University of Twente

201700042 - Safety by Design

E-Bike Safety Analysis

Creating safe e-bike mobility in the Netherlands

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Contents

List of Figures

List of Tables

1 Introduction

In the Netherlands, cycling has always been one of the most important means of daily traveling. Only taking a look the sheer number of bicycles in the Netherlands supports this: over 23 Million in 2018 [1]. In the last few years, an extra means of travelling has become more and more popular: Personal Urban Vehicles (PUV). These vehicles are mostly electrically powered and are therefore of greater ease for the user. Examples of these are e-bikes, E-scooters or the Segway. Of these, by far the most widely used type of PUVs is the e-bike.

With the grown popularity in e-bikes, there is more and more interaction between the traditional vehicles and the more modern e-bikes. This can cause a severe decrease in safety due to the fact that not all regulations and infrastructure were designed to also be used by e-bikes. Therefore, new policies and regulations should be acquired, taking safety in mind as the main focal point.

To do this, the Safety Cube is applied to define what the System Under Consideration (SUC) actually is. Afterwards, safety situations are investigated by looking at past events. Then, possible hazards are investigated and regulations can be made based on the conclusions that could be drawn from the possible hazards.

2 System definition

At the foundation of any safety assessment lies the definition of the System Under Consideration (SUC). A tool to define the system is the so called 'Safety Cube'. This cube consists of six sides through which the SUC can be seen. Each side has its own perspective on the matter and when each side is assessed, the scope of the SUC is defined. The six sides of the cube are the ingredients for safe design [2]. For this project the SUC will be the electric bike (e-bike). This type of bike is gaining more market share each year, but creates hazards due to various reasons. In this section, the following aspects will be elaborated with what they have to do with e-bikes.

1. Human Aspect
2. Technical System
3. Environment
4. Human-Technical Interaction
5. Technical-Environmental Interaction
6. Human-Environmental Interaction

2.1 Human

The human domain, also called the social domain, covers the stakeholders, users and/or other organizations that have connection to the system of interest, which in our case is the e-bike. The human domain consists of, but is not limited to, its users (not always the owner), other road users, service providers and manufacturers. These interact with the system on the different levels of hierarchy. Humans also interact with the technical and environmental domain, as will be explained in the corresponding subtopic.

2.2 Technical system

The technical system can be seen as the e-bike itself. All types of e-bikes have a common denominator: they are powered, or at least aided, by an electric motor. Due to this, velocities and loads are often higher, and there is greater complexity due to the need of extra hard- and software. This complexity has effects on safety during every stage of the systems life cycle, from product development, to usage, to disposal. The technical system consists of all technical component that the e-bike contains or interacts with.

2.3 Environment

The environment of the system is a broad term. It should cover all possible aspects and influences as it will influence (or be influenced by) both the human and technical domain. Examples of environmental factors are weather, other road users or the traffic infrastructure. Also, policies and/or regulations are environmental factors as these form the environment of the system where it will be created and used. Thus, the environmental factors have both influence on the human as the technical domain.

2.4 Human-Technical Interaction

Interaction between the human aspect and the technical system expresses itself in a few ways. This can be either with the technical system as the input or with the human aspect as the input. With the technical system as an input, the interaction is as follows:

- The technical system should provide ergonomic controls and a rider interface. Due to extra complexity in controls compared to 'normal' bicycles, this interface should be easy to understand and control.
- In the user interface, there should also be warnings to given to the user. For example when there are malfunctions or when maintenance is needed
- The technical system provides jobs. This is during each stage of the life cycle. There are jobs in the development stage for engineers and in the production stage for factory workers. Also, when in use, there are jobs for service workers.

- The technical system should provide comfort and an ergonomic position for the user in order to be working safely

When the human aspect is the input:

- The user should use the vehicle in an sensible way. This means that the user should know the capabilities of the vehicle and not be surprised by for example a sudden acceleration. On the other hand, when the user does know the capabilities, he or she should not abuse these.
- The user should maintain the vehicle as necessary. This might be done by the user him-/herself or he/she should make sure a service provider provides maintenance. This ensures that any easily-prevented malfunction does not occur.

2.5 Technical-Environmental Interaction

As stated in the book Safety by Design, the interaction of the technical and environmental domain consists both in physical and non-physical form [2]. Moreover, interaction can go both ways. The technical domain can have influence on the environmental domain and vice-versa. The influence of the technical domain on the environment in the form of physical interaction can be the space usage, carbon footprint or the aesthetics of the system. Moreover, visibility, noise production, or road wear by the technical system can be seen as an interaction between the two domains. A different, non-physical aspect is that the technical system acts as an input for (new) regulations across all phases of the systems life cycle. Looking at the influence of the environment on the technical domain a few things become clear. Regulations and policies on all kinds of factors are a big influence on the technical system. Next to this, the environmental weather conditions also play a big role in the functioning of the new urban mobility vehicles.

2.6 Human-Environmental Interaction

Human-Environmental Interaction depends on a few factors. Most important among these are: climate, regulations, and traffic. Starting off by climate: For instance, the user should be riding an e-bike in conformity with how the environment lets it to be. When it is slippery or when there is low visibility due to rain or fog, the user should take this into account and not ride the same way as when there are more optimal conditions. Furthermore, there is also interaction between the user and other road users and traffic laws.

2.7 Design Structure Matrix

The interfaces mentioned above are summarized into a Design Structure Matrix (DSM), where interactions between the different domains can be seen, see Table 1. The Design Structure Matrix has been elaborated further into each side of the Safety Cube. These 'zoomed-in' DSMs can be found in Appendix A.

	Human	**Technical system**	**Environment**
Human	Urban mobility vehicle users, other road users regulators, service providers, manufacturers	(Correct) Usage of vehicle, knowledge of system capabilities, maintenance	Driving culture of other road users, other types of vehicle, noise production of other users, pollution regulations safety regulations
Technical system	Controls, rider interface, safety precautions, comfort, jobs, system warnings	e-bike	Space usage, carbon foot-print, aesthetics, input for regulations, visibility, noise production, road wear
Environment	Weather conditions, safety in traffic, traffic regulations, climate regulations	Regulations on usage of vehicles, speed policies, helmet laws, tax laws, weather conditions	Weather, other road vehicles, working conditions, industry standards, policies, traffic infrastructure

Table 1: Design Structure Matrix

3 Safety Definitions

3.1 Safety integrity levels

The Safety Integrity Level (SIL) is a measure of how a risk reduction unit that is provided by an Instrumental Safety Function (SIF) is implemented in a process. SIL is an indicator of the acceptable failure rate of a security function. [3]. There are four different SILs, ranging from 1 to 4. The danger of a process is defined according to the level: 1 is safest, 4 is least safe. Therefore, systems that are suitable for a SIL 4 environment needs to be equipped by a lot more safety measures. How the SIL is determined can be seen in Figure 1. The frequency and severity of consequences of a hazard are both rewarded a score from 1 to 5. Then the corresponding SIL level can be seen in the cell in which these scores cross. [4]

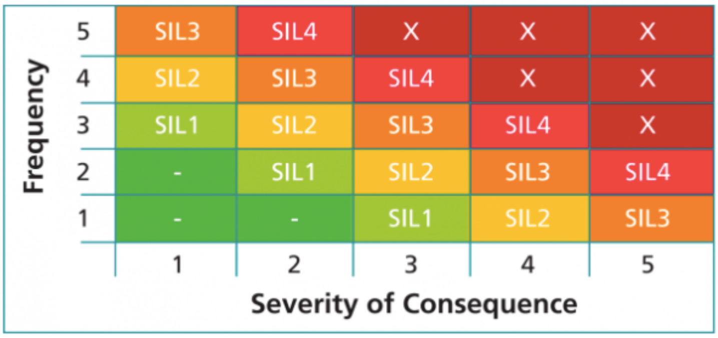

Figure 1: Frequency against severity of Consequence

The e-bike itself cannot have a certain SIL level but SIL levels are referred to the environment in which a device is used. In this case we came to the conclusion that the e-bikes are suitable to use in a SIL 3 environment. This is because of the technical quality control in the Netherlands in combination with separate bike lanes and rules and regulation concerning traffic. [3]

3.2 Safety standards and requirements

In this section the current rules and possible improvement of rules following examples of foreign countries concerning electric vehicles will be discussed.

3.2.1 Current rules and regulations

With the increasing number of electric vehicles the dutch government has started to take action in regulating the e-bikes but mostly e-scooters. A clear list of rules has been made:

- E-bikes have the same rules as regular bikes and are allowed to reach a maximum speed of 25 km/h.
- You do not need a drivers licence
- You do not need civil liability insurance
- The e-bike does not require a registration number
- There is no minimum or maximum age
- If there is a cycle path you are obligated to use this path
- Wearing a helmet is not mandatory
- the bike has a maximum power of 250 Watt [5]

  The second type of e-bike is the speed padelec this bike is allowed to reach a speed of 45 km/h. Some additional rules apply for this bike.
- High-speed e-bikes follow the same rules as those from a moped (normal) e-bike.
- The minimum driving age is 16 years old and the driver must have a moped driving license (driving license AM)
- Wearing an approved moped helmet (standard ECE 22.05) or an approved speed pedelec helmet (standard NTA 8776: 2016) is mandatory.
- It is mandatory to have a yellow moped registration plate on the back of your speed pedelec.
- you need to have a third-party liability insurance.
- Drivers of high speed e-bikes have to use the main road except when their is a path for moped bikes.
- The maximum speed is 45 km/h on the road, 40 km/h on the bicycle / moped path outside urban areas and 30 km/h on the the bicycle / moped path within urban areas. area.[6].

3.2.2 Adaptation examples

In 2017 the e-bike caused a lot of confusion and accidents in traffic. This is why the government decided to make more stricter rules. Also in Belgium the rules have been altered regarding e-bikes. These can be taken as an example when implementing new regulation in the Netherlands and might also bring solutions for a more safe environment regarding the e-bike. A list of the new rules is shown below.

- Clear rules, more parking spaces
- Limited speed of 20 km/h
- Fines for driving and parking on the sidewalk
- Investments in bicycle parking spaces
- Raising awareness about place on the road
- Creating different zones with speed limits [7]

3.3 History of accidents

Electrical powered vehicles like the e-bike and the new upcoming e-scooter has had an increased popularity in the Netherlands. Because of this increase in users there has also been in increase in accidents using these vehicles with electrical assistance. In 2019, 65 people has fatal accidents while using an e-bike in the Netherlands. This were 8 more than the previous year [8]. What is clear is that accidents with an electrical bike are often more severe than accidents with ordinary bikes. In the first 5 months of 2018 341 e-bikers were involved in non fatal accidents which is around 23 percent more than the year before [9]. However this may even be more because when filing accidents with e-scooters and e-bikes almost never a distinction is made between these and ordinary bicycles [8].

There are a few reasons why accidents with e-bikes are more severe than with an ordinary bike. The most important and also most obvious reason is the speed. Being able to reach higher speeds than with a regular bike impacts not only the severity of the fall or accident but it also makes it more difficult for other road users to estimate the actual speed of the users. The next reason is that a lot of elderly people use electric bikes and when they have accidents they are usually more severe than if the same accident would happen to a younger person [10].

3.4 Safety Critical Functions

Safety critical functions are functions that actively contribute to keeping people within the environment alive. Failure of these functions may lead to either loss of life, or significant damage to environment or property [11]. In the e-bike there are certain functions that are safety critical, albeit in certain environments. Some functions are safety critical if an e-bike is in dense traffic situations, whereas it might not be safety-critical if the e-bike is ridden in for example a remote cycling path. Therefore, the following list of safety critical functions applies for dense traffic areas:

- Brake system
- Speed controller (if applicable)
- Traffic signs / lights / markings
- Lights (in the dark)

4 Hazard Identification

For better identifying the hazards associated to the e-bikes, a failure mode effects analysis (FMEA) was used. This approach is a step-by-step procedure for not only identifying all ways or modes in which such bikes can fail but also for studying the consequences of those failures. Hazards are prioritized according to how serious their consequences are and how frequent they occur. For each hazard, its severity and probability are multiplied and assessed according to the risk assessment matrix (Figure 4). The purpose of the FMEA is to take actions to eliminate or reduce hazards, starting with the highest-priority ones, also called critical hazards. Hazards classified as High are seen as Critical Hazards.

4.1 Grading explanations

Both severity and probability have their own grading structures and are given in the figures below. The combination of these grading schemes are combined so the risk assessment matrix can be made.

Description	Severity Category	Result Criteria
Catastrophic	1	Could result in death, permanent total disability, irreversible significant environment impact
Critical	2	Could result in permanent partial disability, injuries or occupational illness that may result in hospitalization, irreversible significant environmental impact
Marginal	3	Could result in moderate injury or occupational illness, reversible moderate environmental impact
Negligible	4	Could result in none or small injuries and small environmental impact

Figure 2: Severity grading explanation

Description	Level	E-bike
Frequent	A	Likely to occur often
Probable	B	Will occur several times
Occasional	C	Likely to occur sometime
Remote	D	Unlikely, but possible to occur
Improbable	E	So unlikely, it can be assumed occurrence may not be experienced

Figure 3: Probability grading explanation

	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low

Figure 4: Risk assessment matrix

4.2 Failure (hazard) mode and effect analysis

After getting insight on how potential hazards should be obtained research was done into finding the hazards that the e-bike comes across. In Figure 5 various hazards are listed with their accompanying hazard mode. The hazard mode can be seen as a failure that leads to the main hazard. All hazard modes are assessed on their severity and probability, leading to their overall risk level. This assessment is based on logical reasoning together with amount if impact the hazard has on either the functionality of the bike or the functionality of the driver. A visual representation of these hazards has been made using fault trees which can be found in Appendix B.

Hazard	Effect	Hazard mode	Severity Category	Probability	Risk
Electrical motor cannot be started	Partial loss of functionality	Faulty component in the motor	4	D	Low
		Sudden discharge of battery	4	E	Low
Motor stalls	Total loss of functionality	Faulty component	4	D	Low
		Misassembled component	4	D	Low
		Virus in the software	4	E	Low
		Frozen motor	4	D	Low
		Fire in the motor	1	D	Serious
		Overload	3	D	Medium
Motor does not respond quickly	Driver losses control of the vehicle	Wrong calibration	2	D	Medium
		Lack of maintenance	2	C	Serious
		Overheating	2	C	Serious
Front fork breaks	Driver losses control of the vehicle	Welding failure	1	E	Medium
		Corrosion	1	D	Medium
Unresponsive breaks	Driver losses control of the vehicle	Lack of maintenance	2	C	Serious
		Overheating	2	C	Serious
		Freezing	2	D	Medium
Weird noises	Loss of efficiency	Loose component	4	D	Low
		Stuck debris	4	C	Low
		Lack of cleaning	4	C	Low
Irregular velocity	Total loss of functionality	Bearing locks up amid drive	1	D	Serious
		Throttle getting stuck in wide open position	1	D	Serious
Disrupted movement	Partial loss of functionality	Tire malfunction	2	D	Medium
		Flat tire	2	C	Serious
Unwanted interaction with other users and environment	Loss of safety	Disrespect for traffic lights and rules	1	C	High
		Aggressive driver	2	C	Serious
		Excessive speed	2	C	Serious
		Large speed difference with other bicycles	3	C	Medium
		Underestimation of e-bikers speed	2	A	High
		No lights	2	B	High
		Sudden direction changes	2	C	Serious
		Driving under the influence of drugs or alcohol	1	C	High
		User falls off e-bike	1	D	Serious
Reduced maximum speed	Loss of efficiency	Too much weight on the e-bike	3	C	Medium
		Driving on non-pavement or dirt roads	4	C	Low

Figure 5: List of possible hazards with the e-bike and their accompanied risk level

4.3 Critical hazards

From analyzing Figure 5 it can be concluded that there are four different critical hazards, which are the disrespect for traffic lights and rules, the underestimation of e-bikes speed, driving with no lights on during nighttime and driving under the influence of drugs or alcohol.

It can be stated that these hazards are caused by the user's irresponsibility and disrespectful attitude towards the other road users. According to [2], hazards that fit in the operational point of view mainly relate to human factors and culture. Furthermore, human considerations, use and misuse are three of the major elements of the operation. Overall, operational aspects predominantly focus on interactions of humans with the e-bikes and with the respective environment. So, all of the previously mentioned critical hazards fit in this category.

These hazards are a big issue with e-bikes as these bikes are often faster than regular bikes. Therefore, the severity of the hazards is increased. Another important aspect to note is that nowadays e-bikes are becoming increasingly popular, so the hazards that are associated to it can become more frequent. It is then extremely important to try to reduce the severity and probability of all the hazards, but particularly the critical ones, as these can result in severe injury or even death of the user. Such four hazards will now be further analyzed, to raise awareness and to understand the real consequences. What can also happen is that other road users underestimate the speed of the e-bike user.

Disrespect for traffic lights and rules

The first hazard deemed as critical is the disrespect for traffic lights and regulations. In developed countries such as the Netherlands cyclists have access to an extensive web of bicycle lanes. In order for the users of such lanes to avoid unwanted interactions with the remaining road users and vehicles, such as cars and trucks, some rules have to be followed. For example, respecting the traffic lights, acting in conformance with the road signs, the road markings and the Dutch regulation. One critical situation occurs when e-bikes users ignore a red light and cross the road used by much heavier vehicles. This situation can easily result in serious injuries or even death. Another very common example is missing the priority signs, often somehow hidden. Missing one priority can also result in a very serious accident with catastrophic consequences for the e-bike user [12].

Underestimation of e-bikers speed

The second critical hazard is the underestimation of e-bikers speed. This can happen in two distinct ways. Firstly, if the user thinks he is riding the e-bike at a much lower speed than he actually is. Secondly if the remaining users grasp the e-bike as a regular bike and estimate its velocity based on that wrong assumption. As known e-bikes are much faster than regular bikes, so in potentially critical situations, such as crossroads or roundabouts this underestimation of the velocity can result in accidents. What can also happen is that other road users underestimate the speed of the e-bike. Other road users tend to correlate a bike with low speeds rather than with 25 or even 40 km/h that for example e-bikes can easily achieve. This leads to gross underestimation of the speed of these urban vehicles which can cause danger in for example road crossings. Other road users might think that they can pass-by before a bike, but don't realize the bike might be there sooner than expected [9].

Non-sufficient lighting

Riding e-bikes without lights in nighttime or periods with lack of visibility is also another critical hazard. During such periods, the absence of lights on these vehicles means that e-bikes are non-visible to other vehicles. Knowing that bike lanes often crossroads and areas with significant traffic, if a e-bike user is not visible, other users cannot predict their movements and actions based on the e-bike presence. This hazard is especially dangerous because it can occur without any driving mistake, simply by a mere oblivion of activating the lights [13].

Usage of alcohol or drugs

Lastly, driving e-bikes under the influence of alcohol or drugs is also considered to be a critical hazard. With the presence of alcohol, controlled substances or even forbidden ones in his organism, the user losses control of himself and the perception of objects and moving vehicles. In other words, the capability of riding sensitive vehicles as the e-bikes is lost. An intoxicated driver performs evasive maneuvers, sudden accelerations and stops, does not assess potentially dangerous situations and involuntary does not follow rules. He puts in danger not only himself, but also all the road users. Nowadays, the hazard is becoming more important to control, mainly due to the easy access to alcoholic beverages and controlled substances. In addition, knowing that e-bikes can be ridden by youth also increases the risks because youth tend to challenge rules and have difficulty estimating the risks [14] .

5 Control Hazards

Controlling the hazards is needed to reduce dangers and possible failures. Risks that are unacceptable are to be designed out of the product, or other ways should be noticed to reduce these dangers. Within e-bikes, critical hazards that are high risk will be analysed and actions should be taken to reduce these risk levels.

5.1 Hazard 1: Disrespect for traffic lights and rules

As explained in Chapter 4, ignoring or not following the traffic lights and rules has a considerate risk to it. It is important to see what corresponding actions can be taken to reduce this risk.

Hazard	Severity	Probability	Risk
Disrespect for traffic lights and rules	1	C	High

The disrespect for traffic lights and rules is a cause of hazards on its own. However, this cause can be investigated further and new 'causes' for this hazard show up. Not following traffic signs and rules can be due to the following aspects: unclear (faulty) signage or faulty behaviour. It can be seen that wrong or unclear road signage can lead to this hazard, which is actually not directly the fault of the user. Faulty behaviour is however related to how the user uses the e-bike. Decreasing this latter cause be hard, as it is tough to change human behaviour. Possible solutions with their responsible stakeholder(s) are given in Table 2

#	Possible solutions	Responsible stakeholder(s)
1	Keep signage in good shape (maintenance)	Regulators
2	Redesign signage	Regulators
3	Create user feedback system on dangerous areas	Regulators, users, owners
4	Stricter regulations and enforcement	Regulators, enforcement
5	Create a sign reader within e-bike	Manufacturer
6	Warning within e-bike when approaching dangerous situation	Manufacturer, regulators
7	Awareness program for e-bike users	Regulators
8	Helmet law reducing severity	Regulators, enforcement
9	Other safety features (e.g. airbag, auto-brake)	Regulators, manufacturers

Table 2: Solutions against disrespect of traffic lights and rules

Also, the costs have been taken into account. There are some options like numbers 1, 2, 4, 7 and 8, that have low to moderate costs and will likely evade accidents on a regular basis. Although in safety perspective options 4, 7 and 8 are good solutions, these solutions should also be looked at in the perspective of the user, since they might not be willing to go through the extra effort of some of these measures. Nonetheless, they are therefore the most easy to implement at low cost. The other options are fairly costly and some of them require a lot of Research and Development (options 3, 5, 6, 9), and thus difficult to implement on short term. However, this is a great option for further increase in safety in the future and have a high benefit since the e-bikes could then be almost inherently safe in the future.

5.2 Hazard 2: Underestimation of e-bikes speed

The underestimation of the e-bikes speed is also a serious hazard that should not be taken lightly. The increase of e-bikes is even going to increase the probability of this happening, so decreasing the risk is of importance.

Hazard	Severity	Probability	Risk
Underestimation of e-bike's speed	2	A	High

Underestimation of an e-bikes speed has a high probability and is expected to be even higher in the future. To guarantee safe urban mobility solutions must be found to decrease this risk.

#	Possible solutions	Responsible stakeholder(s)
1	Lowering speed in certain dangerous areas	Regulators, enforcement, manufacturer, user
2	Motor aid lowered in urban areas	Manufacturer
3	Create awareness under other road users (e.g. programs, education)	Regulators, manufacturers, service providers
4	Create special e-bike lighting for increased visibility	Manufacturers, regulators
5	Noise production by the e-bike	Manufacturers

Table 3: Solutions against the underestimation of the speed of e-bikes

As can be seen in Table 3, some solutions are that of changing the e-bikes speed or motor assist speed. This is not directly related to fixing the underestimation of speed. However, e-bikes with a lower speed are less likely to be underestimated in speed therefore providing a solution in a different way. Also, this solution is now a costly one, and therefore a good option. Other solutions like 4 and 5 create extra perceptibly for other road users. Special e-bike lighting could offer great benefits to the safety of the environment and users, since other road users will then know that it is an electric vehicle with possibly a higher speed. These options are also fairly easy to implement against low costs, and thus their benefits to cost ratio is high.

5.3 Hazard 3: Insufficient lighting

Insufficient lighting is a great problem, even with e-bikes. Not all e-bikes have automatic lighting and this creates unsafe situations when users expect the bike to have light on it, while this is not the case. Also, component failure could lead to this light failure which has considerate impact on the safety of the environment, users and technical system.

Hazard	Severity	Probability	Risk
No or insufficient lighting	2	B	High

#	Possible solutions	Responsible stakeholder(s)
1	Back-up lighting implemented in bike	Manufacturer
2	Automatic lighting when it is gets dark	Regulators, manufacturers
3	Create user awareness on lighting importance	Regulators
4	Stricter enforcement	Enforcement
5	Preventive maintenance	Service providers
6	Stricter regulations (i.e. automatic lighting law)	Regulators

Table 4: Solutions to the insufficient lighting

Insufficient lighting has a user awareness aspect into it. If lighting is not-sufficient, users should have the responsibility to handle this problem. However, not all users do this, thus creating dangerous situations on the road. Backup lighting or preventive maintenance could fix the problem that light is suddenly insufficient. Stricter regulations and user awareness could influence the self responsibility users have, but might have limited effect and high cost. Cost wise, backup lighting and automatic lighting are the cheapest solutions.

5.4 Hazard 4: Riding under influence of alcohol or drugs

As stated in Chapter 4, alcohol and drugs form a major problem in logistics sector. The increase in e-bikes causes an increase in these dangers and should thus be reduced.

Hazard	Severity	Probability	Risk
Riding under influence of alcohol or drugs	1	C	High

#	Possible solutions	Responsible stakeholder(s)
1	Stricter regulations	Regulators
2	Stricter enforcement	Enforcement
3	Create user awareness on alcohol drug influence	Regulators
4	Alcohol test after certain time	Manufacturer
5	Nightly speed limit on e-bikes	Manufacturer, regulators, enforcement

Table 5: Solutions to riding e-bikes under influence of alcohol of drugs

Governments, institutions and other stakeholders have done immense effort to reduce the use of logistic vehicles while under influence. Solutions like stricter regulations and stricter enforcement are already being done and have major costs to it. This hazard might be one of the hardest hazards to fix, also due to the social acceptance of using bikes as a transportation system while under influence of alcohol or drugs. Monitoring these solutions is of great importance, as feedback could help reduce this hazard in the future.

6 Monitoring the System

To verify whether safety measures are working properly, the system must be monitored in the operational phase. To do this, safety indicators can be used. These safety indicators can be either leading or lagging. That is, the indicator gives feedback based on preventive action, or alerting failures afterwards, respectively.

To start off with the easiest means: a log of every incident and accident that caused (severe) harm to anyone in the system should be logged. The regulator should be in control of this. In that way, a clear view on the amount and cause of harmful situations is made. This can be compared to situations where there weren't any safety measures and conclusions can be drawn on the effectiveness off the safety measure. This is a lagging indicator since the incident has already happened before the notification.

As for another monitoring method: The manufacturer and the regulators should take regular surveys on safety means of e-bikes in traffic. In that way, users and other road users can give feedback on different safety measures and events that happen. This gives a clear view on the way measures are working, and how they are perceived in real life situations. This is a more pro-active way of controlling the system and is therefore a leading indicator.

Conclusion

In the Netherlands cycling is one of the most important means of traveling. Over the last couple of years electric vehicles have come into the picture and have proven to be popular in this country. This new way of moving around also brings up new questions regarding safety. In this case study a research has been done on the system and safety challenges revolving around e-bikes. From the analysis we can draw the conclusion that the most critical hazards are caused by human interaction with the environment whether this is on an e-bike or as other road user. Since the e-bike is quite new and can go quite fast there is a large risk of underestimating the speed. Overall the behaviour of the driver or other road users is what effects the safety levels the highest. However this hazard can possibly be decreased using proper signage in reduce the risk of unintentional disrespect of rules. To reduce the risk of accidents an awareness program can contribute as well as regulation to obligate wearing a helmet while using the e-bike.

Discussion

In this report, the focus was mainly put into regulations. However, to really validate whether the mentioned solutions could work, also an elaboration should be done on the technical side. The proposed solutions might not all be viable in the sense that they would cost quite some Research and Development without strictly knowing what the consequences of their safety is in the real world. Also, the proposed solutions of stricter regulations are under the assumption that stricter regulations are also enforceable and are therefore obeyed by the user. In the real world, this is unfortunately not always the case.

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Appendices

A Elaboration on DSM

Human	User	Owner	Manufacturer	Service Providers	Regulators	Enforcement
User		Provides vehicle (rent, borrowing)			Make traffic / usage laws	Ensures laws are obeyed
Owner	Rents / borrows vehicle		Sells vehicle / parts	Provides maintenance	Make environmental laws	Ensures laws are obeyed
Manufacturer		Provides feedback about product		Provides feedback about product	Make safety / production / environmental laws	Ensures laws are obeyed
Service providers		Needs service	Provides parts / Manuals / Information		Make laws	Ensures laws are obeyed
Regulators						Ensures laws are obeyed
Enforcement						

Figure 6: Human-Human interactions

Technical	Steering wheel	Braking system	Accumulator	Electric motor	Lighting	Wheels	Frame	Charging station	Controls
Steering wheel			Electricity			Forces on steering when riding	Provides mounting points		
Braking system	Provide mounting points					Forces			Regulates regenerative braking
Accumulator				Regenerated electricity			Provides mounting points	Electricity	
Electric motor		Signal to charge battery	Electricity			Negative forces	provides mounting points		Heigth of thrust
Lighting			Electricity				Provides mounting points		On/off
Wheels	Direction	Brake force		Thrust			Provides mounting points		
Frame		Force on frame		Forces on frame		Force on frame			
Charging station									Regulates vehicle charging
Controls			Electricity / battery level feedback	Feedback on thrust level	Feedback		Provides mounting points		

Figure 7: Technical-Technical interactions

Environment	Weather	Infrastructure	Other road users	Laws and Policies
Weather				
Infrastructure	Road conditions / Visibility		Usage wear	Laws / regulations
Other road users	Weather-conditions	Signs		Laws / regulations
Laws and policies			Feedback	

Figure 8: Environmental-Environmental interactions

	Human					
Technical system	**User**	**Owner**	**Manufacturer**	**Service Providers**	**Regulators**	**Enforcement**
Steering wheel	steers	owns	produces			
Braking system	applies	owns	produces	maintains		
Accumulator		owns	produces	maintains	Make regulations	
Electric motor		owns	produces		Make regulations	
Lighting	turns on/off	owns	produces	maintains	Make laws	Enforce law
Wheels		owns	produces	maintains		
Frame	sits on	owns	produces			
Charging station	plugs in	owns	produces		Make regulations	
Controls	gives input	owns	develops		Make regulations	

Figure 9: Human-Technical Interactions

	Technical System								
Human	**Steering wheel**	**Braking system**	**Accumulator**	**Electric Motor**	**Lighting**	**Wheels**	**Frame**	**Charging Station**	**Controls**
User	road feedback	slows down		adds power	Increase visibilty	road feedback	Supports		Gives feedback
Owner									
Manufacturer									datalogging
Service Provider									
Regulators									
Enforcement									

Figure 10: Technical-Human Interactions

	Environment			
Technical System	**Weather**	**Infrastructure**	**Other road users**	**Laws and Policies**
Steering wheel				
Braking system				
Accumulator				ensure quality
Electric motor				ensure quality
Lighting	Lower visibility in rain			ensure quality
Wheels	variable grip in dry/wet/slippery conditions	variable grid on differnt road surface		
Frame				
Charging station		charging locations		ensure quality
Controls				ensure quality

Figure 11: Environmental-Technical interactions

	Technical System								
Environment	**Steering wheel**	**Braking System**	**Accumulator**	**Electric Motor**	**Lighting**	**Wheels**	**Frame**	**Charging Station**	**Controls**
Weather									
Infrastructure					visibility	force on road			
Other road users					visibility				
Laws and Policies									

Figure 12: Technical-Environmental interactions

	Environment			
Human	**Weather**	**Infrastructure**	**Other road users**	**Laws and Policies**
User	Operation conditions	Traffic	Operation conditions	Operation restrictions
Owner				
Manufacturer	Requirement input	Requirement input		Design regulations
Service providers				
Regulators	Data input			
Enforcement			Data input	Framework

Figure 13: Human-Environment interactions

	Human					
Environment	**User**	**Owner**	**Manufacturer**	**Service Provider**	**Regulators**	**Enforcement**
Weather						
Infrastructure					might adapt	
Other road users	interaction					
Laws and Policies	must obey		must obey	obey	make	enforce

Figure 14: Environment-Human interactions

B Fault trees

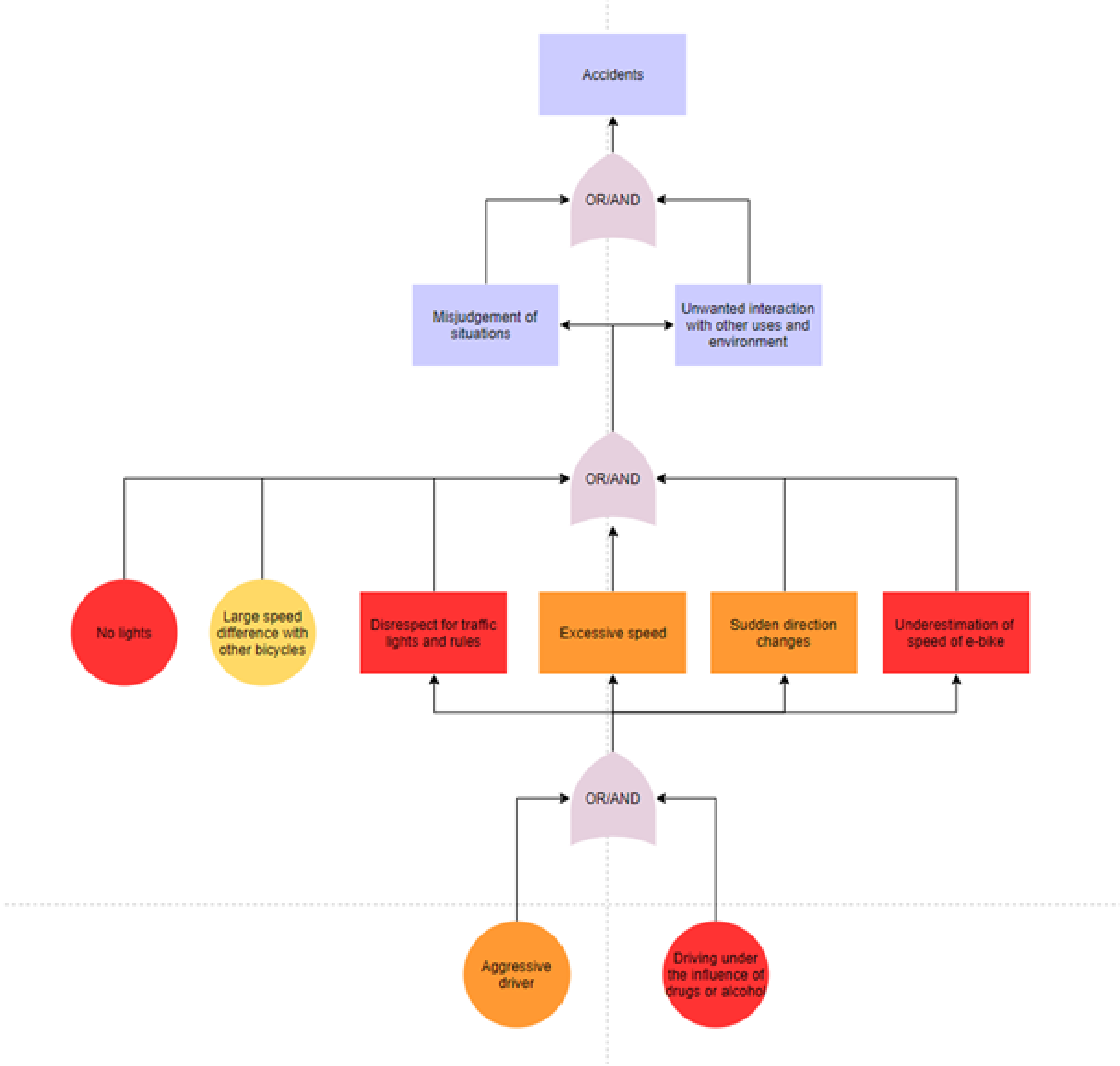

Figure 15: Hazards organised in fault tree

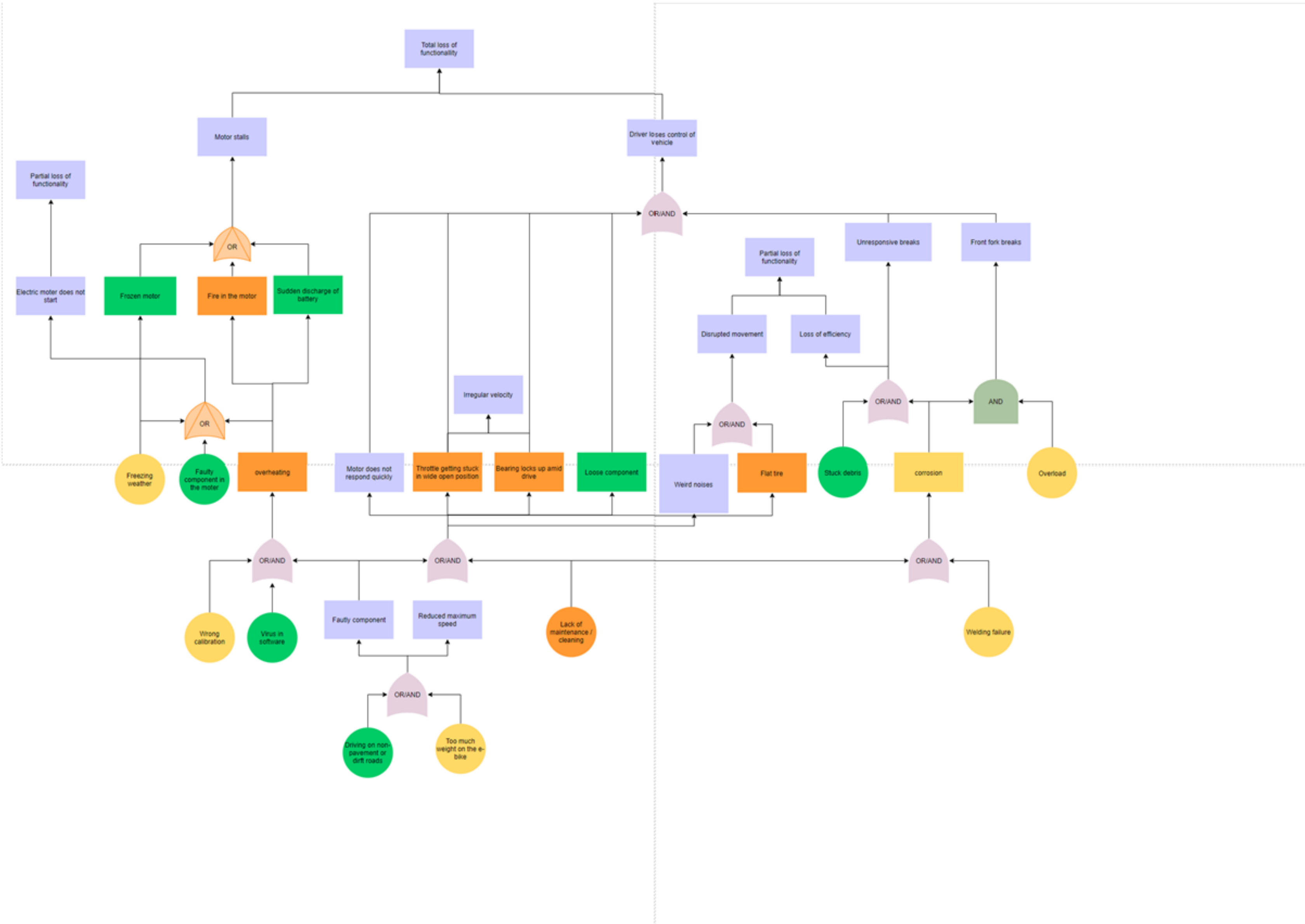

Figure 16: Hazards organised in fault tree