is growing and by 2021 the market size will reach 6,92 Billion USD. For the forecast years, it is expected to reach a CAGR of 11,3%" (Emergen Research, 2020).

- CAGR = Compound Annual Growth Rate. Is the RoR (rate of return) required for an investment to grow (investopedia).
- Market expected to grow due to (Emergen Research, 2020);

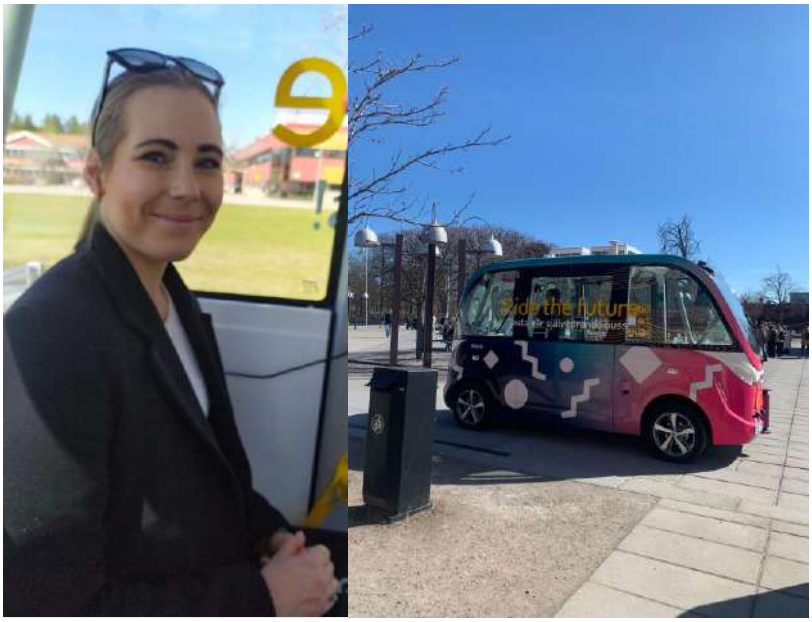
- ❖ The demand for autonomous vehicles keeps rising.
- ❖ There is a need for both easy and convenient driving
- ❖ The increased number of traffic accidents; 94% of accidents is due to driver error or behaviour → increase the demand for more safe vehicles. This inferes the need to detect obstacles on roads.

- "Vehicles equipped with automotive cameras are the best solution for providing safety and reducing accidents…" (Emergen Research, 2020).
  - Camera "...help improve the driver interface by detecting lane markings ahead of the vehicle…"
  - "...monitoring the vehicle's position within its lane…"
  - Give "...warnings when the vehicle steps out of its lane"
  - Used "...to detect other vehicles in front of it and adjust its speed accordingly in order to avoid a collision".
- Factors that is expected to hamper the global automotive camera market growth (Emergen Research, 2020);
  - High installation costs
  - Increasing risk of camera system failure
  - Availability of open-market automotive cameras
- The global automotive camera market, segmented into *passenger vehicles* and *commercial vehicles* (Emergen Research, 2020).

3.2.5. Notes from an interview with "Ride the future", University of Linköping

- The buses are using LIDAR and RADAR technology → they can sense if there is an obstruction and brake differently depending on how close the obstacle is when it is noticed; sometimes instant and sharp brakes create a risk of falling if you are standing in the bus → would be a problem in an ambulance where paramedics are sometimes standing to treat the patient while driving
- The sensors deliver 3D imaging for the bus but it is not used to recognize the difference of objects (for example if it is approaching a bush or a bicycle); the buses are not intelligent enough to know what is in the way, but only that something is in the way.

- The bus does not work under conditions of heavy rain or snow → with regard to emergency vehicles: they must be able to drive in all weather conditions .
- In some of the buses a suggestion can be made based on calculations of whether passing by an obstacle is possible, but manual intervention is still required to follow through with the suggestion.
- The LIDAR of the bus reaches around 90 metres, calculations of whether an obstacle is approaching happens very quickly.
- Usually two separate cameras are required, one that can zoom in and one that has a wide angle. The problem is that the camera that zooms needs mechanical movement which takes a longer time to perform → the ALL could be a solution for this problem



3.2.6 Notes from an Interview with an engineer and head of development of a big automotive supplier

Main Topic: existing safety technologies in cars and how they work

- *Forward collision warning and reversing detection:* usually work with radar (because of larger distance and speed); in the near it uses ultrasound waves (because of low speed and small distances) → cameras could possibly also be used here, for bad sight situations e.g. night, heavy rain combined with heat detection

- *Lane Departure Warning:* camera (usually in the driving mirror) detects the road marking and matches it with the position of the car → Cameras are already used
- *Speed information warning:* camera (usually in the driving mirror) recognizes the street sign (but sometimes problems that for example information on speed limits of trucks or illuminated signs is not perceived in the right way) and also matches it with the information it has from the navigation system
- *Driver distraction warning:* sensors that detect the reaction time or camera that monitors blinkering (in the windscreen pillar)
- *Detection and warning of pedestrians and cyclists:* use infra-red heat cameras (could also be used for forward collision warning)
- BUT: the cameras in cars usually have a fixed focus (--> so why would ALL be especially beneficial?)

3.2.7. Final Comment

Based on the research presented in the writings above and talks with experts (project managers of the self-driving bus ride-the-future and an engineer and head of development for a big automotive supplier**)** we come to the conclusion that cameras in vehicles do have high potential especially in autonomous vehicles. However, since cameras in vehicles usually have a fixed focus to serve their purpose the main advantages of the ALL would not be additionally beneficial so far.

4. Selected idea: Emergency Vehicles (EV)

Research summary

The selected idea to focus on is associated with problems we find with regards to response time and safety for emergency vehicles. The main problem identified is that other vehicles restrict the access of emergency vehicles on route to the place of emergency. This is a major reason for delays as well as accidents involving emergency vehicles.

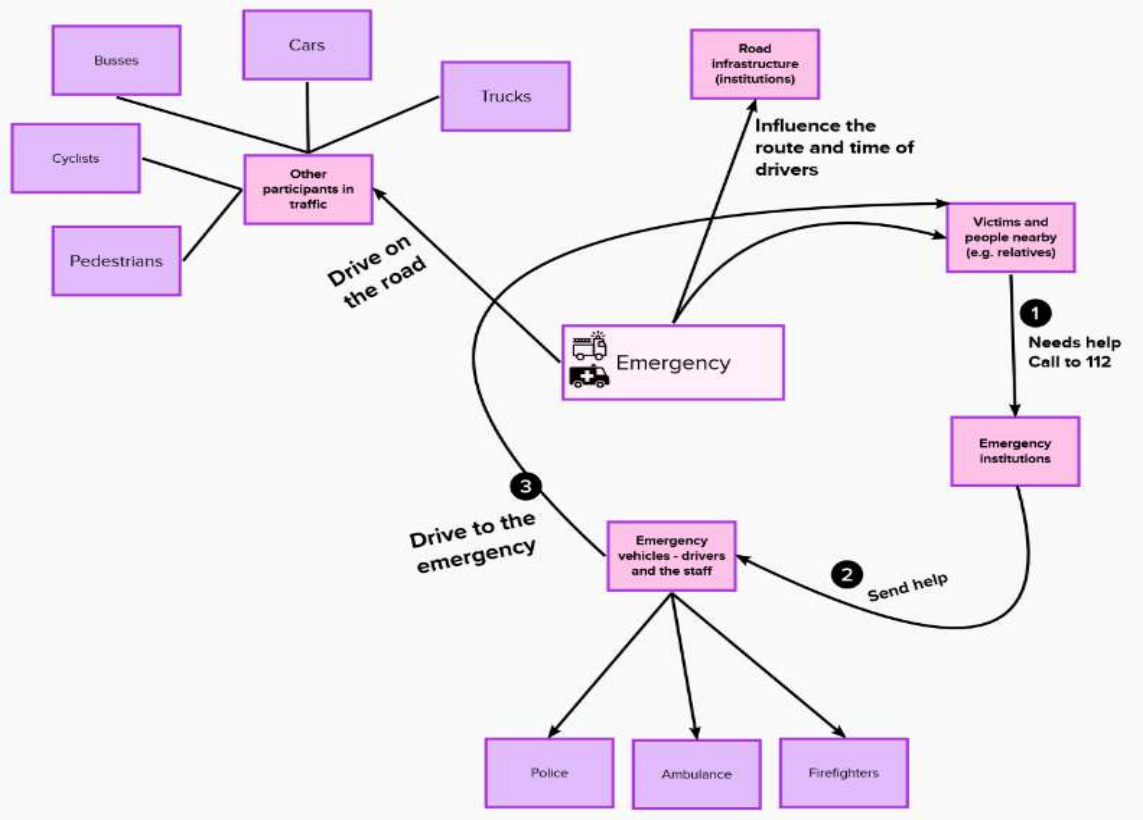
Therefore, we suggest an improved coordination of traffic and this could be done by a vehicle to infrastructure and/or vehicle to vehicle communication. One possible way to communicate huge amounts of data is the Li-Fi technology.

Li-Fi is a means of transferring data using light signals. The lens is essential to transmit and receive these signals and we believe utilising the LED-lights already implemented in both cars and infrastructure in traffic. When the emergency vehicle can communicate with infrastructure, and with other vehicles, drivers can be steered out of the route to the emergency, and be alerted early on. Using the ALL-technology to replace the transceivers lens should create stronger signals due to the fast re-focus and thereby range of the signal.

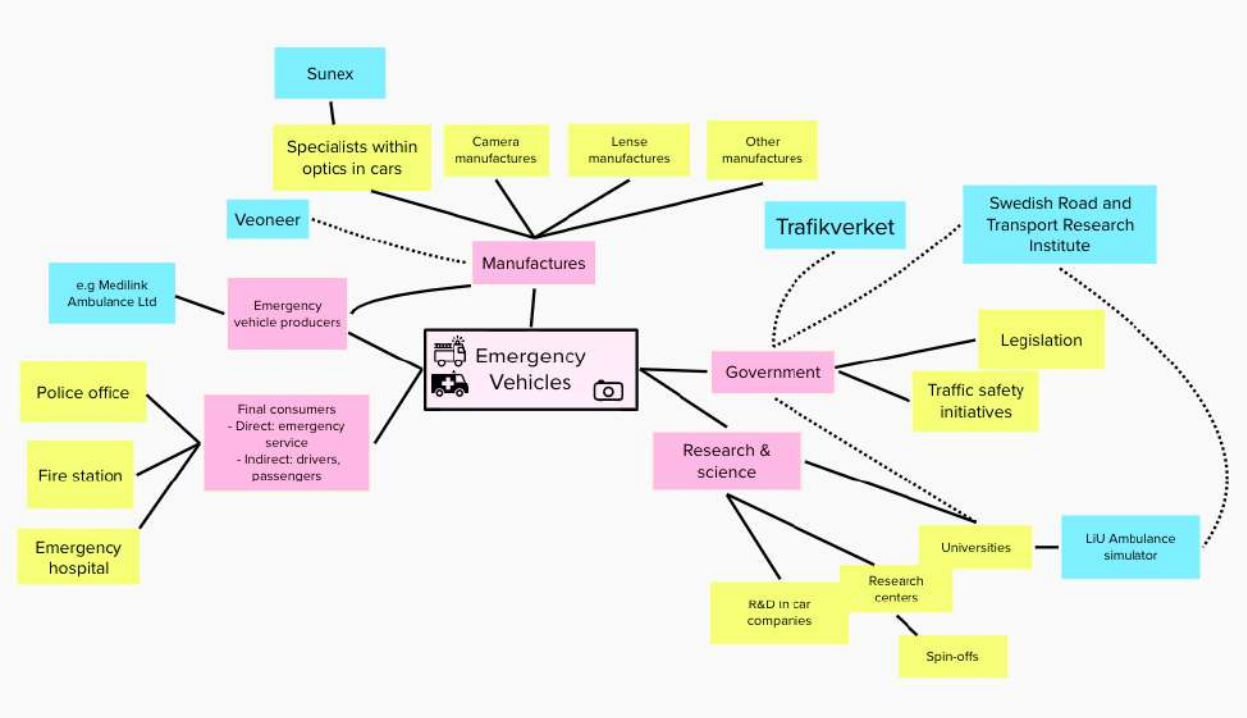
4.1 Context and Background Information

Emergency vehicles (EV) in this documentation refers to police cars, fire trucks, and ambulances. In the following Stakeholder map we aim to provide a simple overview of the situation and context we refer to in this chapter. It is about the situation when an emergency vehicle needs to drive to an emergency because someone is in urgent need for help. However, there are also other traffic participants that are on the same road as the emergency vehicle and this can lead to critical situations and delays.

Stakeholder map 1:



Stakeholder map 2: Other stakeholder related to emergency vehicles



Statistics and information about emergency vehicles

- In 2020 nearly 180 people died in crashes involving emergency vehicles.
- Crash involving police cars include 132 deaths, ambulance 31 and fire trucks 17 deaths in 2020.
- Most of these deaths include people in ordinary vehicles with a 56% ratio.
- 69% of these deaths occured in multi vehicles crashes.
- 89% believe that an emergency vehicle licence should be inplace to increase security.
- Ambulance causes 2600 injuries each year.
- 300 fatalities caused by police cars in police pursuit each year.
- 3100 fire truck incidents occured in the last year.
- Reasons behind this- lack of people-> long work shifts-> hungry/tired drivers-> less concentrated drivers.

Emergency Vehicles - Injury Facts (nsc.org) → information about accidents where emergency vehicles area involved

EMERGENCY SERVICES DRIVING STANDARD

These vehicles are used to drive faster than the usual speed limit. Road fatalities are 4.8 times more likely to occur for emergency vehicles. The stats of accidents have increased due to the involvement of emergency vehicles with ordinary vehicles travelling on the road.The stats mentioned below are based on the accidents that have occurred in the USA in the past years. The report is updated on an annual basis.

Ambulance Vehicles Accidents:

The report issued by National Highway Traffic Safety Administration (NHTSA) in 2014 stated about the accidents that occured from 1992 to 2011 due to fast manoeuvring of ambulance vehicles. Every year around 6500 ambulance accidents occur during the emergency services. 60% of road accidents of ambulance service occur of total accidents during the emergency services. 29 fatal crashes caused by ambulances include 33 deaths every year. 600 people are injured in these accidents yearly.

Fire Truck Accidents:

Following the ambulance the fire truck accidents are the second leading cause of fatal accidents. In the past year the total number 3100 fire truck accidents occurred while emergency services as well as 49 lead to deaths of people including fire fighters. During the last 10 years a total number of 31600 fire truck accidents occurred during emergency services. Around 70% of fire accidents occur during emergency services.

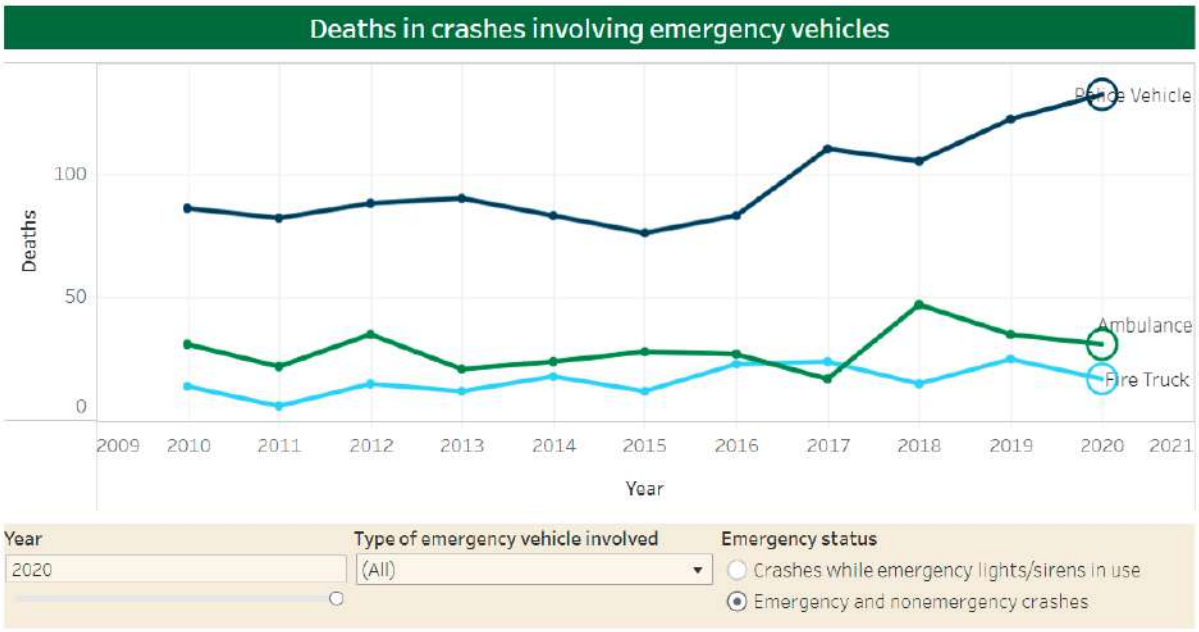
Police Car Accidents:

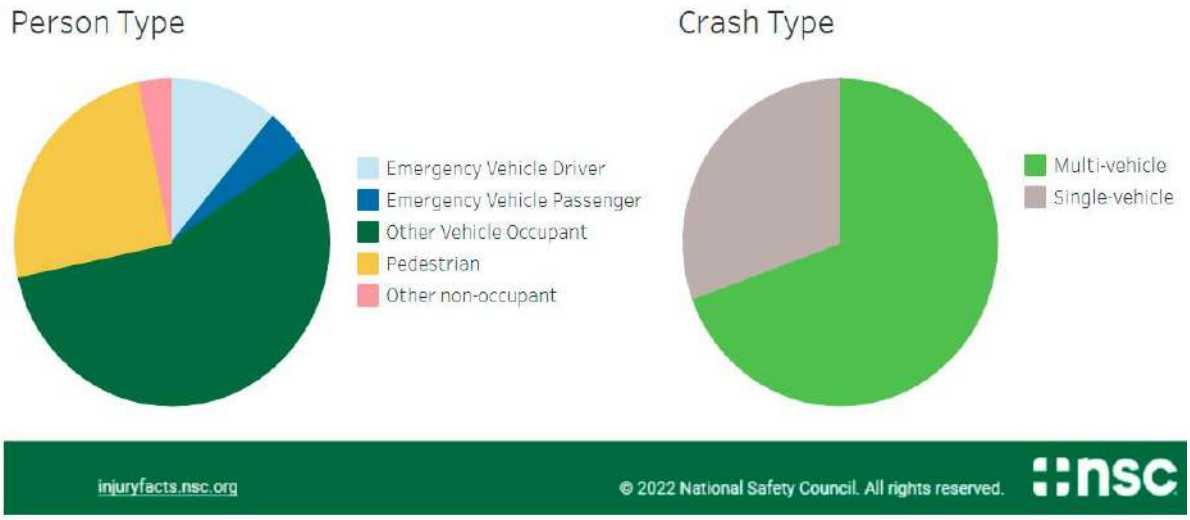
Accidents involving police vehicles consist of significant numbers. Police cars operate at double speed and double the rate of road crashes. Police car accidents account for a total 30% of accidents in which people are not involved in the pursuit. Due to this police officers have double the rate of car accidents per million vehicles driven as a general public.

[Shocking Statistics of Emergency Vehicle Accidents (napolinlaw.com)]

[Emergency Vehicle Accidents – What the Research Shows (thejusticeattorneys.com)]

Graphical Statistics as of 2020 including all types of emergency vehicles:





Emergency Vehicles - Injury Facts (nsc.org)

Why Police cars have more accidents than any other emergency vehicles?

From all the three types of emergency vehicles accidents the police cars have the highest number of accidents and injuries involving drivers and pedestrians. The reason behind this is that the police are mostly in pursuit to catch someone because they need to catch criminals by force so they need to take more aggressive decisions. Secondly, ambulances need to to transport the patient who needs medical treatment most of them are seriously injured. Due to the emergency transportation they are involved in accidents and the ratio is even higher when they have victims inside instead of reaching the scene of accidents. At last fire truck accidents are lower because it does not include transporting and catching someone but more they need to control hazardous situation and their accidents occurred when they need to reach as soon as possible on the incidents scene. Their driving behaviour is safer when they are heading back to the station as they have already handled the situation.

Laws & regulations

DRIVING ON THE ROAD - RULES AND REGULATIONS IN SWEDEN (journals.sagepub.com)

Drivers driving emergency vehicles require special training before being eligible to do so except for rescue vehicles.

What authority does an emergency driver have and do emergency drivers never have to follow the traffic rules?

- Emergency driving does in no way automatically mean high speeds and running red lights, even though the driver may have a statutory opportunity to do so.
- However, the exceptions may only be applied provided that the driving can be done without undue risk and that extra caution is applied.

Groups that are allowed to perform emergency driving in Sweden

- It is a common misconception that only police and rescue services are allowed to drive with blue lights requesting other road users to move. But in fact there are multiple occupational groups, even within the private sector that use emergency vehicles in their daily operation.

How are other road users supposed to act when an emergency vehicle approaches?

When it is an emergency vehicle approaching, it is extra important that you quickly create space for a safe passage. However, in Sweden you are not allowed to violate any traffic rules when doing so. Act calmly, clearly and create space to the extent possible. Pay attention to the intention and signals from the emergency driver and try to let them safely pass.

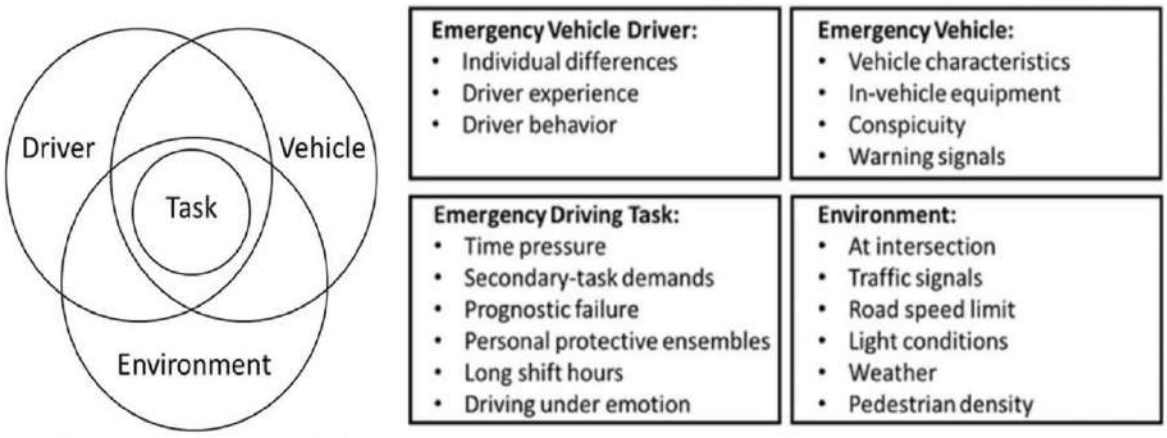
Increased demand in poor weather conditions

Driving in Inclement Weather -EMS agencies may see a greater demand for service as civilians are unwilling to drive themselves to seek medical treatment for minor illnesses and instead call EMS to take them.

Preventing Emergency Vehicle Crashes: Status and Challenges of Human Factors Issues

https://journals.sagepub.com/doi/full/10.1177/0018720818786132

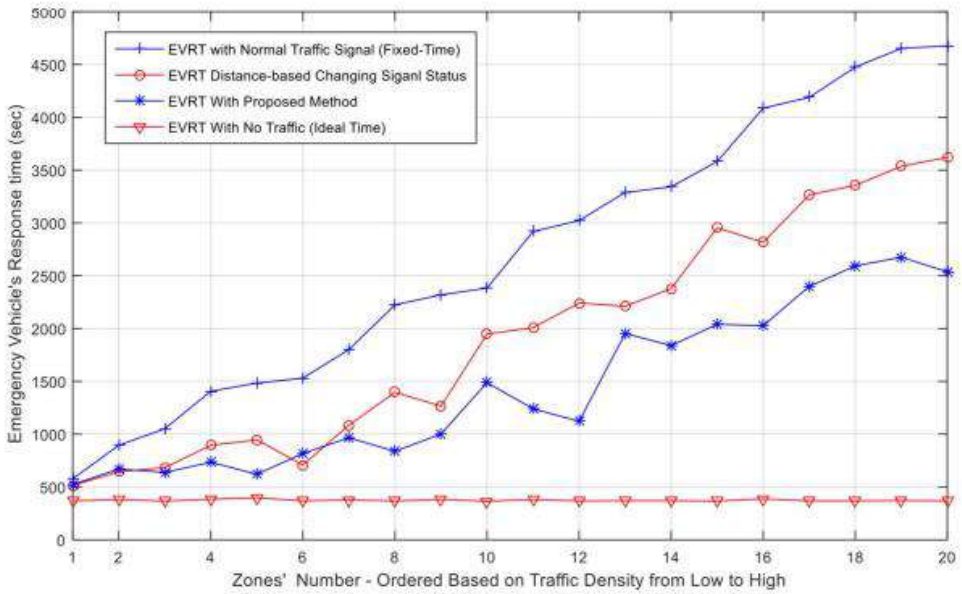
Understanding the significance of reducing the accidents world wide, will allow for an effective strategy to avoid such incidents. Major risk factors for emergency vehicle crashes identified can be categorised into four parts: driver, task, vehicle, and environmental factors. The user-vehicle-environment interactions are also directly influenced by distinct emergency vehicle driving tasks that involve heavy secondary-task demands, such as operating warning devices, communicating with dispatchers, and monitoring potential threats.



Figures: https://journals.sagepub.com/doi/full/10.1177/0018720818786132

How does traffic density impact the emergency vehicle response time?

The graph below shows that the higher the traffic density is, the longer is the emergency vehicle´s response time. Different scenarios of traffic lights coordination are depicted and it becomes clear that no traffic at all would always allow the emergency vehicle to be fasted, but also if traffic lights are steered based on the needs of the emergency vehicle e.g. distance and speed the response time can be reduced significantly.



Noori, Hamed & Fu, Liping & Shiravi, Sajad. (2016). A Connected Vehicle Based Traffic Signal Control Strategy for Emergency Vehicle Preemption

Source: https://www.researchgate.net (Accessed: 03.05.2022)

4.2 Users and Personas

4.2.1 Emergency vehicle driver - real life insights

The following table summarises the information and insights from real-life documentaries[1] and from interviews with users. To learn more about the driving experiences of emergency vehicle drivers in different professions we have talked to paramedics, firefighters and policemen and an instructor for safety driving training for emergency vehicle drivers. The interviewed persons come from different cities in Sweden and Germany.

[1] https://www.ardmediathek.de/video/die-nordreportage/wer-schafft-es-zur-feuerwehr-haertetest-fuer-den-traumberuf/ndr/Y3JpZDovL25kci5kZS84MmEwNzkwYy05NDU4LTRhOGYtOWYyNC05YmIzMWU0MjFkZDU; https://www.ardmediathek.de/sendung/112-wir-retten-hessen/Y3JpZDovL2hyLW9ubGluZS8zODIyMDE4Mw; https://www.tv4play.se/program/112-p%C3%A5-liv-och-d%C3%B6d

Problems, Disturbances & Difficulties	Current ways to deal with the traffic situation	Other insights
Mostly police cars are involved in accidents, firetrucks and ambulances are involved less often Critical driving in cities and at intersections where there is a lot of traffic Road works Driving in rush hours Weather conditions; e.g. slippery roads Infrastructure of roads Traffic signals Other drivers don't hear the siren Other drivers don't see the blue lights Other drivers use the mobile phone which limits their awareness and reaction Siren sound sometimes create more panic for the other drivers → they are unable to behave accordingly then Different rules for international licences → other drivers sometimes don't know how to react accordingly Night vision; Pedestrian not wearing reflex jackets Misinterpretations by the other drivers about different lights and siren sounds → they don´t know what to do Different responses from different drivers; e.g. some move to left some to right → chaos Drunk people come in the way at night when moving in congested area/roads Large size of the EV (fire truck) makes manoeuvres more difficult Hearing problem e.g. because of music in cars	Blue blinking lights Fastest routes can be seen on EV screens Putting on Siren sound Information transfer through radio Compressed air sirens (louder sirens in Ambulances) Education to drivers; e.g. while training and through media Trainings for EV-drivers but they are not mandatory and in many educations it driving is only addressed in theory There are legal rules and requirements for driving of EVs fire trucks often do not drive faster than 90 km/h	Trainings are regarded as important especially for the EV-drivers because it helps them to get familiar with the vehicle and driving → however every situation is also different and challenging While driving the EV-team gets further information about the emergency an additional device to pay attention to is seen critically Tests - physical and mental for police officers Special licence in most cases but no special licence for EVs Other abilities; strong nerves to calmly respond to panic situations Sometimes paramedics in an EV are not sitting and use the seat belt because they need to treat the patient while driving If an EV is involved in an accident another EV needs to go to the emergency High commitment and motivation of the emergency vehicle team The job of the emergency vehicle team is very stressful (sometimes no time for breaks and eating) and often there is also some emotional involvement e.g. when children are the victims

In Sum, the following needs and insights were identified:

- The need for quick and safe passability because time matters extremely (can decide about life or death) → emergency vehicle needs priority to other drivers

- The need to perceive and evaluate information quickly and act accordingly → need to be observant of every detail, what is happening around the car, on the road etc. because neither the ambulance drivers/passengers nor the other traffic participants should be endangered
- The need of visibility in the traffic because other drivers can often get confused of how to react when they become of the EV very late (the unpredictability of the other drivers actually seem to be a major problem)

4.2.2. Emergency vehicle driver - Synthesis-Point of view

The emergency vehicle drivers (professionals) must fast and safely get to the emergency because the time it takes until they arrive can decide about life and death.

User	**Needs**	**Insights**
Saskia has been an ambulance driver for four years. He is 30 years old and enjoys spending his free time with his two young children. However, he also loves his job although it is often very stressful. Every new mission is a new challenge and he never knows what will happen. In his job some minutes can decide over life and death. Sometimes this responsibility can also be very irksome..	- He needs to drive the ambulance vehicle to the emergency and later to the hospital as fast as possible - He needs to drive safely especially when the patient is onboard - He needs to adjust his driving to the other drivers - He needs to stay calm and focused while driving, not getting disturbed by the siren's noise, information he received in the headphones from the main operator, etc.	- Because the faster they are, the shorter is the time the patient suffers and the higher the probability that the patient will survive - Because if he takes risky manoeuvres he endangers the life of himself, his colleagues, the patient and other drivers. Moreover if his vehicle is involved in an accident this also leads to time delays until the patient can be treated. - Because he will only be able to pass the street if the other drivers make space for him. - Because if he gets stressed and

		unconcentrated he might make mistakes that could have severe consequences. - Overall, because he has full responsibility over the situation.
Cissi has been a firefighter for ten years and she is a 32 years old single woman. She loves the team spirit with her colleagues and she knows that she can always count on them, even in very risky and dangerous situations.It always fulfils her a lot when they could successfully put out a fire and everybody survives but sometimes it also happens that they come too late and some hard cases, especially when children are involved, have touched her very much.	-Cissi needs to drive the big fire truck with all her colleagues on board to the emergency as fast as possible -She needs to drive safely -She needs to adjust her driving to the other drivers - She needs to stay calm and focused while driving, not getting disturbed by the siren's noise, information she received in the headphones from the main operator, etc.	- Because the faster they are at the emergency, the sooner the fire can be put out and the smaller the damage is. In addition, if people are still in the burnings the chance to save them is higher the earlier they are rescued out of the fire and smoke. - Because the fire can quickly spread out to nearby buildings/lands and therefore can put in danger more human/animal lives. - Because if she takes risky manoeuvres she endangers the life of herself, her colleagues, and other drivers. Moreover if her vehicle is involved in an accident this also leads to time delays until the fire can be put out.. -Because she will only be able to pass the street if the other drivers make space for her..

		-Because if she gets stressed and unconcentrated she might make mistakes that could have severe consequences.
Chantalle, Police since 20 years back. She has vast experience and is very appreciated at her station. She lives with her family and spends a lot of time with them but she is also very committed to her job. She has been a part of various situations during her career and is therefore always prepared for different scenarios.	- She needs to drive the police car to different locations as fast as possible in emergencies. She has always a partner/colleague accompanying her; - She needs to drive safe since she is responsible for whatever happens during the ride; - She needs to be aware of other drivers; - She needs to be able to focus and make decisions fast and accurately in stressful situations.	- Because it is a part of her job to get to the emergency as soon as possible since that increases the chance of solving the case; -Because if she takes risky manoeuvres she endangers the life of herself, her colleagues, the patient and other drivers. Moreover if his vehicle is involved in an accident this also leads to time delays until the patient can be treated; -Other drivers might disturb her drive and for her to pass she needs to be aware of them -Without focus will she not make good decisions and not make it to the situation or other mistakes

Summarised point of view: The emergency vehicle driver needs to drive fast and safely because they need to arrive at the emergency as fast as possible in order to do their job and to save lives.

Saskia Brand

Female | 46 years | Sweden | Married | 2 children

Persona Description

Saskia is a 46 year-old married woman with two children, one is 12 and one is 15. She lives in Linköping in Tannefors and drives to work most days, some days she takes the bus.

Saskia has been an ambulance driver for 17 years and works in Linköping. She is experienced and well-educated in her area and comfortable behind the steering wheel. She says that her training as an ambulance driver was thorough and combined with experience she feels confident in her ability to make decisions when goin to an emergency. She never drives faster than what she considers to be safe, the most important thing is that she gets to the place of emergency safe.

According to her, out of all jobs involved in emergency services the driver has the most stressful job. Knowing that somebody's life relies on your ability to safely get from point A to point B can be overwhelming. As the alarm goes off she has to instantly get into a special mindset where her focus needs to be divided between the journey to the place of emergency and what awaits her once she arrives. As an ambulance driver you are not only responsible for the outcome of the emergency, but also for all the people moving in traffic. There are many pedestrians, bicyclists, other cars, etc. to account for when driving. You cannot rely on them to hear the sirens or notice the bluelights, especially not now that almost everyone is listening to music in noise-cancelling headphones, or loudly in their cars. The biggest risk Saskia perceives as she goes on an alarm is that a car with the right of way, for example at an intersection, does not notice her as she is passing a red light or going to fast to stop.

For someone whose job is to save lives the thought that an accident would occurr on the way to an emergency can be overwhelming. She "dreads the day" that her actions results in an accident that would harm (or worse, kill) someone else, even if it is the consequence of the other car not paying attention she would likely have a hard time not blaming herself. Likewise, her own life is at risk, and that in turn calls for her responsibility to her family to make sure she gets home safe after a day at the job

As an ambulance driver, it is not only the trip *to* an emergency that can involve time pressure. Even though there are possibilities for some care in the ambulance, it is often necessary to deliver the patient quickly and safely to the hospital for further care.

The time factor is highly determined by the other traffic in the street. If she is slowed down by traffic at one point she might have to drive faster at another point, and driving faster means higher risks. Saskia summarizes that "in a perfect world ambulances and other emergency vehicles could travel on empty roads wherever they needed to go, but for now we have to rely on our own ability to make safe decisions, and the awareness of other traffic".

4.2.3. Other Drivers - real life insights

The following table summarises the information and insights from drivers that participate in traffic. Drivers from different countries and with different extents of driving experience have been asked about their experiences when they encountered emergency vehicles in traffic.

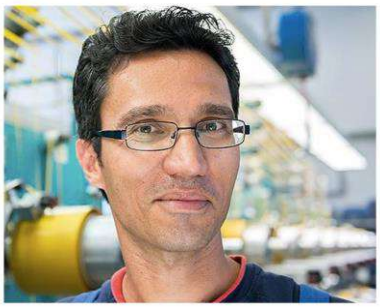
Perception/Awareness of EV	Most drivers are only aware of the sirens when the EV is already close to the vehicles. Drivers are able to recognise the blue light of the approaching EV when they look into the mirrors
Reactions	Drivers sometimes find it difficult to quickly respond to the approaching EV and most of them lack road experience but also experienced drivers face some difficulties in these situations Experienced drivers are more likely to know how to respond when a fast EV approaches and they might react more calmly. Especially female drivers and inexperienced drivers explain that they might be stressed and panicked when encountering an EV vehicle on the road. Traffic and road conditions are seen as big difficulties to manoeuvre accordingly.

4.2.4. Other driver - Synthesis-Point of view

User	Needs	Insights
Mattias is an experienced driver for more than 10 years and he drives a lot. He usually drives alone, both long and short distances. He mainly uses the car when he drives to his office or business clients but in his free time he often drives to visit his parents who live two hours away from the city he lives.	- He needs to arrive at his destination fast and comfortable without any distribution - If there would be an emergency vehicle he would love to know it as early as possible - He needs to stay calm and concentrated when an emergency vehicle comes - He needs to do the right thing when the emergency vehicle comes	- Because he has duties to fulfil at the destination, respectively he knows that his parents are waiting for him and that would worry and wonder if he would be late - Because this would allow him to have enough time to move to the side to let the emergency vehicle pass without any problems, afterwards he could continue driving as usual - Because if he would get stressed and panicked he might not be able to make the right decisions and actions in time - Because if he behaves wrong that could lead to delays in the emergency vehicle´s journey which could endanger lives. Or accidents could happen. If Lars would be the reason for this he would feel very guilty.
Johan is a medium-experienced	- Johan wants to stay calm and	- Because in case of panicking he

driver. He drove occasionally in the last 5 years but recently started driving more frequently as his work requires to have business trips at the periphery of the city.	relaxed while driving and reach the destination without any risky situations. - He needs situational awareness and the ability to adapt to different traffic situations that occur fast and in the right way.	can make unconscious decisions leading to crash or to blocking the lane, which in turn could lead to waste of time for the EV -Because in traffic many unforeseen situations can happen and then every driver needs to adapt his or her driving in order to avoid accidents.
Katarina is a non-experienced driver and she seldom drives. She studies at the University and sometimes takes her parent's car to drive to her extracurricular activities (swimming) within the city. Whenever she sees an EV in the traffic, she tries really hard not to panic and just follow other driver's moves.	- She needs to see the EV in advance so that she has time to react. -She needs to feel more comfortable in unforeseen and difficult traffic situations	- Because in case she doesn't see the EV in advance, she panics and can lead to making mistakes and accidents can happen. If she has more time she is able to deal with the situation more relaxed. - Because if she is more relaxed, confident and experienced she can deal with these situations more professionally.

Summarised point of view: The driver needs to be aware of the emergency vehicle before it is very close and to stay calm because this prevents them from being stressed and panicked and to take the wrong actions e.g. block the way of the ambulance.



MATTIAS TORSEN
Male, 32 Years
Sweden, Linköping

Production Technical Manager at SAAB

Profile

Mattias, 32 years old, has been a production technical manager at SAAB in Linköping since three years back. After graduating as an engineer in industrial economics from the University of Lund, he decided to move back to his hometown, Linköping. He lives together with his partner Rebecca and their dog Sally in a flat outside the city, more precisely in Malmslätt. When he is not working at SAAB, he enjoys working out and prefers doing sports like CrossFit and Padel, and these activities serve as a social gathering as well.

Mattias' experience of emergency vehicles

Mattias usually drives to work since he works approximately 9 km from his home in Malmslätt to SAAB. He sees himself as an experienced driver who drives on a daily basis in all kinds of environments; in the city, on the highway, as well as in the countryside. Like everyone else, he is mostly driving to, and home from, work at rush hours and by this time, there is a lot of traffic on the roads. Due to all the traffic, shorter and longer queues appear which he thinks makes drivers generally more stressed and frustrated. Drivers tend to not keep their distance from other cars, to drive against yellow at traffic lights but also to make more risky decisions when going into the bigger roundabouts. Hence, Mattias feels that driving to and from work can be very stressful since it is important to be fully observant and focused the whole way.

However, whenever an emergency vehicle appears, Mattias finds it hard to know how to act. He believes that it is sometimes hard to see emergency vehicles in advance which makes it hard for him, and other vehicles, to have the time to react. Mattias feels that it can be hard to see emergency vehicles since he is focusing his attention on all the other vehicles, but also since the emergency vehicles can be obscured by the traffic. Also, he does see his driving as a time to breathe after a busy day at work and, therefore, he enjoys listening to music that gives him a good feeling. He does normally not see music as a distraction when driving, but when an emergency vehicle appears, music has been the reason why he did not hear the emergency vehicle's siren.

According to him it is difficult to keep in mind that an emergency vehicle could come at any given time. He explains that when you are at a traffic light for example you only focus on waiting for the light to turn green, you barely look both sides before driving, you just take the green light as a go-ahead. If an emergency vehicle would need priority then he is not sure if he would be able to react fast enough. “I don’t want to be the reason that an emergency vehicle does not manage to do their job, and therefore put other people’s lives at risk.”

4.3 Problems and possible Solutions

The following journey map highlights some critical situations in traffic from the perspective of an emergency vehicle driver and a normal driver. Based on this it becomes clear that one of the main problems is that there are interdependencies between all traffic participants. The time between a driver becoming aware of the emergency vehicle and until he or she has cleared the path has been identified to be crucial for the emergency vehicle response time. Therefore, we analysed the main problems and thought of possible solutions by addressing the following questions (see table below).

What if there was no traffic?	**How might we** reduce the traffic?
What if we could steer the flow of traffic?	**How might we** steer the traffic?
What if there were no emergencies at all?	**How might we** reduce emergencies?
What if traffic behaves accordingly right away?	**How might we** educate drivers to drive accordingly?
What if we could use another transportation system?	**How might we** travel outside of traffic?
What if cars were safe/crash proof?	**How might we** make cars safe?
What if we had a better infrastructure for emergencies?	**How might we** create a better infrastructure for emergencies?
What if traffic would be aware of us before we appear?	**How might we** make everyone aware?
What if we did not have to drive (autonomous cars)?	**How might we** teach a robot to drive fast and safely? And/or to treat victims?
What if the patient would come to us instead?	**How might we** make the patient come to us?
What if we could decrease the distance that we need to travel?	**How might we** decrease the travel distance?

Journey map:

https://app.mural.co/t/clod20206593/m/clod20206593/1650879017968/5c5d78b856274d0d574a91f909d9509abce58845?sender=u678d0cab0cff578e8d7e8284

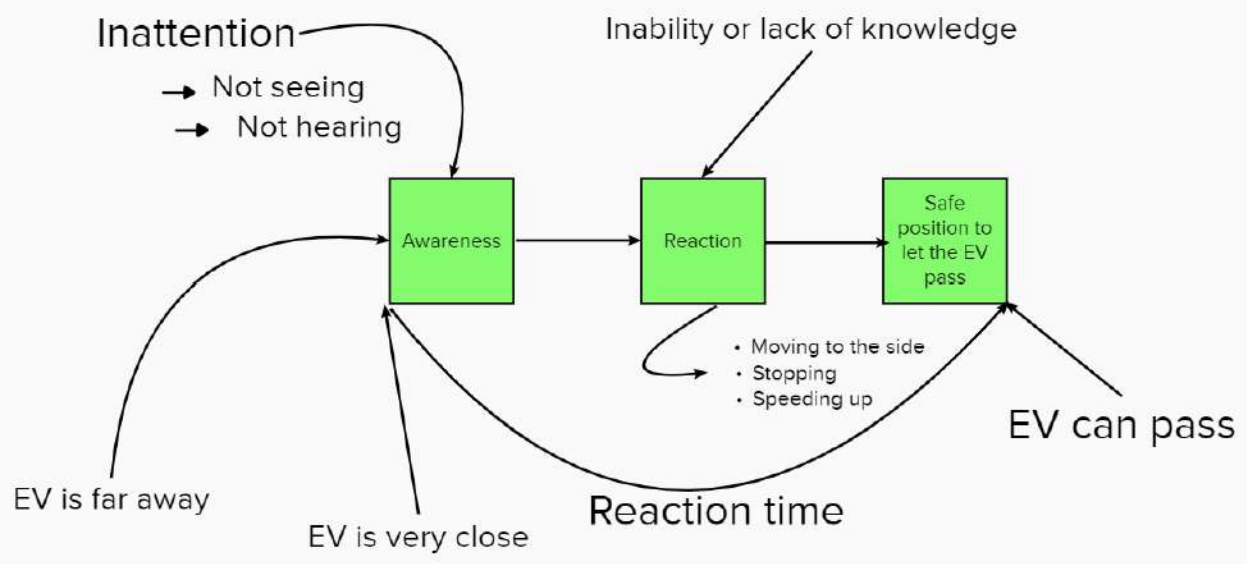


Table showing Triggers and factors affecting the awareness & reaction phase

Trigger	Factors affecting the Awareness Phase:	Factors affecting the Reaction Phase:
Individual Driver	- Inattention e.g. being tired, stressed, Distracted, conversation, using the phone; -Physical seeing or hearing impairments; - High speed (prevent seeing the EV because of the narrow vision); - EV driver not using lights and sirens	- Inexperience (lack of training) of the driver; - Stress, Panic, Fatigue or Fear - High speed (prevent making fast manoeuvring when the EV is detected by the driver);
Environment	- Weather conditions; cloudy weather or lighting (prevent seeing the blue lights); Rainy weather & thunders (prevent hearing the siren); Other weather condition (reduced visibility, reduced steering control, reduced speed and frequent braking) - Density of the traffic (long traffic jam	-Street conditions/Traffic situations e.g. narrow streets with many (parking) cars limit the manoeuvring possibilities; -Actions and behaviour of other traffic participants e.g. need to adapt the own driving to the behaviour of others; -Weather conditions e.g. slippery

	behind that prevent seeing the EV) - Light conditions e.g. night or blinding sunlight limit the ability to detect the EV -Street conditions e.g. crossings or curves limit sight - Co-drivers or passengers (passing other vehicles safely)	streets make manoeuvring more difficult - Co-drivers or passengers
Vehicle	-Vehicle conditions impeding sight e.g. no rearview mirror in trucks; - Vehicles modern equipment (both in helping and distracting the driver);	- Vehicle conditions that make manoeuvring difficult e.g. size of the vehicle, tractability - Vehicles Unfamiliarity - Vehicles modern equipment (e.g. distance warning beepers)

See also: **Accidents Involving Reckless Emergency Vehicles (hoffmannpersonalinjury.com)**

1. **Awareness and attention to the EV → late perception of the EV**

Reasons why drivers do not perceive the EV:

- The EV is not visible to the drivers e.g. there are more cars in front of the EV, the EV is far away, road conditions e.g. crossings, curves.
- The EV is visible but the drivers do not see them e.g. they do not look into the mirrors, they only focus on their own driving behaviour and the lane in front of them, they don't see other drivers reacting to the EV.
- The drivers do not hear the EV e.g. load music, talk with passengers, noise of the vehicle and traffic, bad ears, phone call.

Solutions to improve the perception of the EV (Awareness) and *critical considerations supporting/limiting:*

- Mirrors to make invisible spots e.g. corners visible *(relatively cheap and easy to implement, might only help in some locations, too many mirrors may disturb and confuse drivers).*
- **Camera systems** that film the traffic and can either show this video on screens outside (on a traffic sign or so) or the film can be shown on a screen inside the vehicle. Additionally, this film can instead be analysed and in that way give the driver necessary information and recommendations/decision alternatives *(can give great sight about the whole traffic situation, and in combination with AI, that will analyse the film, the driver could get the necessary information and recommendations without being required to evaluate the videos by himself. for this to work and be efficient, it would be needed in every vehicle or in every location. Also, paying attention to videos could distract the drivers, and some drivers might be sceptical using cameras since they are relying on experience and their own judgement).*
- Louder siren *(relatively cheap and easy to implement because it would only affect the EVs, might be critical for animals or humans in the surrounding, may annoy people)* or intensifier in the car for the siren's sound that perceives sound waves → **potential for the lense?!** *(could be comparatively cheap and could be adapted to the hearing abilities of each individual or the street conditions e.g might need to be louder when speed is higher, would be needed in all vehicles)*
- Maximum volume of the music in the car *(could be good for the health as well, would be needed in all vehicles and should not be able to be manipulated, might face huge refusal by the users) or automatic switch to a lower volume when an EV is near (easy to implement, drivers may find solutions to deactivate this feature)*
- Strict prohibition of phone calls and talks while driving applied to all passengers *(would not have any direct costs of implementation, might face huge refusal by the users and is difficult to control and enforce, would also mean that passengers cannot tell the driver what they see and hear and then this potential solution would no longer be feasible, what about children?, may create other issues (wicked problems) because of not answering to the phone)*
- Passengers in every vehicle that pay attention to the traffic and tell the driver *(4 eyes and ears see more than 2, would not cost anything if one would not have to employ the*

passengers, similar limitations as with the drivers, where would we get a passenger for every vehicle when needed? A pool of passengers → new potential solution of ride-sharing which would also be good for the environment)

- Normal street signs (like the warning signs for elks) in critical spots where EV often drive to increase the drivers´ attention *(relatively cheap and easy to implement, find the right locations to place them → when they are everywhere they are likely to have a limited effect, if they are only in several places, the problem persists in the places without signs)*
- Smart street signs e.g. when an emergency call goes in and it is clear which route to take and how many EVs will be on the street, the warning signs turn on in the right time period, a camera **(with the lense)** could detect the number plate of the EV and turn off once it has passed *(could be very effective because it would only require the drivers attention when it would really be necessary, could be programmed with the optimal time period to allow the EV to reach its destination as fast as possible, location → actually the signs would be needed everywhere and that might be expensive but one could start with the most important dangerous spots; technical development of the signs, what if the EV would take another route than suggested → maybe the sign must be programmed in accordance with the real location of the EV? How would communication take place?)*
- Communication (**through Li-fi and our lens?**) to the other drivers via radio messages that automatically come in the vehicles that are affected. *(An acoustic message would allow the drivers to keep their eyes focused on the traffic, would be needed in every car and should not be manipulated, how would the communication take place?)*
- Communication **(through Li-fi) and the lense?)** to the other drivers via written information e.g. written messages that pops up in the dashboard display of every affected vehicle *(could be very effective because it would only require the drivers attention when it would really be necessary, could be programmed with the optimal time period to allow the EV to reach its destination as fast as possible, would be needed in every vehicle and how would communication take place?)* or maybe the EV could have a projector (**with the lense?!)** that projects the message on the windscreen or mirror of the driver before him *(information would be related with the real location of the EV, EV could manage the projection according to the situation it faces, would only require the update of the EVs,*

conditions for beaming e.g. light? could the projector reach more cars than only the one beforehand?)

- Awareness through light signals e.g. guard railing that sends light signals, for example when a EV passes it starts sending light signals e.g. blinks to the coming part of the guard railing the faster the closer is the EV *(might be a good solution for highways and rural roads where speed is high and you usually have guard railings, also because the sirene might often not be heard on these fast roads, not all streets have guarding roads, what if the EV is not on the lane directly next to the guard railing?* → ***camera that could change focus to detect the EV?!)***
- Light chain reactions e.g. the EV sends light signals or waves that are perceived by the spotlights of the car **(through a lense?!)** in front, this will send similar signals which are perceived by the car in front and so on *(would be a relatively easy technology if it works would be needed in every car, might suffer similar time delays as with the siren and bluelight)*
- Persons e.g. police officers or normal pedestrians or cyclists that recognize the EVs better and can warn the drivers (*could easily be implemented, might suffer from similar time delays as in vehicles but maybe not as strong, need for training how to direct traffic and react to such situations, need to have always a fluorescent cloth, will there always be persons available? Will drivers accept their directions?)*
- a drone that drives in front of the EV and gives a light signal that can be perceived by the car **(camera) to inform the driver about the EV** *(could be programmed in relation with the location and speed of the EV, increase the timespan between awareness and reaching of the EV → drivers have more time for reaction→ less stress and more time for good actions; would be needed in every vehicle)*

2. Behaviour when the EV is perceived (Reaction)→ wrong behaviour that leads to chaos and unpredictability

Reasons why drivers might behave wrong:

- They do not know how to react (lack of knowledge)
- They are so stressed or panicked that they are unable to act rationally

- They think another action would be better than the one that would be right according to the traffic rules
- The street or traffic conditions limit the abilities to take the right actions e.g. no space to move to the side, other vehicles are blocking.
- They don't care or are tired of life

Solutions to improve the behaviour of the drivers and *critical considerations supporting/limiting:*

- Combine solutions from 1 with instructions what to do *(if instructions are given to all drivers they do the same which enhances the predictability of the actions for the EV-driver, instructions could be adapted according to the situation, see limitations of the solutions from 1, would everybody follow the instructions?)*
- Trainings and education for drivers, regularly (like when taking the driving licence) or if one has behaved in the wrong way → camera on EVs **with the lense** that detects drivers that do not behave right and then training or education programs could be mandatory instead or complementary to a fee or other punishment *(training would make drivers more capable and feel more comfortable with these stressful situations, online trainings might be cheap, every situation is very unique and training might not prepare the drivers to every possibility and situation, expensive and time-consuming if real-life training, would be preventive and improve the situation in the future but not help the current situation when the wrong behaviour is detected)*
- Self-driving vehicles that overcome human constraints *(could lead to optimal traffic situations, feasible only in the future, lack of technology?)*
- Improved training for all drivers, especially EV drivers e.g. with simulations that use recordings from real traffic situations or analysing them and giving feedback → **cameras that use the lense (***simulation training is comparably cheap and does not risk any lives, feedback is good for learning, preventions and improvements for the future, recordings will not help in the current situation)*

3. Interdependencies between the actions of all drivers and difficulties to predict the others´ behaviour → delays the decision and action-making and makes evaluation and reaction more uncertain

Solutions to improve the interdependencies and *critical considerations supporting/limiting:*

- The EV drives like all other vehicles (*less risk of accidents, no additional costs or efforts, increases time until the emergency is reached → can cost lives and lead to high damages and costs, there will be no difference between emergency vehicles and other vehicles which will lead to loose of "authority")*
- Reduced traffic because of limited number of vehicles on the road→ **camera with the lense** to count the cars, or because of smart managing of the traffic e.g. crossings, traffic lights or traffic circles *(decreases the number of potential actors that have interdependencies and therefore less complexity, less cars is better for the environment, limiting vehicles might face refusal by the drivers, traffic management is only useful when it does not have negative consequences e.g. traffic jams, hinder other EVs)*
- The EV can transform and fly and does not need to use the roads *(comparable to drones or helicopters, but here there is the advantage that it would be easier to start and land as for a helicopter and that all persons and equipment are included as compared to a drone that has limited carrying weight, expensive and maybe not so realistic?)*
- Better prediction abilities of the drivers (especially the EV-driver) *(could decrease the reaction time and lead to safer actions, abilities of the drivers need to be trained, is human behaviour certainly predictable?)*
- Own lane for EVs or road under or above the normal road *(EV could drive independently of the other traffic, high costs and effort)*
- No EVs in traffic anymore because of beaming, no emergencies anymore or because people can deal with their emergencies by themselves *(perfect solution of the problem, not very realistic)*

Conclusion and preferred solution: The interdependencies between all participants seem to be the major problems that cause delays in the emergency vehicle response time and that can lead to dangerous situations and accidents. Hence, a solution should address both the emergency vehicle and the other traffic participants. Therefore, an improved coordination of traffic would be a great solution. If other drivers could be informed about the emergency vehicle in advance, they would have enough time to clear the path without being stressed or panicked and then the risk of wrong decisions and actions could be minimised. At the same time this would facilitate the driving for the emergency vehicle because the driver would not need to wait for the reactions of the other

driver anymore since the path would already be cleared when the emergency vehicle arrives. Hence, we suggest that smart traffic coordination that allows for vehicle to infrastructure and vehicle to vehicle communication should improve the situation for drivers and the emergency vehicle. Such a communication could be done via Li-Fi.

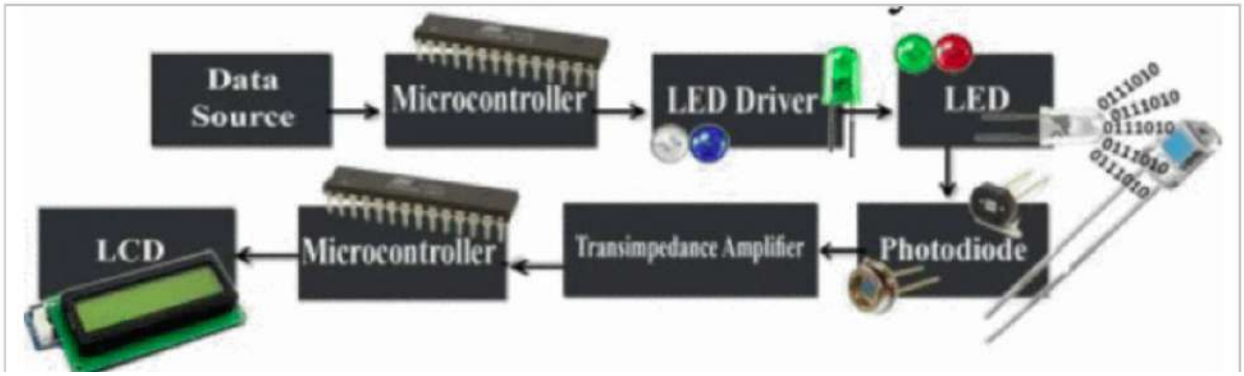
4.4 LI-FI

4.4.1 LIFI and how it works

Li-Fi has been used in experiments where headlights and tail-lights of cars are used as transmitters and receivers respectively. An example of this is an attempt at allowing emergency vehicles to use the Li-Fi's ability to communicate over a large area to automatically turn traffic lights green when approaching them. This allows emergency vehicles to travel faster through traffic-dense areas (Shanmughasundaram, et al., 2018). Since traffic lights already use LED-technology, it appears that a system of LiFi signal communication between cars and traffic lights should be easy to implement (Kalaiselvi, et al., 2017). The reason for this is that LED is an electronic device with an intensity that can be modulated at high speeds, as well being turned on and off at high speeds, making it ideal for transferring data. With this technology you can deliver thousands of data streams at higher speeds, compare this to IR which can transmit a single data stream at a much slower speed (H.Haas, 2011).

Building blocks of developed Li-fi System (Al Abdulsalam, 2015).

The speed sensor (data source) reads the vehicle's speed in the form of Alternate Current (AC) voltage. It is then converted into Direct Current (DC) voltage in order to be readable by microcontroller. The change in the speed is calculated and transferred to the LED driver. The LED driver will send the data through light wirelessly and the photodiode will detect the transmitted light in the form of current that will be transformed into current and then voltage that will be processed through the microcontroller to be readable by the LCD.



Li-Fi vs Wi-Fi

Pointers	Wi-Fi (Wireless Fidelity)	Li-Fi (Light Fidelity)
Application	Internet browsing with the help of Wi-Fi hotspots.	Airlines, undersea explorations, operation theatres, offices and homes.
Coverage Distance	32 meters (varies based on transmit power and antenna type)	10 metres
Data Density	Less dense environments	High dense environments
Operation	Uses radio waves	Uses light sources
Privacy	Less secure	More secure

Source: https://www.jagranjosh.com/general-knowledge/li-fi-light-fidelity-advantages-disadvantages-applications-and-more-1611311388-1

Importance of LIFI: (Soley, 2021) Li-Fi: A New Wireless Alternative for Cars - RTInsights
In the past, LIFI was introduced as an indoor technology but many experts considered that it will bring revolutionary change in the automobile sector by implementing a headlight that can transmit data through LED. The LIFI is being used in aeroplanes as an alternative to wifi as it does not interfere with the navigation system of aeroplanes which make it more secure in the air. It is also

being used in hospitals, power plants and in enclosed environments to overcome the issues of radio frequency. It also helps hospitals to protect users' data as recommended by the government authorities because its signals can not transmit through walls. It is also useful for military bases and banks as well.

In recent study it is concluded that the lifi can be used in cars with 5G connection as it can also transmit signals in the open. Also if there is no connection the vehicle is still able to transmit data between vehicles through headlights, tail lights and cameras. It is considered as a disruptive technology which has possibilities in data transfer and may enhance warning systems in cars. Lifi can be used as an alternative tool when there is dead connection of mobile networks in hazardous situations such as hurricanes, earthquakes, wars, and electricity shortfalls. The flow data transmission can still be online and able to communicate with people and authorities. It can be upgraded to vehicle infrastructure which can maintain connection of information on an open road. It can be very useful on the intersection of roads especially for emergency vehicles which often drive against the traffic rules. It will lower the accident rates and provide safety to ordinary car passengers and pedestrians.

4.4.2. Li-Fi and the use of lenses

The Li-Fi module consists of a transmitter (Tx) and a receiver (Rx). The transmitter uses light emitting diodes (LEDs) or laser diodes (LDs) for signal transmission, whereas the receiver incorporates a photodiode (PD) for signal detection. Both parts are characterised by their field-of-view (FOV). Typically, both FOVs are designed equally (Kirrbach et al., 2019).

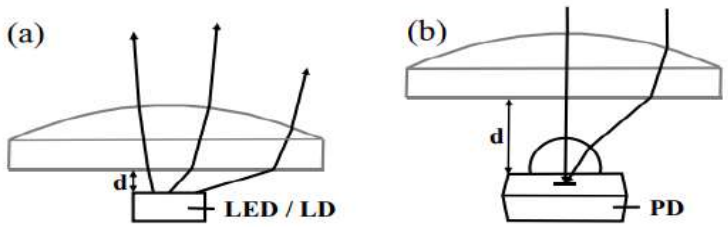


Figure 1: Li-Fi transceiver consisting of a transmitter (a) and a receiver (b). Simple systems incorporate spherical lenses as shown here.

The optical link is further characterised by its dynamic range which defines the spatial distance where data transmission is possible. It is limited by a minimum and a maximum range (Kirrbach et al., 2019).

Why we think that Li-Fi can be implemented in traffic related to Emergency Vehicles

Policemen, firefighters and ambulance drivers would be able to communicate with other vehicles in the traffic through Li-Fi with the help of both traffic lights and the lights of the cars. We see potential in this since it can be used more efficiently and cheaper than today's Wi-fi communication. The speed is also greater and it uses a broader spectrum than radio waves. The security is also better since it is harder for others to access the data that is being sent. This is important in our case because if it would be easy to hack the system, it could have bad consequences such as people controlling other cars and traffic lights without permission. All cars also have lights which makes it feasible to implement. It is also more efficient to use already existing devices (Javiad, 2021).

4.4.3 Argumentation of Li-Fi's safety improvements in traffic

Benefits of Lifi

Communication	**Deliver huge amount of data**	**Aim**	**Security**	**Market potential**
-Communication over a longer range; allows faster & safer commute for EV (Shanmughasundaram , et al., 2018). -Vehicle to Vehicle communication. -Vehicles are able to transmit data through headlights, tail lights and cameras (Soley, 2021).	-LIFI can deliver thousands of data streams at higher speeds (H.Haas, 2011). -Can be utilised more than 1000 times greater than the entire spectrum used for radio frequencies (Javiad, 2021).	-To reduce road accidents and manage traffic more accurately (Yeasmin et al., 2016). -Used as a tool in traffic control management and road safety (Yeasmin et al., 2016). -Cost effective (Al Abdulsalam, 2015).	-Harder for other people to access your data (Javiad, 2021)	-"It is to be noted that the LiFi market was valued at USD 143 million in 2019 and is expected to reach USD 3.52 billion by the year 2025", Javiad (2021)

4.4.3 Limitations

- The technology should be available/installed in every vehicle in order to be fully implemented (Al Abdulsalam, 2015).
- The overall cost of this technology and the other supporting technologies need to be reduced to make its use economically viable (Al Abdulsalam, 2015).
- Limited range (cannot pass through walls) (Javiad, 2021)
- Limited Compatibility (every device is not compatible with this) (Javiad, 2021)

4.4.4 Argumentation of why ALL is a good option to have in LIFI

In traditional lenses implemented in optical wireless transceivers the design is limited by the need of specific shapes to reduce costs and maintain simplicity of production (Kirrbach, et al., 2022).

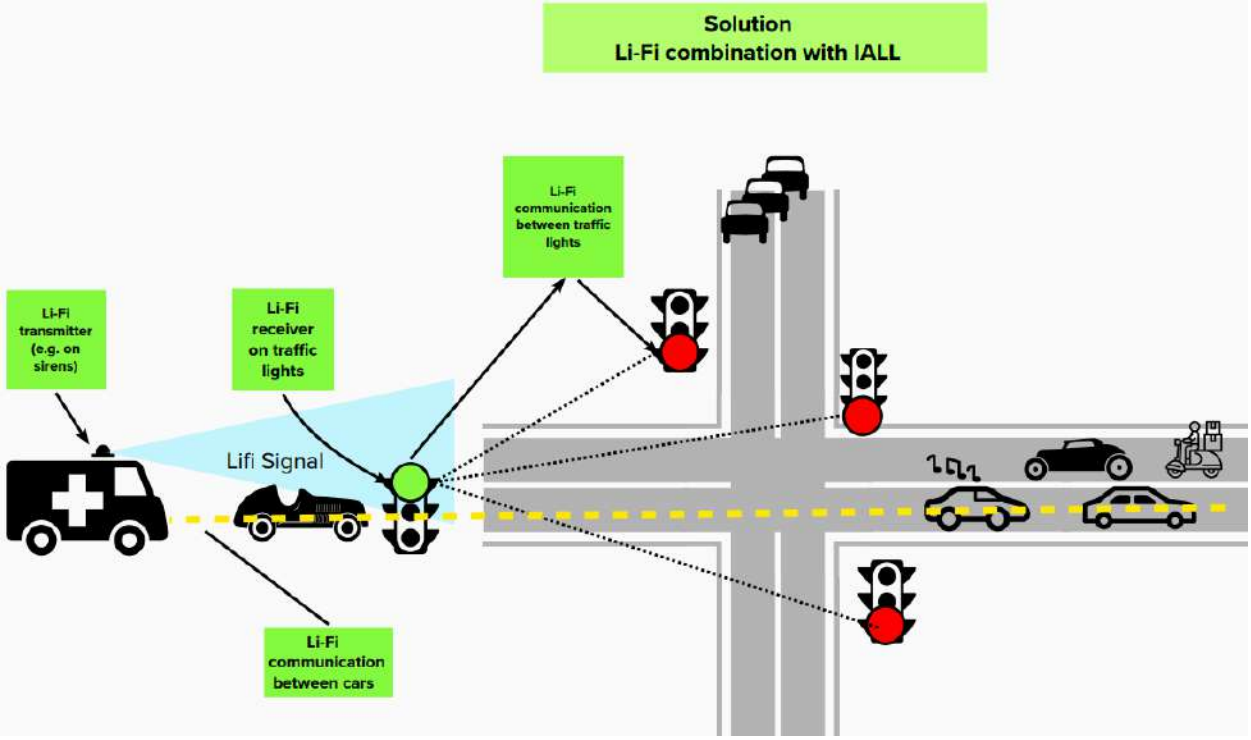
The ALL is more flexible in regards to the design of the lens. The ALL-technology's ability to adapt its' focus quickly could potentially improve the Li-Fi's ability to transmit and receive signals in motion, especially because these adaptations happen rapidly. Further, if the lens can adapt on demand we can choose whether to send simple data on a wide radius, or a strong signal in a straight line far away. This opens up for different functionalities of the Li-Fi to traffic and Li-Fi to infrastructure solution.

Kirrbach, R., Schneider, T., Stephan, M., Noack, A., Faulwaßer, M. and Deicke, F., 2022. Total Internal Reflection Lens for Optical Wireless Receivers. *Photonics*, 9(5), p.276.

4.4.5 Three Phases of LIFI implementation

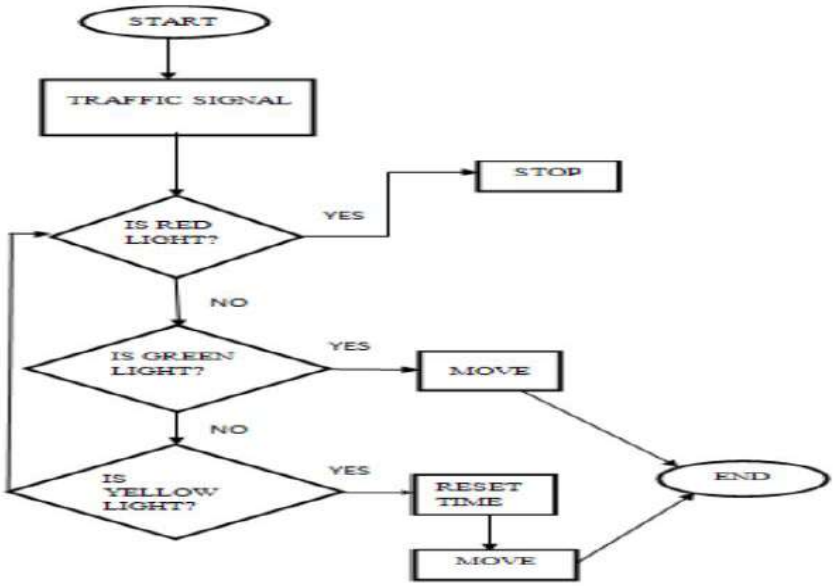
With regard to the feasibility of the implementation of Li-Fi for traffic coordination, we suggest three phases. First, vehicle to infrastructure communication would be most feasible because it would not require all vehicles to be equipped with the needed transmitters and receivers. Later, when all vehicles are equipped or retro-fitted with this technology a vehicle to vehicle communication would be possible and this would then also be very useful in autonomous vehicles. One could also imagine that the technology not only informs the drivers about the emergency vehicle (awareness) but also gives a recommendation what to do e.g. move to the left or right (reaction). This would be challenging but probably possible in the future.

Phase 1	Phase 2	Phase 3
Communication between Emergency Vehicles to Infrastructure (Traffic Lights)	Communication between vehicles	Implementation in autonomous vehicles



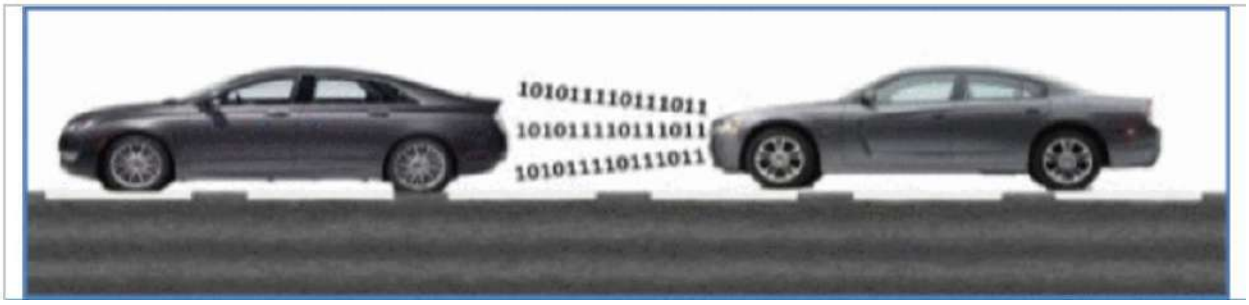
Phase 1: Communication between Emergency Vehicle to Infrastructure (Traffic lights)

Flow chart defining the meaning of Traffic control signals that is based on Li-Fi technology **(Yeasmin et al., 2016):**

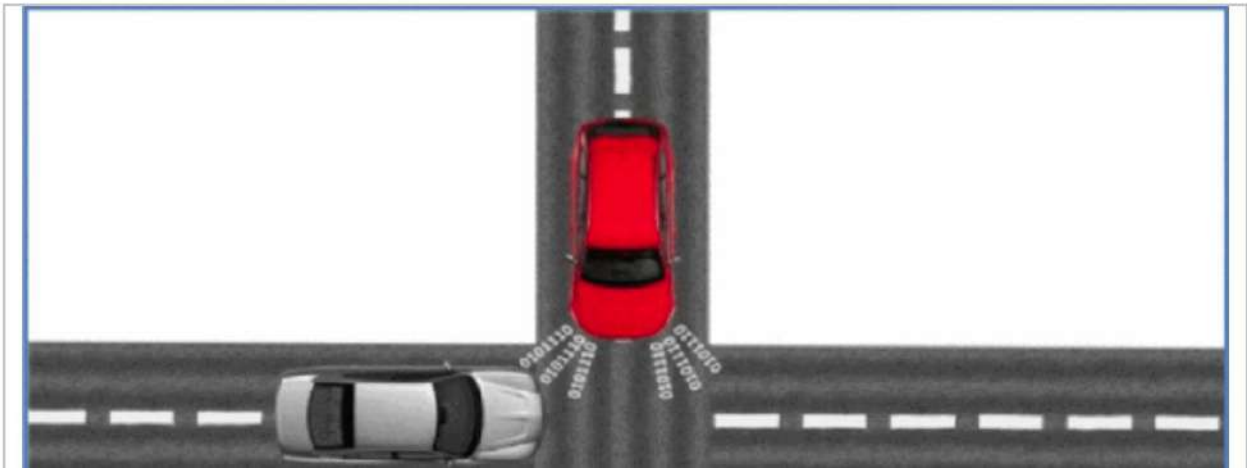


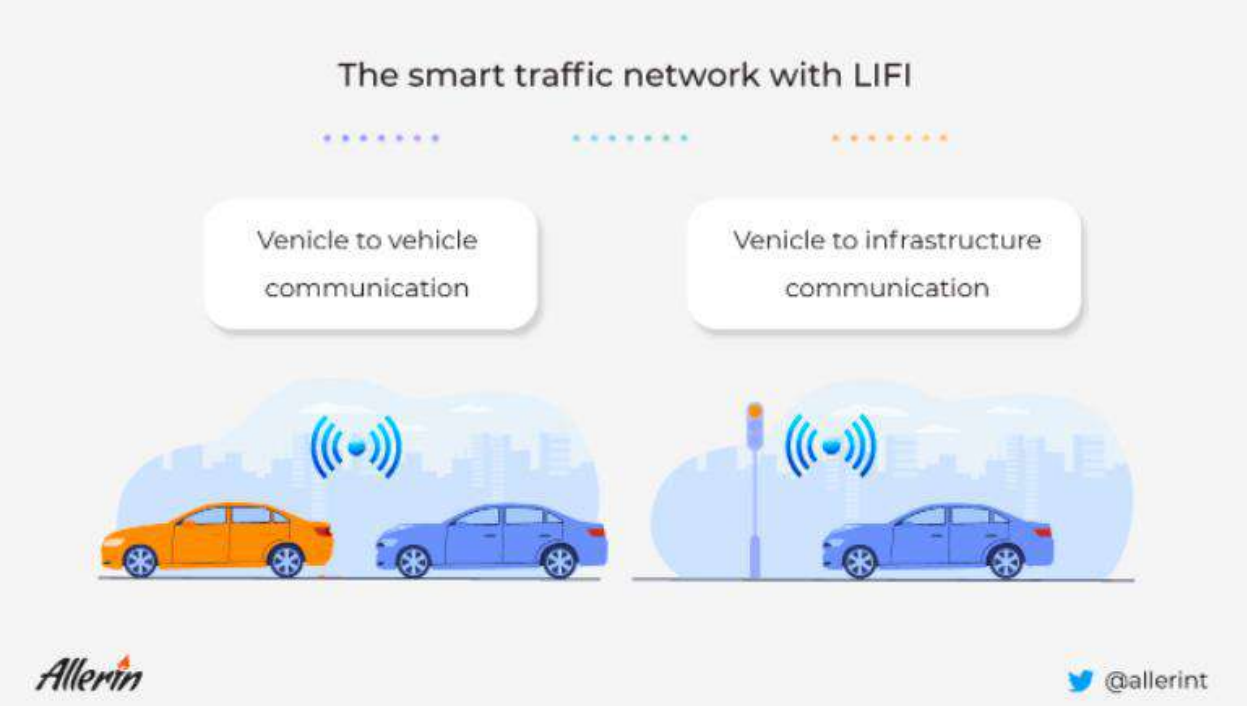
Phase 2: Communication between vehicles

When vehicle 1 will apply brakes, the speed-o-meter in vehicle 1 will sense the reduced speed thus will send a message through a transmitter placed in rear lights to vehicle 2. Vehicle 2 will receive the message using a photodiode placed in front of it and a slow-down message will be displayed in vehicle 2 using LCD **(Al Abdulsalam, 2015).**



Similarly, drivers in vehicles using Lifi technology will be able to avoid the possible accidents while taking sharp turns on the roads by getting the alerts of coming vehicles from other directions **(Al Abdulsalam, 2015).**





Source: https://www.allerin.com/blog/is-lifi-the-key-to-a-safer-autonomous-vehicle-network

Phase 3: Implementation in autonomous vehicles

Autonomous vehicles are becoming more and more common but are still facing some technical and other obstacles, e.g. such as not being able to go over certain speed limits. Therefore, the implementation of the Li-Fi technology would allow the autonomous vehicles to communicate with other autonomous vehicles, thus allowing a much faster speed using the combination of ALL and Li-Fi technology.

4.4.6 Insights from experts

4.4.6.1 Written answers of Rene Kirrbach, a researcher in at the Fraunhofer Institute

What purpose do lenses provide in Li-Fi technology?

In LiFi technology, lenses are used in the transmitter and in the receiver. In the transceiver lenses steer / focus the light into the desired direction. For the receiver, the lenses focus the incident light / optical radiation onto the detector. This focusing can be modelled as an optical concentration ratio / optical gain.

What characteristics of the lens could improve Li-Fi?

Transmitter: Forming a small spot enables a high power density. Thus, you can achieve a high link range. However, a small spot also means low coverage. An adaptive lens can adjust the steering direction / focus. It can achieve a high range AND coverage by adjusting the steering direction in such a way that it follows the receiving device.

Receiver: As a rule of thumb: Increasing the optical concentration ratio by a factor of 4, one is able to double the link range. However, the optical concentration ratio is physically limited due to the conservation of Èndue. There is a famous equation to calculate the maximum theoretical concentration ratio g_o_max:

$$g_{\mathrm{o\,max}} = \left(\frac{n_2 \sin(\theta_{\mathrm{out}})}{n_1 \sin(\theta_{\mathrm{in}})} \right)^2$$

Where: n_2 = refractive index of the medium in front of the detector, n1 refractive index of the medium in front of the lens, \theta_out=90° in best case, \theta_in = acceptance angle = field of view

A large concentration ratio requires small FOV. It is not possible with static, geometrical optics to achieve a large coverage (=large FOV) AND large concentration ratio (=large range).

Similar to the transmitter, an adaptive receiver lens can solve this issue. The adaptive lens can shift the focus to steer the receiving beam and allow a large coverage and a large range.

Our idea is to use Li-Fi to improve the traffic situation with emergency vehicles and are therefore interested in how feasible or promising it is to implement Li-Fi in the headlights of cars in the future to use them as receivers and transmitters of these signals. What is your evaluation on this idea?

There was already a lot of work in the field of vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication. In general an adaptive transmitter and receiver lens could increase the link range and coverage. Range is still an issue (you may need something like

20m…100m range depending on the vehicle speed). However, there are some challenges with this approach:

- Steering always means you only look in one direction. You might be "blind" for the other directions in this moment (unless you have multiple steering systems)
- Steering requires a control loop and hardware à expensive, maybe large
- V2V and V2I require a very high level of reliability, no mistakes are allowed. The link might be blocked or interfered by other light sources / LiFi sources
- Liquid lenses might be prone to vibrations / mechanical shock

In summary, liquid crystal lenses are an interesting topic for optical wireless communications (OWC). Technically it is possible to use them in V2V and V2I. However, there are a lot of practical issues. I would say it is easier to use them in other application fields like industrial communications where one needs range and coverage.

4.4.6.1. Notes from an Interview Sergiy Valyukh, Senior Lecturer, Linkoping University

- Li-Fi works based on the modulation of the light (switch on and off which is like 1 0 1 0). The modulation means that the information is transmitted.
- There could be made changes in the modulation intensity with the help of lens
- Lens (incl. liquid crystal lens) can direct the light (but surely not 360°). Therefore, there is a need to insert reflections (e.g. mirrors) so that the light can be redirected.
- The use of infra-red light is also an option.
- Communication between cars with the help of Li-Fi and lens (incl. liquid crystal lens) could be possible to implement.
- Benefits: low energy consumption, small, no mechanical movement. With the lens, there is no need for additional equipment, it requires only the installation of the lens over the light.
- Limitations: distance - in long distance could not properly work (for traffic reason the distance is good).
- Li-Fi has the potential to be developed in the future.

4.4.7 References, Interesting articles other sources about Li-Fi

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Interesting articles

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Ted talks

https://www.ted.com/talks/harald_haas_wireless_data_from_every_light_bulb?language=en

https://www.ted.com/talks/harald_haas_forget_wi_fi_meet_the_new_li_fi_internet?language=en

5. Closing words about the suggested solution

In a perfect world, [emergency vehicles] could travel on empty roads wherever they needed to go, but for now we have to rely on our own ability to make safe decisions, and the awareness of other traffic

- Ambulance driver, Linköping 2022

Since we have identified the interdependencies between all traffic participants and the emergency vehicle as the crucial problem, we thought of a solution that addresses the problems of both the other drivers and the emergency vehicle drivers. Therefore, we suggest smart traffic management via Li-Fi to steer traffic in order to increase efficiency and safety. However, when designing a smart traffic management system for emergency vehicles, several specifications need to be taken into consideration:

- The technology should be easily applicable and readily available to emergency vehicles and traffic infrastructure;

- The technology should work automatically to be for ease of use and should not require any additional actions by the drivers;
- The technology should enable path clearance for the emergency vehicles in a safe and efficient way;
- Other traffic participants should have enough time to react and clear the path but waiting times until the emergency vehicle passes should still be minimised;
- The technology should work in different traffic environments e.g. urban areas, rural roads and highways, but also under different weather and light conditions.

One important consideration associated with the proposed Li-Fi solution is that light only travels in one direction by itself and cannot be sent through obstacles such as buildings. This brings some implications for the potential range of the Li-Fi signal; it would therefore be necessary to figure out how to send the signal in paths that are not straight but curved. If one could utilise reflecting surfaces and/or direct the light through the lense accordingly it should be possible to direct light around corners. Thereby, light signals can be received by certain infrastructure or cars even if they are not directly in front of the transmitter. This would greatly enhance the solution as it could warn cars that are out of sight of the emergency vehicles. Hence, it could contribute to a less unperfect world.