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Case V: Bicycle safety

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0. Introduction

This report is the result of a collaborative project developed by a group of students for the course Safety By Design at the University of Twente. The task is to analyze a case study concerning bicycle safety. This is divided into five different and consecutive parts. The process starts by defining the system and safety objectives. Then it continues with the identification of the hazards and definition of how to control them. After these steps have been performed, it is possible to continue with an analysis on how to monitor the system and its safety. These steps are visualized in Figure 1. With this process, it is possible to define bicycle safety, what are the risks in the system, how to control them and set the preliminary knowledge for the task of how to increase the safety of the bicycle.

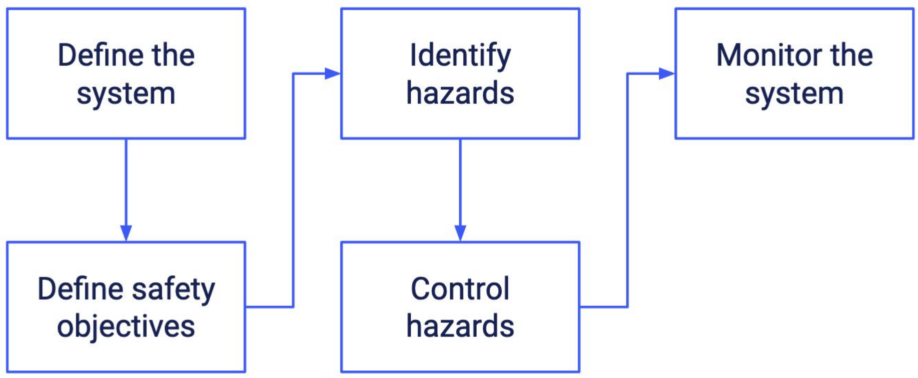


Figure 1. Steps for system safety analysis.

In the Netherlands cycling is a popular transportation method. It is estimated that 34% of all trips up to 7,5 km were made by bicycle in the year of 2007. From all trips the equivalent number is 26%. (Ministry of Transport, Public Works and Water Management Directorate-General for Passenger Transport, 2009) Compared to a passenger car, which is the most popular transportation method, a bicycle can achieve as high speeds in city traffic but cyclists usually do not have safety equipment or a protecting frame around as in cars.

Nonetheless, in the Netherlands there are approximately only two cyclist deaths per 100 million driven kilometers. This is a low number compared to other European countries, even though the Dutch cycles 3 km per day on average. (Ministry of Transport, Public Works and Water Management Directorate-General for Passenger Transport, 2009) Still, casualties among cyclists are causing suffering and money expenses to society. Therefore safety of bicycles can be increased and there is existing demand for that.

1. System of Interest (SoI)

The bicycle is the ea also results in a more exhausting experience for this transportation mode. Also, due to the fact thsiest transport mode people can offer. It is cheap, eco-friendly, and flexible. It is also healthier, due to the fact that its driving power comes solely from humans themselves, so humans do exercise to go with bicycle, which results in an active lifestyle (Andersen et.al., 2000). But, thisat the bicycle has no roof or body panels to cover the user, it has become subject to safety issues, because an impact will go directly to the user.

Here, the system will be defined, then we will also define human-system interaction, and environmental-system interaction issues that build the analysis of safety by design on bicycle.

System

In the Bicycle, there are 5 main subsystems:

1. Frame and Seat: Components for sitting, connecting wheels to the human saddle.
2. Crank Set: To motorize the chain to the rear wheel for acceleration.
3. Brakes: Support of the bicycle movement, brake for helping the bike reduce the speed, steering for directing the movement of the bicycle.
4. Wheel: Essential components of bicycle movement. Connects the Bike system with the environment.
5. Shifting (Gears): Main driver of the bicycle for movement. Depends on bike specifications, there are bikes that have multiple gears that allow for different levels of cycling speed (increase or reduce) depend on the users need.

Here, the bicycle movement is primarily driven by gears, brakes, and wheel. Frame and Seat is where the user connects and rides the bike by sitting on it.

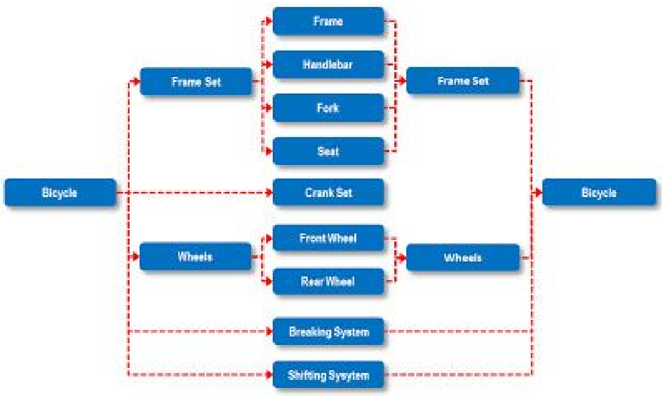


Figure 2. System of Systems of Bicycle (Source : http://3d-gantt.blogspot.com/2011/06/ automatic-task-links-establishment.html)

Human-to-System Interaction

Even after all system aspects in the bicycle have been improved by safety (e.g. ergonomic design of frame, wider and deeper profile of wheel thread, and contoured pedal to avoid slip) it's the user that counts for the safety result. Users have to know the use profile, environment, and supported infrastructure they face.

In terms of use profile, users have to know how a system is used for a safer interaction. An understanding on the systems (and subsystems) working interaction is needed. For example, users have to know how tall they are in terms of bicycle height, so they can step in while stationary to avoid an unbalanced position in the bicycle. Another example is to know whether they can use the frame profile with appropriate clothes (with skirt or pants) while getting on the bicycle is based on ergonomic reason. This is why bicycles often has 2 different types of frames: *Damen* (for women) and *Heren* (for men) (Angloinfo, 2015). And finally, users have to know how each subsystem in bike works. For example in gearing, users have to know whether they need to upshift the gear for more speed or downshift the gear for going uphill. Users have to avoid using upper gear for uphill so cycling will not be heavy and possibly cause a fall due to no torque. Yet another example is how the brake is properly helpful to reduce speed by maintaining the brake canvas. Users have to know when to change the canvas if the bicycle feels hard to slow down.

Figure 3. Simple example of use profile by safety, by not hindering vision (umbrella use) while cycling. (source : observer.com)

Environment-to-System Interaction

The bicycle is a system which has many environmental aspects that influence its safety, such as weather, road and infrastructure and other traffic users (e.g. bicycles, motorcycles, cars, buses, etc.). The bicycle relation to its environment is important to understand in order to ensure its safety. Here, the environment has been defined as weather, road and infrastructure, and other traffic users, while the system is the bicycle itself. Bicycles have to deal with the situation of things such as slippery, uneven road, with weather such as rain or even flood.

First of all, the weather is important to be discussed. Bicycles are always interacting with weather wherever they go. Dry or wet conditions will change the level of risk for the bicycle. This will influence the use profile of the bicycle. Because with proper safety apparel, calculation, and design to safety, if the environment does not support the interaction with the bicycle, it will not be safe to use. Below there is an example picture on how the bicycle is "unable" to use due to environment.

Figure 4. As a result of a flood, the bicycle is not safe and comfortable to be used due to uncleared road and the possibility of an accident. (source : republikaonline.com)

Then there is road and infrastructure. The road is the media for the bicycle to move. The interaction between bicycles and roads is inseparable. Any condition of the road (slippery, rough, smooth) will influence the safety level of the bike. Therefore, bicycles have to be made to adapt to the road conditions by adjusting its subsystems. For example, for muddy and slippery roads, there are BMX Bikes that can be applied (due to rugged tyres); or for smooth and asphalt road, there is *omafiets* that can be used. On the other hand, infrastructure to control the traffic of vehicles is also important to keep bicycle safety. Road signs have to be clear, so bicycle users can react well on hazards that they will face.

Integration of Human-System-Environment

Then there's integration between Human-System-Environment. In this instance humans and bicycles, interact with other competing systems like motorcycles, cars, or even trains. To face this, bicycles have to be equipped with reflectors for other systems to detect them, especially during the night. But, without human knowledge about the system safety of the bicycle, it would result useless in the environment, so it is important to take into account for safety factor.

Additionally, awareness and carefulness of the user is an important part in the factor of the safety issues in cycling. If the user is in a hurry and speeding, the risk of bicycle accidents is increased (Vanparijs, J et al., 2015). Another example, which is shown in figure 5, is regarding unawareness of the system (bicycle and human) with other competing systems. Due to user not paying attention to the car across, a crash between the bicycle and the car is unavoidable. Therefore, human factors are also influencing the safety of the bicycle.

Figure 5. Bicycle-Car Crash example. (Source : propertycasualty360.com)

Then, there's also a possible system-environment hazard that could lift as an accident. Here, the user has to know whether an environment is suitable or incompatible with safety integration of the system. For example, when all of the bicycle components are in proper condition, but if the environment (i.e. roads) is not supporting safe usage (i.e. slippery, uneven roads) it could lead to an unsafe condition; or when the infrastructure is not supporting safe riding for cyclists (e.g. hidden signs), which leads to unknowing cyclists regarding possible danger approach. Below figure 6 is an example regarding unclear road signs due to vegetation, which could lead to unsafe conditions for traffic users with their systems.

Figure 6. Hidden Road Sign that endangered all traffic users, including cyclists. (source : safety.fhwa.dot.gov)

2. The safety objectives

After defining the system boundaries, it is relevant to set safety objectives for the system, to be able to identify and control hazards. The general object for the bicycle is obviously that bicycle is safe for its user. But there are also other stakeholders, such as other people in traffic, other cyclists, motorized vehicles and pedestrians. The bicycle as a system has to be safe for these other stakeholders also. For environmental aspects, the bicycle cannot be dangerous or toxic, for example by leaking oil. The bicycle has to be visible for other people on traffic and act predictably. Usually the highest risk factor for accidents is human error, when the bicycle is misused or used unpredictably. For a bicycle manufacturer, a safe bicycle is the goal, but still, it is necessary to accept that a certain number of bicycle users can and will lose their lives. In this phase, safety objectives are gone through by safety regulations and familiarizing known accident types.

Standards and regulations

To ensure this, for bicycles sold in the EU area there are general regulations and directives, made by the European parliament. Directives are setting standard levels for how products must be designed. For more detail safety design, there are standards to fulfil. In the EU are, there are EN-standards. For the whole world, there are standards made by the International Organization for Standards, known as ISO-standards. ISO and EN standards 4210 defines testing methods for bicycle different components. These standards and regulations do not define how to design and build a bicycle, but define what kind of tests bicycles have to pass to be safe for users.

General regulations

Directives are made by the European parliament and they provide the base layer for other regulations for products sold in the EU area. These directives are not specified for bicycles but for general products. Relevant directives are listed in Table 1. The key content for bicycle aspect is listed for each directive.

Table 1: Directives for safety design

Number	**Name**	**Content**
2001/95/EC	General Product Safety	The purpose of the directive is that any product ending to user is safe product. It means that under normal or reasonable conditions including usage, service and installation product doesn't include risks or they are minimized to protect user safety and health.
2006/42/EC	Machinery directive	This directive applies to all machines on the market in the EU area. The bicycle is also considered as a machine. This requires manufacturers to follow safety standards to produce face product that for example power transmission chain is protected. Machine can't cause health or safety risk for user or at least these risks must be minimized and informed to user.

Specific regulations

Standards such as ISO and EN standards are setting more specific requirements for the product. These standards define how product should be tested and the level of condition it should be after standard test. These tested features are safety relevant features and components. Standards also define reflectors and lightning equipment. In most of the countries, they are required by law and therefore they are defined in law. There might be also national standards such as NEN-standards in Netherlands and SFS-standards in Finland for example. However, mostly these are harmonized to EN-standards which these countries are part of the EU. The relevant standards for bicycle are listed in Table 2, which in Appendix 1.

Accidents

The history of bicycle accident is diverse. They can be divided into two groups: failure in bicycle and human or environment based failure. Failure in bicycle means that some critical component in a bicycle fails such as a chain or brake cable snap. Therefore control over the bicycle is lost and this leads to accidents. Failures in bicycles can also cause accidents by encountering with the environment such as other cyclists or cars, but still the main root cause for accidents is failure in bicycle such as a failed lighting device, causing the bicycle to not be seen at night.

Human or environment based failures are for example when other humans in traffic run into the system. Usually these accidents happen in intersections or other similar places where driving lanes crosses. (European Road Safety Observatory, 2018)

Examples of bicycle components failure based accidents:

- Brake failure causing lack of braking moment
- Chain snap
- Tire surface lack of friction
- Lighting system does not illuminate
- Fracture in frame or forks

Examples of human or environment caused accidents:

- Collision caused by observation mistake
- Change in driving conditions is not considered
- Other vehicle user loses control of the vehicle
- Unpredicted behaviour in traffic and traffic rules violation

Safety critical functions

In this section the main focus was to get familiar with safety standards and also define safety critical functions in our system of interest (SoI). By analysing safety standards and accident types, it is possible to summarize bicycle safety critical functions. Failure in these functions will lead to health hazard with high probability. These safety critical functions are:

- Lighting system and reflectors
- Wheel assembly with rubber tires
- Braking system to decrease the speed and stop the bicycle
- Power transmission to control the speed of the bicycle

On the other hand, functions related to illuminating and being visible same as controlling the bicycle ride are safety critical.

3. Identifying hazards

Safety Cube Analyze

This part of the report concerns the identification of possible hazards with the help of the safety cube. These will be promoted from structural hazards to functional hazards and finished with operational hazards. The promoted hazards are based on brainstorming, literature review, history of accidents, checklists, and scenario thinking.

Based on the structure and requirements of safety cube, the time framework should be clearly identified so that all the hazards that are brought up can be filled into the appropriate column. The assessment of the time framework will be listed as follows.

Past

In the past category, it will be divided by the point of the adapting of national cycling policy in the 1990s, which means before that, the bicycle lanes were not everywhere for cyclists to use.

Present

With the help of comprehensive networks of cycling lanes, roads could be much safer in spite of the increase of cars. The present column will be identified as the current situation, where the policies and legislatures are thinking-through and the road situations are complicated.

Future

In the last column, the focus is on the situations that might occur in the future. And all the situations are brought up with the process of brainstorming, reasonable assumption based on the current and former situations/accidents. The possible situations would be:

- More cyclists on the road
- More cars on the road
- Cycling lanes getting massive changings
- Popular on electric cycles/cars
- Adapting 5G in traffic conditions
- New type of bicycles
- New type of cars
- New type of other transportation being created and made
- New laws being adapted
- Parts which can make the bicycles move faster being made
- Climate changing

Table 3. Structural hazard assessment

Physical/structural integrity hazards or related hazardous situation	**Past**	**Present**	**Future**
Environment or supersystems for SoI	The road can be chaotic because of unclear lines among the bicycle lanes, motorways and the sidewalk. The parking spots for bicycles are not organized. People tend to park their bicycles everywhere. During the rush hours, especially on a crossroad waiting for the red lights, the owners of bicycles and vehicles can be a mess since they all think that they can be the first in the waiting line of the road, which could cause an enormous traffic jam. Because of the rain and the snow, roads can be slippery, which could make the braking distance longer. Also due to the weather conditions, cyclists may not see the road condition.	The chaotic now are mostly happen in the cycle lanes. The lanes can sometimes be narrow, which makes space not enough for those cyclists want to spend up if there were slow-paced cyclists in front of them. In some cross-sections, there are no traffic lights, which could be dangerous for cyclists to cycle across the road. During the rush hours, especially on a crossroad waiting for red lights, cyclists tend to be the first in the waiting line so that they can move on as soon as the light turns to green. Therefore, the beginning of the line is always more crowded than the end of the line. Because of the rain and the snow, roads can be slippery, which could make the braking distance longer. Also due to the weather conditions, cyclists may not see the road condition.	There will be more bicycles, vehicles and many other transportation, they could make the road even more crowded and dangerous. With the demand for speed from consumers, the size of the bicycles might become bigger and bigger. The lanes still don't have enough space, which could cause hazards when cyclists are overtaking and the high speed itself could also cause hazards. People might aware that cycling will be good for the environment and also, their own health, so they might choose bicycles over driving cars. That's going to cause a more complicated road situation. Because of the rain and the snow, roads can be slippery, which could make the braking distance longer. Also due to the weather conditions, cyclists may not see the road condition.
System of interest	The size of bicycles back then could be big, which might be difficult for some people to control them.	Now some of the sports bicycles have more than 7 gears, which means that bicycles like that can move really fast. The braking distance could be longer. And the cyclists are easier to lose control of the bicycle.	Electric bicycles could be welcomed because of its high-speed. And the popular of which could cause more accidents. The bicycles might be designed to be faster. And for a better grip, the tires of bicycles might be thickened. But it will be a lot easier to lose control when turning around with the bold tires. The bicycles can be installed with an intelligent module, and that might be a distraction for the cyclist.
Subsystems or components of SoI	The bicycles might be structural inappropriate for women in dress and relatively short people. Instead of next to the handlebar, the brakes of the bicycles are linked with pedals. These kinds of brakes need cyclists to use	The bicycles might be structural inappropriate for women in dress and relatively short people if they are using the wrong size. Brakes could go wrong sometimes. So that the cyclists won't be able to	Cycling lanes could be divided into different paths based on the speed requirements, just like the motorways. Cyclists can change lanes way easier and freer. Because of the free of changing lanes, more hazards could occur.

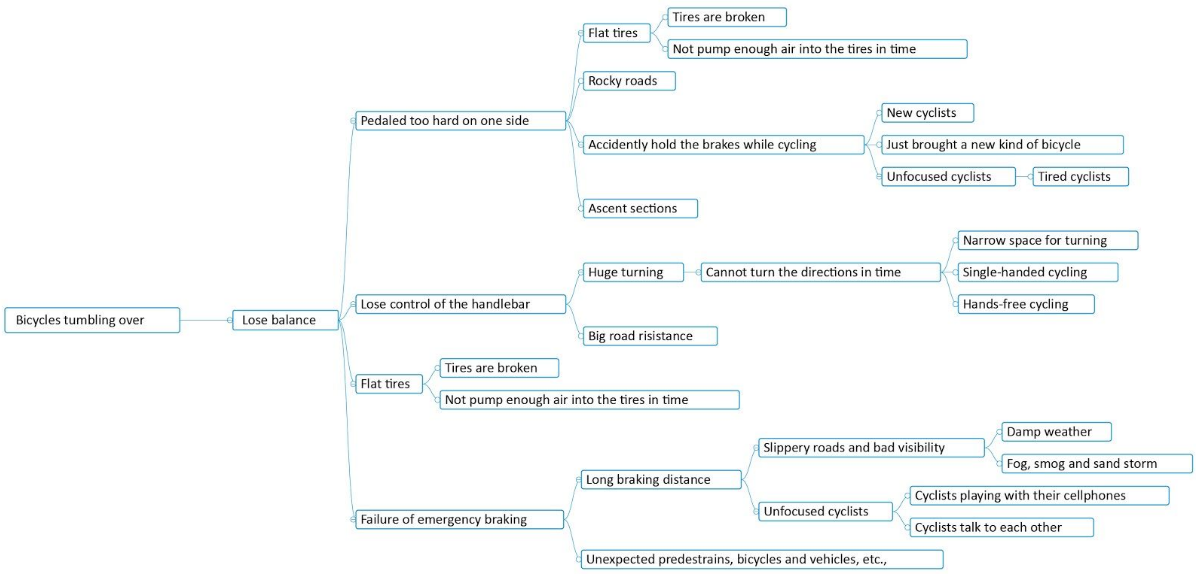
	their feet to slow down and stop. They are going to need more time to adjust the status from 'moving forward' to 'cycle reverse to slow down'	stop in time. Flat tires could cause the lack of control for cyclists. Bad visibility of road situations.	

Due to the page limitations, tables of functional and operational hazards assessments are put in Appendix 4.

Fault Tree Analysis

Using the fault tree analysis, we tend to find out how the specific accident happens which could cause by the elements we conclude above. We listed four frequent accidents that can present the safety of cycling, which are bicycles tumbling over, bicycles collide into each other, bicycles collide into pedestrians and bicycles collide into vehicles. Fault trees of the latter three ones can be found in Appendix 2.

Figure 6. Fault tree for bicycles tumbling over



4. Controlling hazards

Analysis

After having identified the hazards it is necessary to determine their probability and severity. In order to do this, a Risk Assessment Matrix was created (see Table 6). For a better understanding of the matrix, definitions for the different levels of severity and probability of the hazards are provided below. These were considered to be a consequence of, most commonly, human error, environment conditions, design defects or component failures.

Hazards

1. Bicycles tumbling over
2. Bicycles collide into each other
3. Bicycles collide into pedestrians
4. Bicycles collide into vehicles

Severity

Catastrophic: Accidents that result in the death of one or more users of the system or the road. Also, damage to the equipment will be so massive that it will result in a total loss of the system.

Critical: These incidents have as a consequence severe injuries for users of the system or the road and considerable damage to the equipment. The system will require several days to be repaired and a big cost.

Marginal: Accidents that cause only minor injuries to users of the system or the road. Damage to the equipment will be so slight that only small repairs and will be necessary with a little cost.

Negligible: These events will not have any injuries as a consequence, or less than minor injuries. No damage to the equipment means that no time and resources are required for repairs.

	Catastrophic	Critical	Marginal	Negligible
Frequent				
Probable	2,4			
Remote		1,3		
Improbable				

Table 4. Risk assessment matrix.

In this case, all hazards are important risks for the system and must be considered for design and control. However, hazards 2 and 4 are higher and more probable to occur, special attention must be paid to those aspects in the next phase.

Social aspects

Accidents

A report by the Ministry of Infrastructure and Water Management in the Netherlands shows that in 2016 there were 629 fatalities in the country that were caused by road accidents. Out of that number, 189 were cyclists and e-cyclists, which represents 30% of the total. However, 40% of all fatal accidents among cyclists did not involve another motor vehicle.

Regarding non-fatal road accidents, the report shows that cyclists represented 63% of all road accidents that resulted in serious injuries. However, of that total, only 11% involved a motor vehicle.

A study published in 2019 in the Traffic Injury Prevention Journal shows that, in the Netherlands, the body part that was most frequently injured in bicycle accidents was the head. This is followed by the lower extremities and the upper extremities in second and third place respectively (Leo et al. 2019). These results are hardly surprising considering that the use of a helmet in the Netherlands is not mandatory. According to an international survey conducted in 2014, only 34% of 712 Dutch respondents owned a helmet, 7% of often wore it and only 2% always wore it (Haworth et al. 2015).

Dutch policy has not focused on enforcing the use of helmets or any other protective gear for cyclists because their objective has been the prevention of accidents through a safe environment and infrastructure rather than softening the outcome of accidents. There is a concern about the enforcement of such regulations because it is expected that it would discourage some people from cycling at all, reducing bicycle use among the population, as it has occurred in other countries.

Infrastructure

In the Netherlands there has been a big focus on the creation of infrastructure to support and encourage the use of the bicycle. Not only have cycle paths been constructed alongside roads, but there are also completely independent paths that are isolated from motor vehicles and cross through neighborhoods and other areas. The objective is to offer direct routes to certain places and make a safer environment for cyclists.

Another thing that has been implemented are cycling highways, that creates a network that connects working areas and living areas. The goal of this type of infrastructure is to stimulate the use of bicycles with drivers living within 15 km from their work. These paths do not cross with other motor vehicles and have a good flow with no traffic lights.

Regulations

As was stated before, in the Netherlands the use of helmet is not mandatory by law, however, there are other rules that have been established regarding the use of a bicycle. The following are requirements that every bicycle must comply with, or otherwise the users can be fined:

- A bell that can be heard up to a distance of 25 meters.
- Lights, front (white or yellow) and back (red).
- Reflectors, on the back (red), the pedals (yellow) and tires (white or yellow).

Additionally a list of traffic regulations concerning cyclists in the Netherlands can be found in Appendix 3.

Improvements

From the analysis of the hazards performed through the fault trees, it is visible that the sources of accidents come from three main sources: structural deficiencies, human errors and unpredictable road conditions.

As the hazards cannot be designed out, the most effective and straightforward way in which safety could be increased for cyclists would be the implementation of protective gear. However, as was mentioned previously, the effects that such a measure would have on bicycle use must be carefully considered. Mandatory protective gear would result in a much safer system but, if as a result there is a reduction in the number of accidents, something to consider would also be the inevitable decrease in bicycle use.

It is then necessary to look into other possible improvements that can be done to the system. Additional research is necessary to determine which specific design changes in the system would be optimal in order to create an improved and safer experience. However, these can be broken down into three distinct categories, which are presented below.

Mechanical

As was previously stated, some accidents occur because of failures in components, this category encompasses any change that can prevent accidents by altering the bicycle in itself. These changes can be an enhancement or a complete modification of a part of the system. For example, prevent failure in the brakes by implementing more resistant wires or creating some form of emergency brake; to change the material of the tires so they do not need air and rule out the possibility of a flat tire; or a better implementation of reflective surfaces to counter any failure in the lighting system.

Environment

Another area in which major risks can be found is the environment in itself. However, changes in this category may be more difficult to achieve, because the most important risk factor here is the unpredictability of road conditions, given the fact that there are multiple factors that produce alterations in it.

Technological

To counter the risks coming from human errors, there is the possibility of enhancing the system by linking the bicycle to the environment. The improvements comprised in this category involve greater alterations to the bicycle system and more complex technology. For example, to prevent cyclists from riding without using hands, a system could be implemented that does not allow the bicycle to be used unless it detects that at least one hand is on the handlebar; in a smart environment, bicycles could detect and react to red lights and stops to protect cyclists from collisions; or to comply with speed limits, smart bikes could implement a system that controls the maximum speed at which it can move on certain areas.

5. Monitoring the system

After defining the system, identifying hazards and controlling the hazards, it is possible to monitor the system. This is often done by researching safety indicators. Through these indicators, it is possible to monitor trends in the system of interest. The demanding feature of these safety indicators is that they are usually lagging behind. The only reliable source and with most coverage are national accident statistics. However, they have the problem of not including minor accidents, only those where the police or medical services are required. European Road Safety Observation is keeping statistics from road accidents in the EU area. According to them there was 2700 cyclist accidents in year 2007 and the number has had a decreasing trend. In 2016 there was only 2100 accidents for cyclists in the EU area. (European Road Safety Observatory, 2018) They also sort accident types, time of accident and causes for accidents. Based on these statistics it is possible to monitor how cycling safety is developing and what kind of trends there are.

Changes in bicycle safety culture are happening slowly and culture varies depending on the country. An effective way to develop bicycle safety is to develop a safety culture for bicycle users. The user is responsible of the bicycle condition and also their own driving conditions and safety equipment. Affecting to the users willingness to use a helmet when cycling and also driving condition. Many users are riding a bicycle when under intoxicants. That causes a lot of risks for users. These are based on education for users and therefore education may increase safety.

Political decisions and governmental issues are also affecting safety. Separate bicycle lanes are separating bicycles from other road users which can increase safety and also traffic lights in cross-sections. Also surveillance for bicycle condition as well as for user behaviour will motivate users to take care of these. Misbehaviour, such as using a mobile phone while driving, will cause risks. There is also other road users using bicycle lanes such as mopeds. They often behave unpredictable such as using high speed. Safety can be also increased during regulations for example requiring double brakes.

6. Summary

As a daily usage mode of transportation, the bicycle has system of systems in its own design, with tends to safety. But, if the human neglects the factor of safety, it will be not effective. Humans also need to check their environment and make sure whether certain condition appears to make hazards and they have to know how to react and avoid it.

The design of bicycles sold in the EU area is defined by general directives such as 2001/95/EC General Product Safety and 2006/42/EC Machinery directive. There are also many standards to define bicycle design more precisely. ISO-EN 4210 standard defines how bicycle design should be tested and naturally these tests should be passed. There are also standards for safety relevant components such as lighting devices and reflectors. For children, bicycles and e-bikes there are also standards.

The safety of cycling can be a complex issue because of all the conditions of users, and environments (both natural and man-made). By adapting the theory of safety cube, it is possible to organize the hazards in order to design solutions to avoid such hazards from happening. And with the rapidly-developing technology, it is hard not to take the timeline into consideration. The safety cube provides a chance to really deepen the development of cycling and to freely imagine the future of it, too. It is always good to be prepared when it comes to safety and the chance of safety itself from the future.

By achieving a good understanding of the system and its interactions, a better planning can be developed on how to work on preventing the hazards in the system. This is a complex part of the process, as there are many aspects that can happen unpredictably, and it is only possible to be prepared in case they happen. This step can span different projects in itself, however, having a deep and complete analysis makes possible to prioritize and structure the future steps that must be taken.

Bicycle safety can be monitored mostly through national or EU level accident statistics. For example European Road Safety Observation collects statistics about accidents, but also where and how they are happening. It is a challenge to collect data from minor accidents since they are not usually reported if there is not need for authorities or health services. The safety culture can be affected through education and regulations. Being aware of road conditions, the user's own driving style and condition in which they drive, comprise a large part of risks for accidents happening.

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Appendix

Appendix 1 Table 2: Standards for bicycle design

Table 2: Standards for bicycle design.

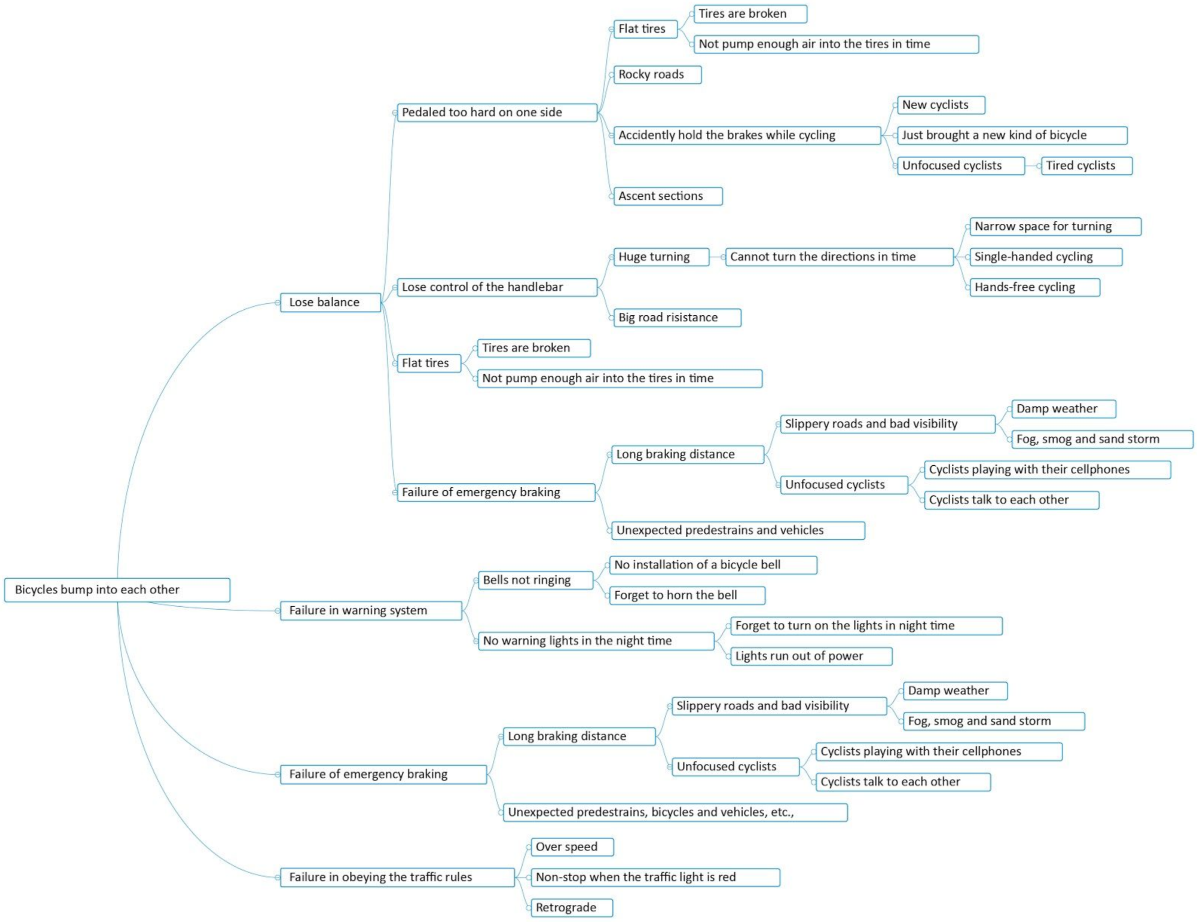
Number	Name	Content
ISO-EN 12100	Safety of machinery. General principles for design. Risk assessment and risk reduction	Defines how to perform risk assessment. Risk assessment is required for all products. Defined also how to reduce risks from many aspects such as shape, stability, maintainability, electrical and hydraulic aspects.
ISO-EN 4210-1	Cycles. Safety requirements for bicycles. Part 1: Terms and definitions	This EN and ISO standard defines safety requirements for bicycle. This is the first part of standard where terms and definitions are listed.
ISO-EN 4210-2	Cycles. Safety requirements for bicycles. Part 2: Requirements for city and trekking, young adult, mountain and racing bicycles	This EN and ISO standard defines safety requirements for bicycle. This part of standards defines requirements for different kind of bicycle based on use profile.
ISO-EN 4210-3	Cycles. Safety requirements for bicycles. Part 3: Common test methods	This EN and ISO standard defines safety requirements for bicycle.This part defines what kind of test has to be done for bicycle and how bicycle has to pass these tests.
ISO-EN 4210-4	Cycles. Safety requirements for bicycles. Part 4: Braking test methods	This EN and ISO standard defines safety requirements for bicycle. This part defines brake performance such as brake lever or pedal dimensions, applied forces, braking performance and test methods for the performance in different conditions.
ISO-EN 4210-5	Cycles. Safety requirements for bicycles. Part 5: Steering test methods	This EN and ISO standard defines safety requirements for bicycle. This defines how steering bar is tested and what kind of forces and torques bar should handle.
ISO-EN 4210-6	Cycles. Safety requirements for bicycles. Part 6: Frame and fork test methods	This EN and ISO standard defines safety requirements for bicycle. This part defines how frame and fork should be tested and what kind of forces it should handle.
ISO-EN 4210-7	Cycles. Safety requirements	This EN and ISO standard defines

	for bicycles. Part 7: Wheels and rims test methods	safety requirements for bicycle. This part of standard define how wheels and rims should test and what kind of forces they should be able to handle.
ISO-EN 4210-8	Cycles. Safety requirements for bicycles. Part 8: Pedal and drive system test methods	This EN and ISO standard defines safety requirements for bicycle. This part defines how power drive system should be tested and what kind of loads should be used in tests.
ISO-EN 4210-9	Cycles. Safety requirements for bicycles. Part 9: Saddles and seat-post test methods	This EN and ISO standard defines safety requirements for bicycle. This part of the standard how saddle sub-assembly should be tested and also test loads.
ISO 6742-1	Cycles -- Lightning and retro-reflective devices -- Part 1: Lightning and light signalling devices	The lights and reflectors are safety critical components for bicycles. This standard defines requirements for these components. This part of standard defines what these devices are.
ISO 6742-2	Cycles -- Lightning and retro-reflective devices -- Part 2: Retro-reflective devices	This part of the standard defines requirements for the reflectors for example shape, reflecting, temperature limits. Also how these photometric and colorimetric features should be tested.
ISO 6742-3	Cycles -- Lightning and retro-reflective devices -- Part 3: Installation and use of lighting and retro-reflective devices	This part of the lightning and reflector standard defines how these components should be installed to bicycle and also operation principles.
ISO 6742-4	Cycles -- Lightning and retro-reflective devices -- Part 4: Lighting systems powered by the cycle's movement	This part of the lightning and reflector standard defines how lightning systems should be powered from bicycle movement by safe way.
ISO 6742-5	Cycles -- Lightning and retro-reflective devices -- Part 5: Lighting systems not powered by the cycle's movement	This part of the lightning and reflector standard defines how lightning systems should be powered from independent power source, typically from battery.
ISO-EN 8098	Cycles. Safety requirements for bicycles for young children	For young children there is small bicycles on the market. These bicycles have their requirements to be safe for users. The standard has requirements e.g. for brakes, steering, frame, toxicity,

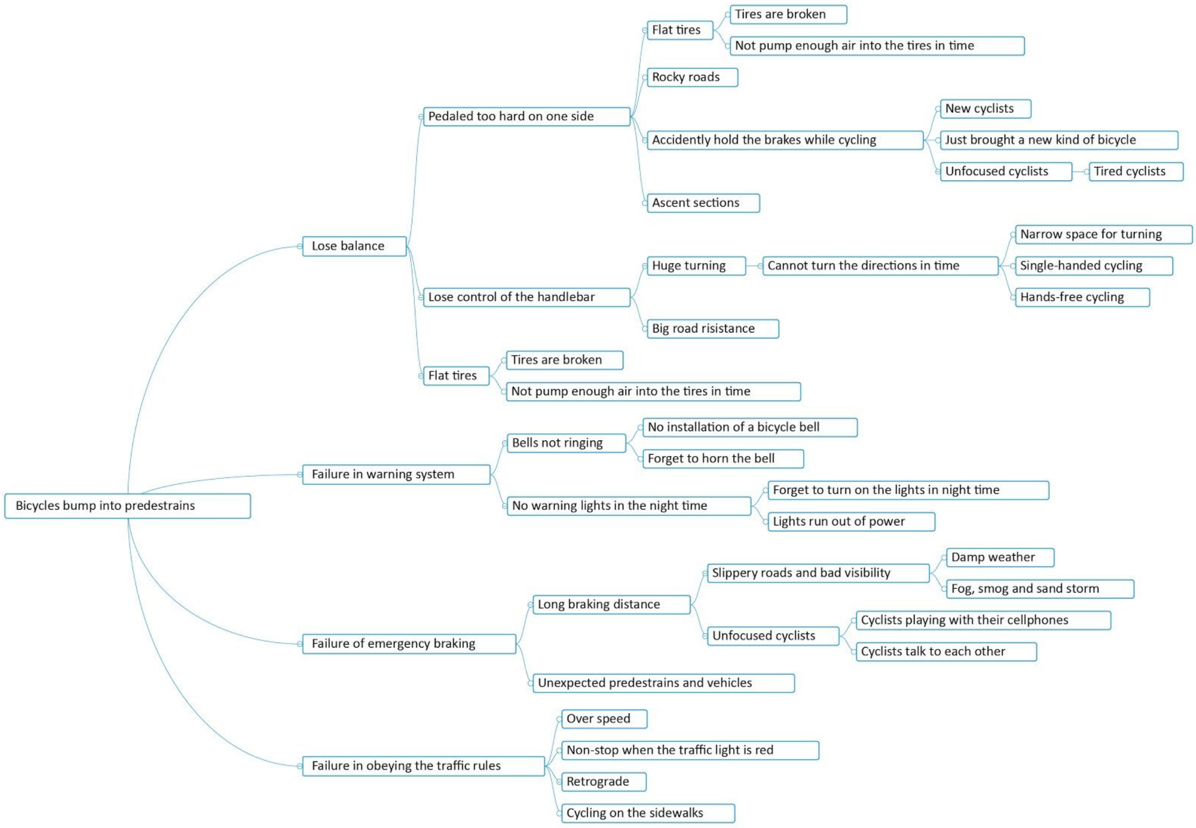
		sharp edges, chain-guard and stabilizers.
ISO-EN 11243	Cycles. Luggage carriers for bicycles. Requirements and test methods	This standard set requirements for bicycle luggage carriers. Safety requirements and also how to test them and rated test loads.
EN 15194:2017	Cycles. Electrically power assisted cycles. EPAC Bicycles	This European standard set requirements for electrically assisted bicycles known EPAC bicycles. Requirements based on safety are set for example for power drive, performance, brakes and battery.

Appendix 2. Fault trees for bicycle accidents.

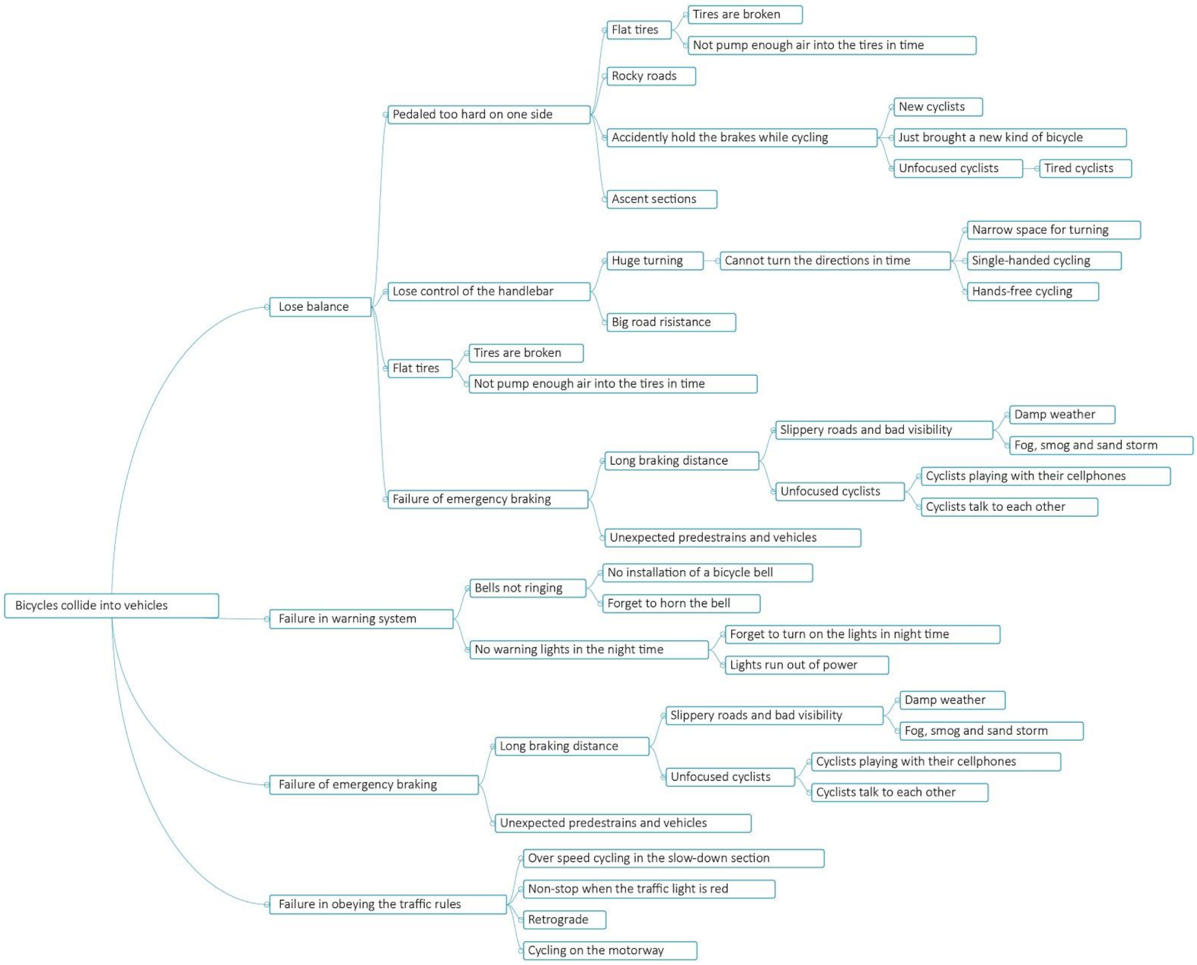
Bicycles collide into each other



Bicycles collide into pedestrians



Bicycles collide into vehicles



Appendix 3. *Traffic regulations concerning cyclists in the Netherlands.*

- Cyclists have to keep at the right side of the road.
- There are cycling paths that are compulsory and others that are optional (indicated by signs).
- It is not allowed to cycle on the pavement or other pedestrian areas.
- It is mandatory to indicate with hand signals the direction of a turn.
- Cyclists have to stop at a red light.
- Two cyclists are allowed to move side by side, but not more.
- Cyclists are allowed to take passengers on the front or back of their bikes.
- Children under the age of 8 must be transported in a child seat that complies with its respective safety requirements.
- Cyclists are allowed to listen to music.
- It is illegal to hold and operate any mobile electronic device while cycling.
- It is mandatory to hold the handlebars with at least one hand when cycling.
- It is illegal to cycle under the influence of alcohol or drugs.

Appendix 4. Safety cube analysis

Functional hazard assessment

Functional/malfunctional hazards or related hazardous situation	**Past**	**Present**	**Future**
Environment or supersystems for SoI	Damp weather like rain and snow tend to wet the machinery parts, which could make the bicycles are difficult to use and control. These can cause intense hazards.	Damp weather like rain and snow tend to wet the machinery parts and electric parts, which could make the bicycles are difficult to use and control. These can cause intense hazards. Weather could cause road conditions like traffic lights and the position of other bicycles or vehicles all blurry. Cyclists tend to misjudge the position or traffic lights. That could sometimes cause the hazards	Damp weather like rain and snow tend to wet the machinery parts and electric parts, which could make the bicycles are difficult to use and control. These can cause intense hazards. Cloudy weather could do harm to the electric and intelligence part of the system. Heavy cloud could cause malfunction of GPS, lead the cyclists misjudge the environment in front of them.
System of interest	Bicycles tend to be big-sized for the speed without the help of gears back then. The big-sized bicycles can be hard for short people to ride. They choose the inappropriate size for themselves. Sometimes it is hard for cyclists to control a bicycle has the size like that. Back then, people tended to assemble their bicycles on their own without any professional tools. The bicycles they assembled were not sturdy enough to anti-bumping. Therefore, hazards could occur.	Now, the maximum number of gears tend to increase, which makes the bicycles can go way faster than usual. The rapid speed can cause intense hazards People now still tend to assemble their bicycles on their own. The structure of the bicycles nowadays are quite complicated that normal people cannot assemble well even with the help of manual book and tools.Therefore, hazards could occur. To save money, people tend to repair the bicycles themselves. Sometimes the old issues are not being solved but new issues come up due to the unauthorized repair. These kind of behavior add the risk of the road hazards during cycling.	We assumed that the transportation system in the future will rely on the network because of the development of 5G. All the communication and information are exchanged through the Internet. It could cause hazards with if the Internet broke down, cyclists cannot receive all the information in time. Motivate system tends to break down. As the technology matures, the price of electric bicycles could get lower. And people could afford the electric ones. There will be more and more electric bicycles on the street. The functions of electric bicycle will be greatly influenced by the weather and other elements. To save money, people tend to repair the bicycles themselves. Sometimes the old issues are not being solved but new issues come up due to the unauthorized repair. These kind of behavior add the risk of the road hazards during cycling.
Subsystems or components	Without the organized	Front lights could easily go	Front and back lights would

of SoI	bicycle lanes, traffic conditions tend to be chaotic. There is no specific laws and legislation to protect the cyclists if an accident happens. Front and back lights would break. They won't be able to show the positions and the conditions during the night time. Brakes would be break. And it will be hard for cyclists to stop in time. It could cause really intense hazards. Gears tend to be broke. And it would be hard for cyclists to change gears in time. This situation happens to the bicycles from the 80s a lot. Bells could go wrong, which make it cannot serve as a warning	wrong if they are the ones that powered by the movement of cycling Front and back lights would break. They won't be able to show the positions and the conditions during the night time. Brakes would be break. And it will be hard for cyclists to stop in time. It could cause really intense hazards. Gears tend to be broke. And it would be hard for cyclists to change gears in time. This situation happens to the bicycles from the 80s a lot. Bells could go wrong, which make it cannot serve as a warning	break. They won't be able to show the positions and the conditions during the night time. Brakes would be break. And it will be hard for cyclists to stop in time. It could cause really intense hazards. Gears tend to be broke. And it would be hard for cyclists to change gears in time. This situation happens to the bicycles from the 80s a lot. Bells could go wrong, which make it cannot serve as a warning

Operational hazard assessment

Operational hazards(use/misuse) or related hazardous situation	**Past**	**Present**	**Future**
Environment or supersystems for SoI	Damp weather makes the road slippery, which makes the bicycles hard for cyclists to control. Windy and cold weather can make the cyclists wear thick clothes. They cannot move flexible when hazards happens. Cyclists talking to each other or seeing the views during the riding process. Unfocused cycling can cause damage as well. Sometimes It will happen to other people on the road as well such as drivers and pedestrians.	Damp weather makes the road slippery, which makes the bicycles hard for cyclists to control. Windy and cold weather can make the cyclists wear thick clothes. They cannot move flexible when hazards happens.	Damp weather makes the road slippery, which makes the bicycles hard for cyclists to control. Windy and cold weather can make the cyclists wear thick clothes. They cannot move flexible when hazards happens.
System of interest	Bicycle brakes experienced the transition from brakes on the pedals to the brakes on the handles. It will be hard for some cyclies to adapt this kind of transition. Big-sized bicycles might make cyclists uncomfortable, which will influence the speed of their reactions and movements. Cyclists tend not to pay attention to the road when they are cycling.	Cyclists tend not to pay attention to the road when they are cycling. Cyclists talking to each other or seeing the views during the riding process. Unfocused cycling can cause damage as well. Sometimes It will happen to other people on the road as well such as drivers and pedestrians. Now a lot of cyclists tend to ride without hands on the handle or a single hand on the handle. This can easily cause the bicycle to turn in a timely manner. And it would make the reaction time longer if the cyclists need to pull their hands out first. Though there's a law against using cell phones while cycling, there are still many people on the street behaving like that, which also can cause an accident. They might ignore the road sign such as the slow down sign, the speed limit sign, etc. which could cause tremendous accident if they ignored or neglected signs like those. They might speed up in the section where they are supposed to slow down. To save time, some cyclists	New system based on the Internet is quite difficult for some people to understand and use. It may cause misuse and hazards. With the universalization of the electric bicycles, the average speed will go up. And compared to the normal bicycles, the electric one are hard to control when it comes to turning and stopping. Though there's a law against using cell phones while cycling, there are still many people on the street behaving like that, which also can cause accident. They might ignore the road sign such as the slow down sign, the speed limit sign, etc. which could cause tremendous accident if they ignored or neglected signs like those. They might speed up in the section where they are supposed to slow down. To save time, some cyclists will continue crossing the road even though they see the red lights.

		will continue crossing the road even though they see the red lights.	
Subsystems or components of Sol	Unable to stop in time when something on the road like cars, pedestrians and animals, etc., comes up. Unable to cycle on the giant bicycles. Unable to adapt to the new brakes which are installed next to the handlebars. Unable to open the lights during the night time. Unable to turn smoothly. Unable to start riding without jiggling.	Unable to stop in time when something on the road like cars, pedestrians and animals, etc., comes up. Unable to open the lights during the night time. Unable to turn smoothly. Unable to start riding without jiggling. Unable to cycling without the navigation in a new place. Unable to read the meaning of the traffic lights.	Unable to turn on the network system to learn the road condition and to receive the information from the system. Unable to interact with the network system. Unable to read the meaning of the traffic lights. Unable to stop in time when something on the road like cars, pedestrians and animals, etc., comes up. Unable to open the lights during the night time. Unable to turn smoothly. Unable to start riding without jiggling. Unable to cycling without the navigation in a new place.