21-01-2020

Safety by Design

Electric Scooters - Individual Report

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1 Introduction

This individual report is for the Safety by Design course taught by df. M. Rajabeli Nejad at University of Twente. The objective of this report is to demonstrate the student's knowledge of theory learned in this course and produce safety improvements for electric scooters used in the Danish public traffic.

Technology changes and evolves everywhere, and personal transport is no exception. We see electric cars and busses entering the market these years, joined by Segway's and electric scooters. In Denmark however, the two last-mentioned technologies have not yet been allowed on roads and cycle lanes. This changed in January 2019 where a pilot scheme became effective, meaning that small electric vehicles like the electric scooter, were now allowed on the roads. After one year of usage the opinions are very split. Some people embrace them and see them as future personal transport. Others detest them due to a high number of accidents despite the relative low number of units. Are they really dangerous and bad for traffic as some doctors and politicians say, or is it just a matter of time before people get used to their presence? This report will investigate the safety of using electric scooters, discuss potential issues, make proposals for solving these and prove an increased level of safety.

2 Method

A proper approach when improving safety is to use useful and meaningful tools that can help you with this improvement process. In this report the System Safety Process (SSP) will be the tool in being able to proactively search for opportunities to improve safety in the process of using electric scooters. Even though it is a systematic approach, the model is flexible and allows you to put most stress on certain parts depending of your safety focus. The process consists of following steps [1]:

1. Define system of interest (SoI), which include the scope of the system, the stakeholders, the environment affecting the system and their interactions.
2. Define objectives, where safety critical functions, safety objective, boundary conditions are defined, and relevant regulations discussed.
3. Hazard Identification, first part of the process hazard analysis (PHA), where literature and history of accidents is used to identify hazards seen from different perspectives. The hazards which will be illustrated by a hazard tree, is analyzed and evaluated.
4. Controlling Hazards, second step in the PHA, where unacceptable hazards are designed out or reduced in severity and/or frequency and cost-benefit discussed.
5. Monitoring the system, where safety indicators are suggested, and the safety culture is discussed.
6. Prove of system safety, where goal structuring notation (GSN) is used to prove the safety of the improved system.

3 System of Interest

Defining the exact system of interest (SoI) is crucial as an inaccurate description of this will result in a flawed safety analysis and unusable design proposals. The section will define the scope of the SoI by describing the system and what physical parts it consists of, the people who have an interest in this system and the environment that influences the system. Finally, the Safety Cube will be used to illustrate and discuss the interactions between these elements.

3.1 Electric Scooters

Electric scooters (ES) come in various shapes and sizes and lots of them are related to Segway, so before the SoI is described, picture 1 shows what kind of electric scooter this report will focus on. Minor design details will differ depending on the manufacturer, but this picture represents the system.

System

This type of ES is described as a two-wheeled personal vehicle, powered by an electrical motor and steered by human. The system consists of several components:

- Front and back wheel
- Stem
- Handlebar
- Folding
- Deck
- Suspension
- Motor
- Battery
- Brakes

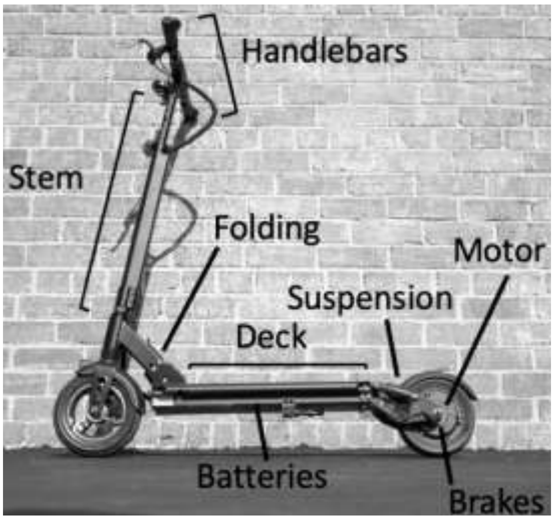

Figure 1 [2]

These components affect each other and interacts as part of the user experience. To get an understanding of this vehicle is here a brief walkthrough: The user stands on the deck while riding the ES and can hold on to the handlebar which also steers the ES through the stem, which is connected to the front wheel. Batteries supply the motor with energy and please note that the placement of the motor and battery can vary. In some ESs the battery is placed inside the stem and the motor can be placed at both wheels, however this does not change the functionality. Speed and brakes are usually controlled with small thumb pedals on the handlebar, braking on the left side and speed on the right. In other cases, there is a brake lever on the left side of the handlebar and their right handle is used as speed by rotating the handle with the wrist.

Human

The humans associated directly or indirectly with the ES are the stakeholders which in this case are: The users, manufacturers, dealers, the executive and legislative power (e.g. road traffic authority, government, EU), hospital staff. The road traffic authority is a part of the ministry of transport in Denmark, which is responsible for regulating and overseeing traffic. The Danish government and EU are the ones making the law and regulations for vehicles such as these. The hospital staff are the ones taking care of injured users of the electric scooters and other road users are cyclists, pedestrians and cars.

Environment

The environment includes both cooperating system, competing systems, physical elements and regulations that can influence the SoI. For this SoI, signs, roads, bicycle path, traffic light, weather, other road-vehicles, regulations and policies influences.

3.2 Safety Cube

An important task for engineers improving safety for a certain system, is not only to define the elements mentioned in section 3.1, but also to ensure a safe integration of the system. For this safe integration a safety cube will show these elements and their relations [3].

	Human	System	Environment
Human	SE riders, road users like cars and bicycles. Hospital staff treating injured, the legislative power	Human steering, traffic rules,	Driving culture/mutual respect in traffic of cars, bicycles etc. Change of regulations, users comply or ignore these.
System	Quick, safe and enjoyable transport	Electric scooter	Clear visibility both day and night an in different weather conditions. Comply with regulations
Environment	Traffic rules, weather requirements, mutual respect for other road users.	Road, bicycle path, climate/weather, obstacles on the road/path, traffic regulations	Signs, roads, bicycle path, traffic light, weather, other road-vehicles

Table 1 - Safety Cube for safety integration

Table 1 gives a brief summary of the SoI and the connection between the three elements for safe integration of electric scooters. However, to be usable for further work, a better and more in-depth understanding is needed. Therefore, focus is shifted more towards the SoI. This will be done in the next table representing the system safety cube, where the system, it's subsystems and supersystems are considered, why they exist, how the system is influenced and used/misused by the human factors etc.

	System requirements, functions, and behavior	Physical system (system-SoS/environment relation)	User/misuse scenarios (human-system relation)
Environment, super systems	Traffic rules in Denmark to ensure safe use. Function control. Regulations with respect to requirements and functions.	Traffic infrastructure, roads, different types of crossings traffic lights.	How one act upon traffic rules like who has the right of way. Behavior and mutual respect of other road users.

System	CE marking, must meet requirements and required functions regarding e.g. visibility and braking/speeding	Two-wheeled personal vehicle, powered by an electrical motor and steered by human.	ES user going in the opposite direction of traffic, not complying with traffic rules, not taking into account that it is a silent vehicle, misusing functions of product
Sub-systems	ES components must comply with required EU and DK standards e.g. reach of lights	Front and back wheel, Stem, Handlebar, Folding, Deck, Suspension, Motor Battery, Brakes, Lights	ES user sits on stem, drives with another person, tuning motor

Table 2 - System Safety Cube

So far, this process has contributed with a description of the SoI and the interaction between the elements of safe integration, that has provided a useful understanding of the SoI. Using approaches like this makes you able to go into great detail, however for the scope of this report, these results are sufficient.

4 Safety Objectives

4.1 Safety Goal and Objectives

The electric scooters are new in town and it will be very interesting to investigate how safety around this product and its user can be improved. As mentioned earlier the trial of allowing these vehicles on the roads in Denmark has only lasted for one year. However, we already hear a lot of different people, some mentioned as stakeholders in this report, publish their opinion. Some are good, but others bad. Last mentioned will be investigated, because is it just a bad product with inefficient components or is the traffic culture the main issue? The safety goal of this report is following:

- Improve safety for electric scooter users.

This goal is rather abstract and could be more precise. However, the idea of this report is to look at different aspects when adding this new type of vehicle in traffic. These aspects are defined below and will help to reach the goal mentioned:

- Investigate the traffic culture and make suggestions towards drawing attention to this new type of vehicle.
- Investigate the functionalities and components of the SoI and make suggestions for improvements.
- Analyze previous accidents and control hazards, to lower the frequency and severity of accidents.

Desired Level of Safety

Defining the desired level of safety in a given system or environment is quite difficult. Most would either say as high as possible or maybe even complete free of risks and accidents. In most situations that is not realistic. For this particular system, the desired level of safety is to reduce the number of hazards with high frequency and high severity, according to the results of the risk assessment matrix. The system is considered safe or safer when this has been achieved and when the risk of riding electric scooters is similar to riding bicycle.

4.3 Regulations and requirements

This part will look at national and international regulations that influence the electric scooter. As the focus is on the Danish market for ESs, regulations and standards set to influence this particular product and market. Regulations are rules required by e.g. the European Commission or a national government, meant to carry out specific legislation that, in this example, ensure a lower boundary of safety. These regulations are usually enforced by a regulatory agency. Relevant regulations for this product on the Danish marked is handled by Færdselsstyrrelsen (eng: Danish Road Safety Agency) [4].

CE mark

In the European Economic Area [5] an agreement/directive has been made in order to protect the consumer from dangerous or harmful products. Therefore, a set of requirements have been set to ensure a certain level of safety before a product is released on the market. A technical requirement for the electric scooter is that it is CE marked, more specifically the 2006/42/EC directive on machinery [6]. The directive states an enormous number of interesting and important requirements, here are some of them highlighted:

- General Principles: "*The manufacturer of the machinery or his authorized representative must ensure that a risk assessment is carried out in order to determine the health and safety requirements which apply to the machinery"* [6].
- 1.1.2 Principles of safety integration: *"Machinery must be designed and constructed so that it is fitted for its function, and can be operated, adjusted and maintained without putting persons at risk when these operations are carried out under the conditions foreseen but also taking into account any reasonably foreseeable misuse thereof."* [6].
- 1.1.2 Principles of safety integration: *"When designing and constructing machinery and when drafting the instructions, the manufacturer or his authorized representative must envisage not only the intended use of the machinery but also any reasonably foreseeable misuse thereof.*
  The machinery must be designed and constructed in such a way as to prevent abnormal use if such use would engender a risk. Where appropriate, the instructions must draw the user's attention to ways — which experience has shown might occur — in which the machinery should not be used." [6].
- 1.1.5 Design of machinery to facilitate its handling:
  "Machinery, or each component part thereof, must: be capable of being handled and transported safely, be packaged or designed so that it can be stored safely and without damage." [6]

These are some of the many requirements listed in this directive for which the electric scooter must comply with. This directive, however, is very abstract due to the wide range of machines that it applies to. It would therefore be relevant to investigate which rules the Danish government has specified. The Danish Road Safety Agency enforced the CE marking on electric scooters in order for it to be legal on public roads.

However, even though the manufacturer is responsible for complying with the above-mentioned requirements from the CE marking, the Danish user of an electric scooter has the responsibility to only use a CE marked ES on public roads. You are allowed to purchase non-CE marked ESs, but you are not allowed to use it on public roads.

4.4 Safety Critical Functions of the SOI

Previous section highlighted some of the regulations and requirements needed for manufactures to put on the CE mark on their electric scooters. However, the CE mark is not enough when using an ES on public road in Denmark. This leads us to the set of requirements, for which the user is responsible, formulated in legal information sources [7][4] as following:

- Age requirement: You must be at least 15 years of age.
- Field of application: Here applies the same rules as for bicyclists. Use bicycle path if possible and follow bicycle lighting signals and signs. Give sign when you step or turn. Only one person at a time may use the ES. Alcohol limit must be under 0,5 and zero limit for drugs.
- Lights and reflectors: Lights must be mounted on the scooter at all time, being turned on both day and night. A white/yellow light is required for the front and a red light for the back. Both lights must be visible at a distance of at least 300 meters. It must be equipped with reflectors on four sides, a white in the front, a yellow or white on each side and a red in the back.
- Insurance: The provisions of the road law on insurance obligations apply for rental vehicles, but not for private owned vehicles.
- Speed: The speed must not exceed 20 km/h by the force of its own motor.
- Technical requirement: The electric scooter must be CE marked.
- Weight and dimensions: The weight must not exceed 25 kg, a length of 2 m and a width of 0,70 m.

Advice

Make sure that the ES complies with above-mentioned requirements and drive safely. The ES is a new vehicle on the road and other road users are not used to it yet. It will take time for both the environment and the human to adapt, both in terms of orientation and movement pattern. Note that if above requirements are not respected, the user of the ES will be fined either from 94- and 134 euros. The penalty for driving affected by drugs or alcohol are even higher and can result in imprisonment [8].

5 Identifying Hazards

Throughout the next two main sections, the process hazard analysis will be applied. Based on preferences there are different methods that eventually leads to achieving the same goal. The goal of this process is to identify, evaluate and control hazards in a system, which should result in minimizing potential risks and consequences of these hazards. This section will look at the history of accidents, determine root causes and evaluate them by determining hazard severity, probability and ranking of priority [1, ch.5].

5.1 History of Accidents

The history of accidents provides a good overview of the extent of accidents and what the cause for these might be. This provides a foundation for the further analysis that goes into detail by identifying hazards. Usually one who wants to analyze accidents concerning a specified field would contact DST (Danish Statistics [9]), however since electric scooters are still a novelty, they could not provide any helpful statistics for this analysis. Luckily, the major hospitals in Denmark have published statistics [10], however they are limited.

Statistics

Statistics provided by Ulykkes Analyse Gruppen (UAG) (eng: Accident Analysis Group) at University Hospital of Odense (OUH) shows the number of registered accidents in the municipality of Odense. The statistics cover the period from July 1st to September 6th, 2019. This reflects the very introduction of electric scooters in the streets of Odense, a city in the center of Denmark with around 200.000 citizens [11]. Here are the accident characteristics [10]:

- 22 persons registered injured after using an electric scooter, 20 were users and 2 were hit by one
- Distribution of inquiries was day/evening/night: 10/8/4
- 3 of the users used a helmet, 17 did not
- Distribution of genders in the incidents: 15 males, 7 females.
- Average age of injured persons was 22,9 in the range of 11-50 years old.
- In 17 of the inquiry descriptions the word “topple” was used and in 4 the word “curbs”.
- The injuries looked like typical bicycle injuries: wrist/hand injuries (10), facial/teeth injuries (6), leg injuries (6) and factures (5).
- Alcohol did not play a significant role.

The statistics from Odense states nothing about deaths as a result of the accidents, why it is assumed that no one died in this period. Alcohol was not an issue in Odense but police in Copenhagen reports in an interview, that it is an issue there [12].

As mention, the period of these statistics is rather narrow does not cover the entire country but the UAG also draws a comparison between number of accidents by ES and by bicycle:

- Bicycles travels a distance of 2,88 billion km per year in Denmark. OUH’s area covers app. 6,14% of the population, which gives a bicycle travel distance of app. 17.736.000 km per month. With 130 injuries per month, the risk of getting injured on bike is $8{,}82 \cdot 10^{-6}$ per km or one injury for every 113,354 km.

- Electric scooters have traveled a distance of 156.000 km in the mentioned period, with 22 injuries. An expected increase of usage shortly would give 312.000 km which means a risk of $7{,}05 \cdot 10^{-5}$ injuries per km, or one injury for every 14.182 km.

In the same period (July 1st to September 6th, 2019) two hospitals in Copenhagen have reported 50 patients with the same kind of injuries as in Odense, however also injuries with broken arms, brain concussion and damage to the skull [13]. Approximately 40% of injuries here are head injuries. The statistics suggest that there is room for improvement of safety for the electric scooters. Recently used references [12,13] expresses a concern for the new vehicle on the roads but are also aware that this is still in the early phase where they would expect a relative high number of injuries. Based on this information, electric scooters are currently eight times more dangerous than bicycles.

5.2 Identification

Previous examination of accidents with focus the municipality of Odense suggest that safety for using electric scooters can be improved. But what causes these accidents? In this section, the aim is to identify hazards that might lead to these accidents. Through a brainstorm of use case scenarios, prior knowledge from this report and interviews with hospital staff and users of the ES, a list of hazards will be conducted.

Scenarios

Use case scenarios that could potentially lead to a dangerous scenario are listed. These will try and capture design faults of an electric scooter which provides a better understanding of the impact these could have on the users and its surroundings.

While at full speed (20 km/h):

- The front wheel hits a small rock on the road what makes you fall.
- The reduces noise surprises other bicyclists which you share lane with, and you collide.
- You jam the front brake fall over the steering of the ES.
- An uneven ground makes it difficult to handle the ES.

Entering a traffic light:

- You want to turn right/left, you pull one arm out to make sign and loses control over the ES.
- You want to turn left on an ES with only front brake, due to high speed you lose control.
- You want to turn right, let go of the gas and use your right arm to make sign, but loses speed which make a road user behind you collide with you.

Other scenarios:

- Other road users miss you due to lack of concentration or bad weather.

By combining the scenarios with the statistics and knowledge from references [13,14] a hazard tree will be created to give a good overview of what may cause the accidents which results in injuries. It is a graphical model that tells why procedures, processes and systems fail. The advantage is that different levels of hazards are identified which gives greater details by breaking down larger bits into smaller once, that essentially are easier to cope with. For the scope of this report the focus is on the use of the ES and the environment around it, not so much if certain malfunctions occur. The reason for this is, that its previous knowledge from the report indicates that the hazards interesting here are the ones cause by the environment, the use of the ES or the ES design itself. Below is the hazard showing an overview of relevant hazards:

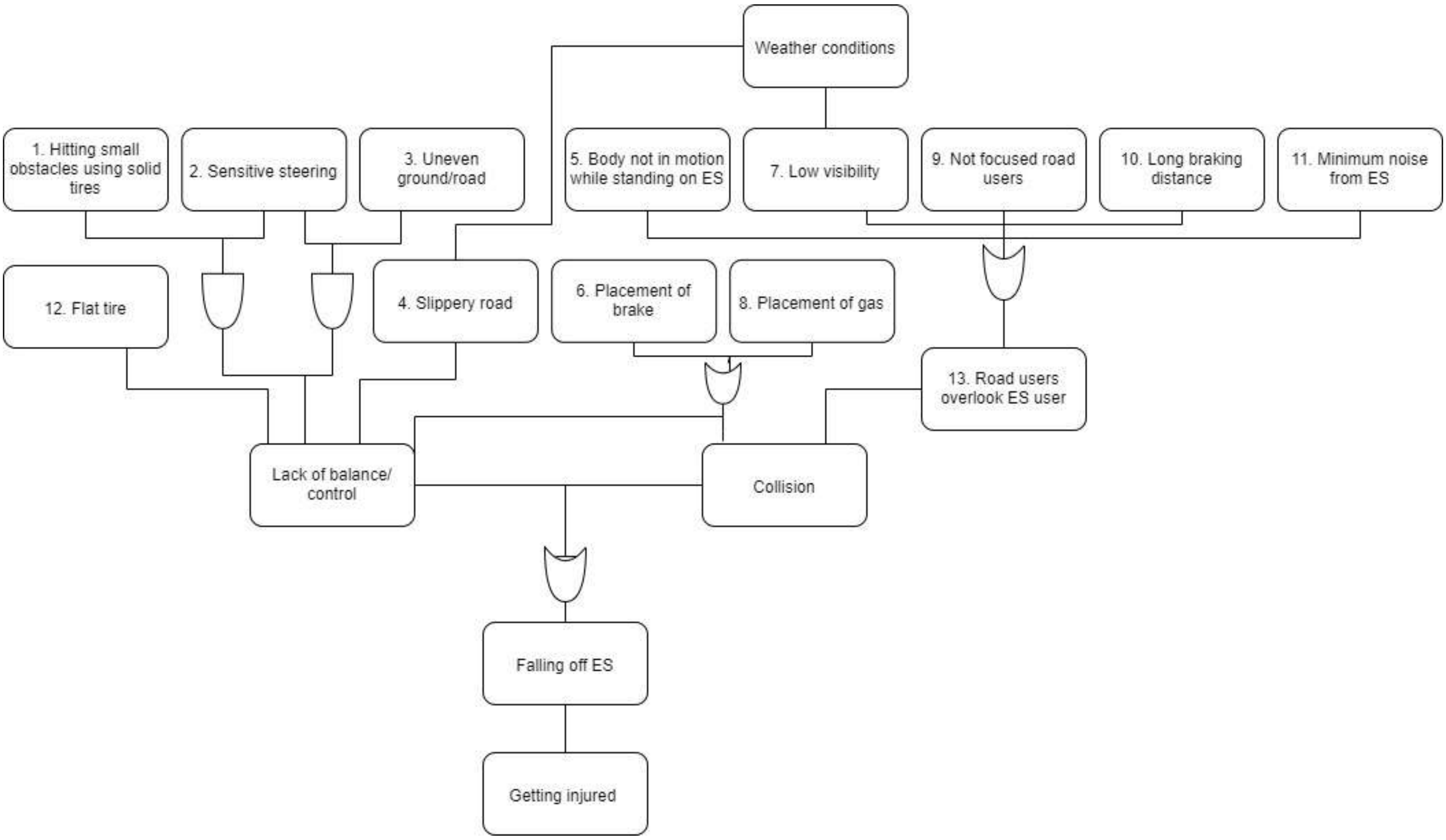

Figure 2 - Hazard Tree

The top row underneath the weather conditions are the preliminary event s that can be the beginning of an accident. This leads to the next layer of initiating event that causes the accident to occur including lack of balance/control and collision. Finally, the intermediate level where we find falling off ES, which dependent on how the fall occurs, can increase or decrease the effect of the accident.

5.3 Evaluation

Before getting to the next section with controlling the hazards, we first have to evaluate the hazards shown in the hazards tree above. To aid the evaluation of these hazards the risk assessment matrix will be used. But before that, severity categories are briefly described. This will provide knowledge about the severity and likelihood for a hazard to happen, which results in knowing which hazards that are most important to control.

As the hazard identification shows that hazard appear from the system and the environment, typical hazards such as malfunctions of the system will not be considered in the coming part of the PHA.

Defining Severity Categories

Description	Category	Definition
Catastrophic	1	Total disabilities or death
Critical	2	Partial disability, hospitalization, injuries inhibiting people for a longer period
Marginal	3	Injuries inhibiting people for a short period
Negligible	4	Minor injuries that inhibit people a day or less

The table above is inspired by [1, ch.5] and formulated this way, because as indicated during this process, the analysis focuses on hazards causing damage to people using the ES and around it.

Risk Assessment

In this small section a risk assessment matrix is creates based on prior knowledge form the report. As indicated before, each hazard is placed in a box based on its severity and probability of occurrence [1, ch.5]. The limited statistics and material available for this research, however, makes it very difficult to determine both. Nothing clearly indicates the likelihood of the hazards to happen or the severity of them, as they lead to the same event (falling off ES). Furthermore, the fall itself can lead to different accidents/injuries of different severity. The numbers in the table refer the hazard number each of them was given in figure 2.

Due to this, the assessment is done from a subjective point of view where solutions will differ, depending on the people doing the analysis. However, the purpose of the risk assessment matrix is still fulfilled, namely giving a good overview of which hazards that are the most important ones to focus on preventing, to improve safety.

	Catastrophic	Critical	Minor	Negligible
Frequent		2, 6, 8,		
Probable		11, 13	5	
Occasional		9		
Remote			1, 3, 4, 7, 10, 12	
Improbable				
Eliminated				

Table 3 - Risk Assessment Matrix

Risk Evaluation

Based on history of accidents from section 5.1, the scenarios from 5.2 and the articles with interviews [13,14], the risk assessment has been done. Before deciding which hazards to examine further in next section, a reasoning over table 3 is made.

Approximately half of the hazards are placed in the critical zone and the reason for this is, that the sensitive steering and placement of gas and brake make the user unsafe, which can result in both collision and lack of control that leads to injury. Especially the interviews with the police and users of the ESs helped with this conclusion. Experiences from these sources indicate that the silence of the vehicle is often an issue with respect to other road or bicycle path users. Lastly the unawareness of other road users can also result in collision which have the potential to be very severe.

In the minor zone the rest of the hazards are placed. The hazard of the body not being in motion are the one of these with highest frequency. The reason for that is, that used references indicate that there is a bigger chance to overlook ES users over bicycle users, because on the bike you use your legs but, on the ES, you stand complete still. With lower frequency we find the rest of the hazards being things like hitting obstacles, uneven road, slippery road, low visibility, long distance braking and flat tires. Based on the acquired knowledge these hazards are less likely to result in an accident and are therefore placed here.

Since the safety goal of this report is to increase safety for electric scooters and one of the objectives is to reduce severity and frequency of hazards leading to accidents, the focus should be on those which pose the greatest danger. Therefore, the next main section of controlling hazards will be based on following hazards: 2. Sensitive steering, 6. Placement of brake, 8. Placement of gas, 11. Minimum noise from ES and 13. Road users overlook ES user. But since hazard 5. Body not in motion while standing on ES and 9. Unaware/not focused road users are the two reasons leading to hazard 13, these will be considered as well.

6 Controlling Hazards

For safety engineers the dream scenario is to eliminate all risks by controlling every hazard. In reality this is not possible though. If lucky, some can be eliminated or controlled partially but some cannot. Based on previous results and knowledge this section will try and contribute to the increase of safety for electric scooters on public roads.

Increasing safety can be done in various ways. Some worth mentioning are designing, using safety or warning devices and procedure or training. These types of improving are usually focused the manufacturer or maybe even resellers, but in some areas other sources are very helpful. In this case where we are working with transportation it would be interesting looking at how other parties could be involved to increase safety. As results from previous section shows, there are some hazards that are at an unacceptable level of risk. These will one by one be discussed and proposals will be made to decrease their level of risk.

6.1 Improvements

Sensitive steering (2)

The steering is mentioned [13,14] as something very tricky on these ESs. After the writer of this report tried one, the comments are understandable. Compared to a bicycle it is very sensitive while riding. If you hit the smallest object it can quickly turn and get you off track. For this hazard a design proposal seems like a good idea. First this that affect the steering is the front wheel. Electric scooters come with various widths of tires (see pictures below), so this proposal would be a general recommendation on wheel and tire design.
In general, manufactures should aim for a tire width like normal city bicycles which are a couple of centimeters. The size of the wheel which also influences the steering. A smaller wheel more sensitive to

cracks on the road or small rocks, why wheel A is not preferable. Other thing is the height of the tire itself, not the total wheel but the tire. Higher tire gives better comfort and greater absorption, as the same applies for cars and bicycles. This also excludes wheel B, except if it got some suspension, as that would improve stability on a bumpy road or riding over small objects. Due to consumers' different needs and riding style, they should have different choices. But a mix between wheel B or C, with a slightly bigger wheel, will give both better stability and comfort. Another proposal for reducing the steering sensitivity would be to add some resistance in the steering. This could be incorporated into the stem, which connects the handlebar to the front wheel. This will make it easier to steer while making turn using only one hand.


Wheel A [15]


Wheel B [16]


Wheel C [17]

Placement of brake (6)

On most electric scooters there are two brakes. One on the left side that can be like brake 1 or 2, as illustrated below, and on the back where you stand on the rear wheel to slow down. The issue with only having a brake on the handlebar is that when you have to make sign and let go of the handle, you are maybe unable to brake enough in the turn. That of course depends on your speed. Another issue is the that the rear brake is not as powerful as the front. An easy adjustment would be to increase the power of the rear brake which would make you able to brake while turning left. So, the design proposal here is to make sure that there are two brakes, one front and one rear with similar braking power. Another proposal would be turn signal like on a regular scooter placed on each side of the red rear light.


Brake 1 [18]


Brake 2 (brake left and gas right) [19]


Brake 3 [20]

Placement of gas (8)

The issue here is similar to the placement of the brake, however the gas as showed above is placed on the right side of the handlebar. The issue is that when you approach a light where you want to turn right, you should give sign in good time before you make the turn. However, this will reduce the speed quite fast and your speed might be reduced to half or two third of the current. Other road users behind you might not be aware of your speed dropping which can be dangerous. It is hard to design this one out as the gas should sit somewhere on the handlebar, but perhaps a click function on the gas could make it maintain the current speed throughout the turn. Then the user should only get to the desired speed and lock it there before entering the turn. Another proposal could be turn signals as mentioned above.

Minimum noise from ES (11)

As other electrical vehicles the electric scooter makes almost no sound. Only the noise of the tired would be present, but they are hardly noticeable for other road users. Unless some motor noise should be added to the scooter, the proposal here would be an information campaign. It should inform the people to be extra careful to look over your shoulder if changing lane, making a turn or crossing. This applies for all electrical vehicles and could be a part of a national campaign advertised by e.g. Rådet for Sikker Trafik (Council for Safe Traffic) as they are the main information source when it comes to road safety in Denmark. Making people aware of new types of vehicles takes time and repetition, as it should affect the culture in a positive way.

Road users overlook ES user (13) (Body not in motion on ES (5), Not focused road users (9))

As these hazards (5,9) together with (11) can result in road users overlooking ES user, the proposal here is the same as above. To this information campaign, not only information about the lack of noise should be mentioned but also that the drivers of these vehicles are not moving. It might seem like an object standing still in the distance, but their speed then surprises. Fortunately, this issue is reduced when it gets darker as all ESs are equipped with lights that are to be spotted from a distance of 300 m. In bright sunlight you might not see the light. Other parties like police, municipalities and schools could also help in advertising and spreading the message. The schools are efficient for spreading the word to the youth as children in Danish schools have practical days in the early years in primary school where they are taught in bicycle safety.

6.2 Cost-Benefit

When is a system safe enough? And what costs are one willing to pay for that? In this section cost over benefit will be discussed based on the suggested improvements for increasing the safety level of electric scooters. For this discussion, the ALARP principle is considered.

ALARP

ALARP is based on a principle that say controlling hazards is implemented to reduce as far as reasonably practicable [1, ch.2], which is quite difficult to put a specific number on. It basically means that at the point where a risk is considered ALARP, a cost-benefit analysis shall demonstrate that the cost of reducing a risk further would be disproportionated to the safety benefit gained from it.

Current level of risk

Currently the level of risk is too high according to hospitals in Odense and Copenhagen [13,14], as the number of accidents and injuries are higher than expected. The numbers from section 5.1 suggest that the risk is eight times higher with electric scooters compared to bicycles. Looking at the ALARP principle model in appendix A, the current level of risk is somewhere in the top in the intolerable area. Therefore, the ALARP level should be the level aimed for, where the chance of injuries are not eight times higher than for bicycles. At the moment it is considered beneficial to use resources by: the manufacturer optimize their products, the Danish government to inform the population about the new vehicle and advise them what to be aware of, in a national campaign to place greater focus on the matter. It is believed that the technical design changes and an information campaign would be useful improvements in getting closer to an acceptable level of risk.

7 Monitoring the System

Indicators are used to monitor the safety of a system. In this section leading and lagging performance indicators will be suggested, to help measure the progress ahead. The lagging indicators are based on historical data that tracks e.g. number of accidents or safety problems, ensure that it is implemented correctly or check that the controls are valid after some time [1, ch.2]. Problem with these indicators is that damage is done before you can act, and this is where the leading indicators come in. Leading indicators help the company or organization future issues that threatens the safety performance, making them able to act proactively. Lagging indicators suggested for this SoI is:

- Number of accidents (statistics)
- Categorization of accidents/injuries (statistics)
- Number of users with helmet for every head injury registered.
- Number of kilometers traveled by electric scooters
- Number of rental and purchased ESs

These indicators are primarily focus the hospitals and the government's traffic safety department. As discussed in this report, the statistics regarding electric scooter accidents were very limited, despite it being a new vehicle. You would have thought that for new implementation organization like Danmarks Statistik (Danish Statistics) or Færdselsstyrelsen (Danish Road Safety Agency) would have been more interested in tracking these numbers. However, in order to improve this kind of measurement in the future, those are the lagging indicators proposed. Leading indicators suggest are following:

- Improved information to the user about how to safely drive an ES on public roads
- Number of safety announcements/commercials regarding ES safety
- Improve product development cycle
- Practical education for children in primary school

These indicators are for manufactures, resellers, the government and schools. Manufactures can make better and more material on how to use their product safely. This information can be passed on to the reseller as they often have more contact with the customer than the manufacturer. Even though number of safety announcements and commercial are a number, it is still seen as a leading indicator. The goal is to increase the awareness of this new vehicle both from the driver's and the environment's perspective, in order to chance the culture. Manufactures can look more closely at their development cycle and apply safety analysis to avoid designs that increase risk. Practical education for children, the new generation, would also be able to affect future driving culture potentially reducing risk over time.

8 Prove of Safety

This section will conclude on the report. The safety goal was to improve safety for electric scooters and this section will argue that this has been done. The process of identifying the SOI, identifying hazards, creating safety goals and mitigating risk, which have been done throughout this report, results in a safety case. This safety case will demonstrate that the system is safe, through structured arguments supported by evidence. To help with this, the GSN (Goal Structuring Notation) developed by Tim Kelly. GSN is a graphical notation that makes the safety case easier to read as it clearly shows the goals, arguments and evidence [21].

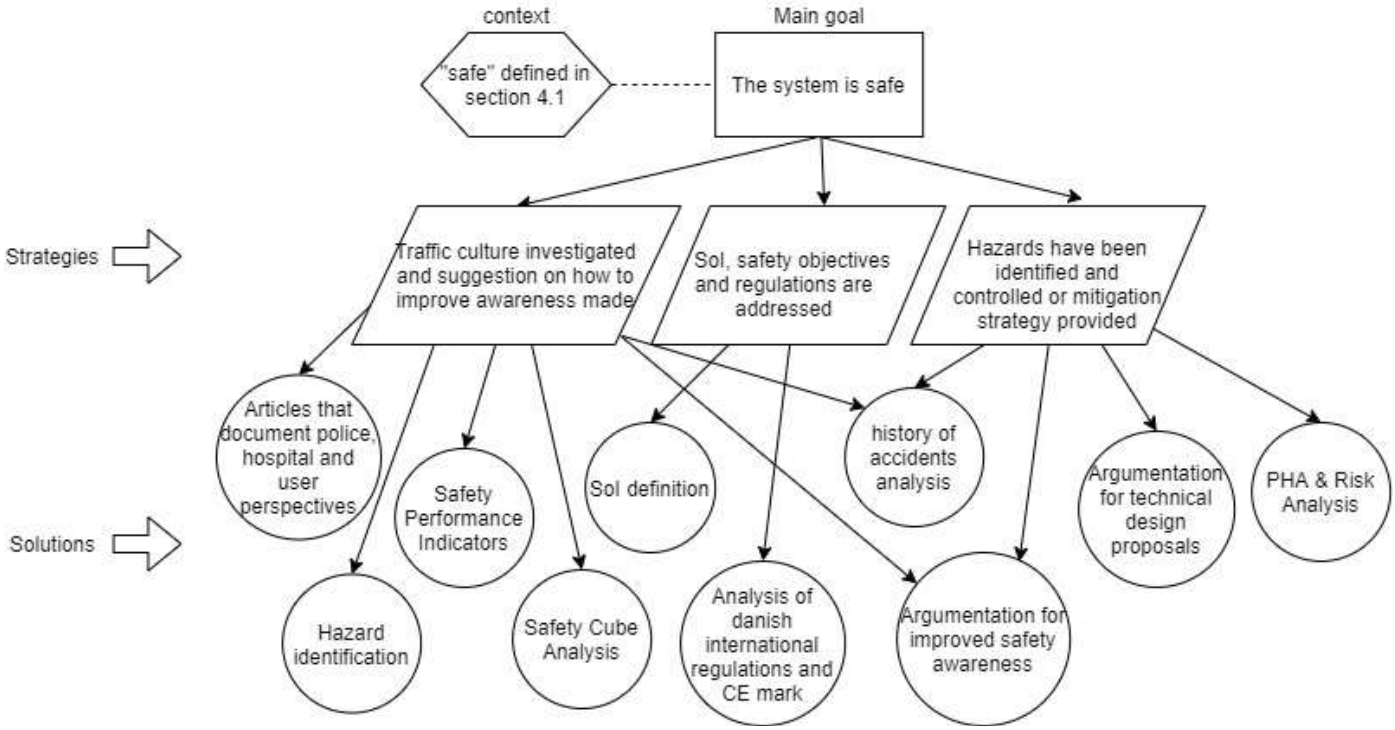

Figure 3 - GSN Model

To sum up on figure 3, it illustrates the safety case of this report. It shows the goal this report intended to achieve. To prove this is achieved, strategies or arguments are included to describe how this is done. These are then support by evidence or solutions that supports the arguments in achieving the goal. This evidence is represented by all the work throughout the report.

All in this proves that the system is safe. The safety objective has been achieved through the safety objectives which have led to an increased level of safety for electric scooters in Denmark. The ES has been criticized by users, but especially hospital staff and police claiming the vehicle is dangerous. Some politicians have also expressed their skepticism for this new vehicle and one even want them to be removed complete from the roads [22]. Skepticism is understandable, as the number of accidents has been unacceptable. This, however, should not mean the end of it but rather lead to a discussion of improvements, which this report contributes with.

9 Reflection

Having this course have been an interesting experience. I study software engineering back in Denmark, which is a lot different that most of the other students on this course. However, I see how engineers can work together, even though we might have different views and skills. The problem-solving mindset is the same for any engineer which makes sharing experiences and knowhow very interesting.

From my software engineer background, we have been taught in what is called software engineering processes. It is a process of dividing the work of developing software and is split into different phases depending on which approach you follow. There are a lot of different approaches. However, what is interesting is, that a part of all of these processes called requirements engineering has similarities to aspects of this course. We are taught in the importance of capturing the requirements, given by the customer, and then process them and implement them, roughly said. So, we are quite used to the approach of have a set of requirements of different sort, process them, an fulfil them.

From this course I will take away the board set of tools and approaches on how to address safety issues. Even though this course is not aimed at students like me directly, we will still work with the safety aspect if we are to develop software for machines in the production industry or with robots or drones. These new skills will undoubtedly, be useful in my future journey as a software engineer and I will probably think more safety in my every day.

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Appendix

A - ALARP Principle

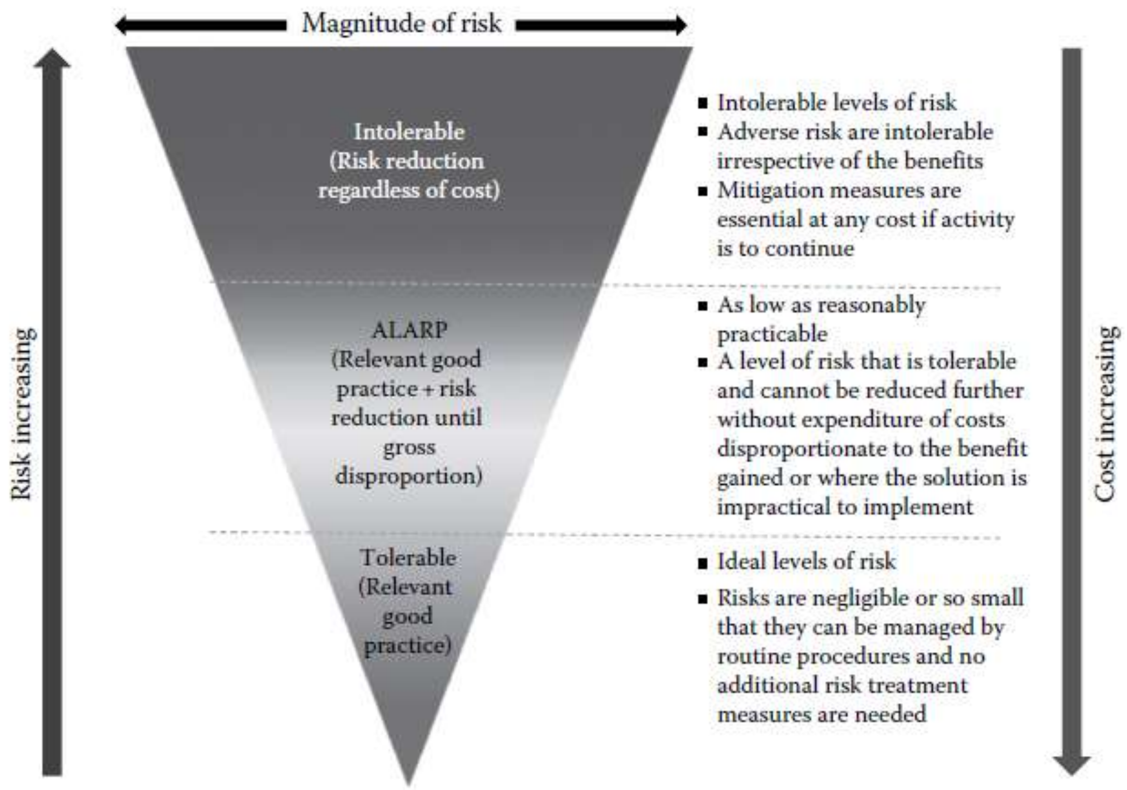

FIGURE 2.2 **(See color insert.)** ALARP principle.