Safety Risks of Personal Urban Mobility and Accessibility

On the safety and risks in the development and design of the personal urban mobility and accessibility (PUMA).

Group 8 of the “Safety by Design” Course by dr. Rajabali Nejad

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1. Introduction

In the following report, a safety analysis is performed on the personal urban mobility and accessibility, for the course ‘Safety by Design’ by dr. Rajabali Nejad at the University of Twente. Personal Urban Mobility and Accessibility (PUMA) is a type of vehicle made by a joint project of General Motors and Segway. It is an upcoming trend in the innovative environment of big population centers in which a quick and reliable means of transportation is required. Characteristics of these are light, energy efficient and maneuverable, small vehicles suitable for an urban environment.

A number of these urban vehicles already exist ranging from the concept phase to existing designs already on the street. The accompanying safety measures required for vehicles are a well-known and important factor for traffic safety. Meaning that these vehicles transport people and goods in an urban environment, where human interactions with all types of traffic is frequent. The first step in the process of the safety design is mapping the existing regulations and rules for which an urban vehicle should comply to. Secondly, a number of models, figures and diagrams are employed to determine the risks, safety criteria and hazards of the newly developed model PUMA.

This report is divided into several subsections including a system analysis, in which the safety system is developed and elaborated upon. Here, the functions, requirements and the stakeholders at play are displayed. Furthermore, existing rules and regulations are discussed in the section of safety objectives, which also include new safety goals which arise in the design of the urban vehicles. After the system is established, all risks are mapped and categorized during its lifecycle. Subsequently, a system redesign is proposed for which a safety analysis is performed. Moreover, a total risk assessment is executed in which risks are identified by severity and frequency. The level of acceptable risk of the system functions is determined. Residual risks are accessed afterwards. As a final step, means of risk monitoring are proposed for the newly proposed system in which the human factors are also considered. A final conclusion is drawn in order to establish the safety system’s functions and overview.

2. System Analysis

In order to address the safety system at hand, an analysis is performed. The first focus is on the system concepts and its environment. Subsequently, the system's functions and requirements are defined across the entire lifecycle and past and possible future failures are mentioned. To finalize, all relevant stakeholders and their importance with respect to the (safety) system are briefly mentioned and displayed in a relationship diagram, revealing interrelationships between actors.

2.1. System concept and its environment

Urban personalized vehicles are becoming indispensable helpers for the transport industry and narrow infrastructures. They are used in order to move in an easier and faster way than a regular personal vehicle. Consequently, the fields of application of these vehicles are urban environments particularly the city centers of huge cities that suffer from traffic congestion where different types of vehicles (regular cars, trucks, bus, tramways…) share the road. Consequently, it highlights the importance of a safety system which assures an equivalent level of safety for the user as a regular personal car in order to develop this new personal way of transport. This system will be based on an ADAS (Advanced driver-assistance system) which through a safe human-machine interface will inform on road data and detect nearby obstacles or human error and will respond accordingly.

2.2. System functions and requirements

First of all, the structure has to be built in the most secure way possible for this type of vehicle in order to reduce or avoid most of the accidents possible. This function includes items like:

- Low center of gravity and high grip tyres for a better handling
- Bright colored vehicles with LED headlights to see and being seen
- Good mirrors and/or high quality cameras to reduce blind spot
- Seat belts and airbags in order to reduce deadly impact of the user during accident
- Structure with crumple zones which absorb the impact of a head-on collision

Secondly, in order to avoid unforeseen problems due to the vehicle, all the necessary information about the power supply and other technical information are collected and maintenance programs are orchestrated for reduce negligence :

- Sensors which informs on engine and battery status, brake wear and tyre pressure
- Develop system of vehicle rental where the rental company manages the maintenance and ensures for all the users a constant 100% operational vehicle

Then the vehicle collects data from the environment and the users in order to establish the safest way of driving. In consequence the system will help the driver or act in his place if there is a risk of collision:

- Environmental and Intersection scanner and Communication between other users to share data on weather and road conditions and plausible accidents so the driver is not surprised
- Alcohol lock to reduce impact of blood alcohol on the roads
- Adaptive headlight and Cruise control, Speed limiter with sign reading
- Lane Assist, Auto-Parking system,Blind Spot Detection
- Traction Control, Anti-Lock Braking System (ABS), Automated Emergency Braking

2.3. Relevant stakeholders

Stakeholders are any individuals, group or parties that have an interest in an organization/ product and the outcomes of its actions.

The (past and future) stakeholders that are involved in this project are listed in the following categories and analyzed below:

1) **Users**
    - (In)experienced drivers. They are stakeholders because PUMA is an easy way of transportation and it is a small vehicle which is easy to park.
    - High-medium income users
    - Urban travelers. They are stakeholders because one of the main functions of PUMA is that they offer faster urban transportation
    - People with mobility problems such as elderly people. They are stakeholders because PUMA provides an easier way of transportation.
2) **Legislators**
    - Government. They are stakeholders because they want to have sufficient law and regulations to ensure the safety of the urban vehicle and of the passengers.
    - Regional Authorities. They are stakeholders because they want to ensure that no traffic offenses and regulations are violated, endangering the life of pedestrians and of the passengers.
    - Municipalities. They are stakeholders because they want to ensure the safety of the environment.

3) **Operators**

- Public mobility operators. These stakeholders provide the services to rent/sell the vehicles to customers. These are in direct contact with the customers and need to provide the necessary services.
- Infrastructure management agencies. These stakeholders determine the type of road and traffic regulations, in combination with authorities, which the vehicles have to comply with. Providing the proper structure, ranging from roads, to loading docs, storage and parking spaces is a goal of this stakeholder.
- Maintenance companies. During the use of these vehicles, maintenance is the largest share of the costs. Structured and accessible maintenance companies, which might be part of the manufacturing companies, are an important part of the level of warranty and maintenance.
- Mobility dealerships. These stakeholders distribute and sell and or rent vehicles to customers or public mobility operators.

4) **Manufacturers**

- Technology suppliers. These range from developing new technologies for the required design to delivering existing simple technologies. These companies and organizations are interested in delivering the most optimal and cost-efficient technologies for the manufacturer.
- Vehicle manufacturers. Companies which build and manufacture the vehicles and its (sub)components. These are interested in fabricating the most market-suitable and cost effective product for the consumers.
- Energy suppliers. Given the nature of the electric vehicles, energy suppliers, in the form of (renewable) power supply are crucial for the working principle of these vehicles. These actors could jump into the gap of home charging and accessible supply points on the road.
- Insurers. Given the new nature of these vehicles, insurance companies are interested in setting up policies, regulations and insurances for users as well as producers.
- Car industry. These actors are involved because of the resemblance to car vehicles. Design and safety features of the body can be copied based upon the PUMA design.
- Distributors. These actors are at play during a wide variety of the stages of the process, including production supply, retail supply, delivery, maintenance accessibility and waste management supply. These are the links between a number of other actors and connected stakeholders.
- Recycling plants. During the final stages of the life cycle, these stakeholders are interested in reusing, repurposing and recycling the vehicles and its components. Given the nature of the system, a number of components are suitable for the aforementioned purposes.
- Waste management. These stakeholders manage waste streams during production as well as at the later stages of lifetime. Parts and components which are not useful for reusing, repurposing or recycling need to be addressed accordingly.

A stakeholders relation diagram is presented in Figure 1.

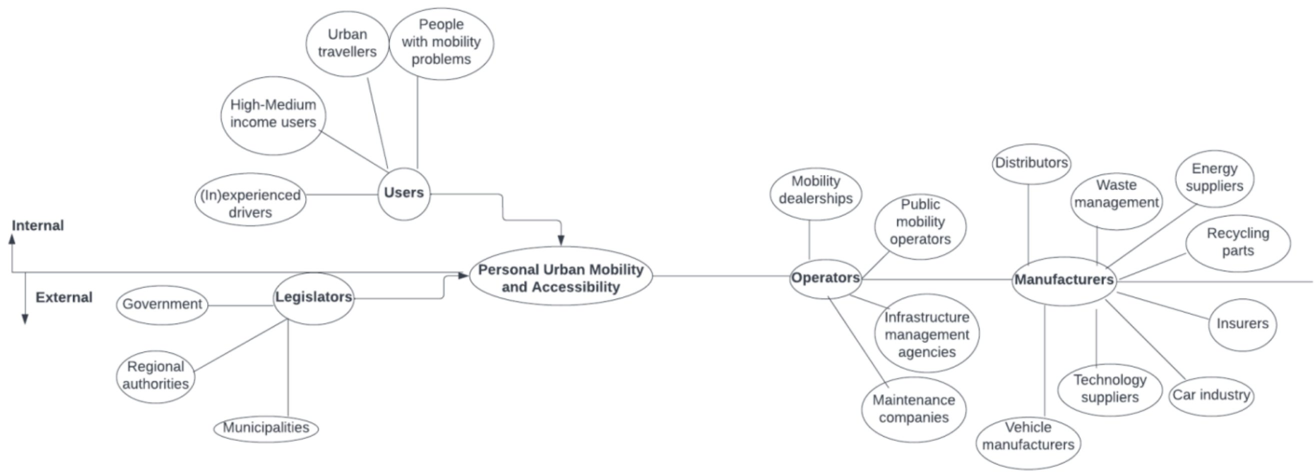

Figure 1: Stakeholders relation diagram.

A table has been made about the influence and importance of the different stakeholders and a justification is provided on these estimations , which is presented in table 1.

Table 1: The prioritization of the stakeholders.

Stakeholder	Estimated System Influence	Estimated System Importance	Justification
(In) experienced drivers	High(8)	High(8)	They are highly important and have a high influence in the project because PUMA is an easy way of transportation and it is a small vehicle which is easy to park.
High-medium income users	High(8)	High(8)	They are highly important and have a high influence in the project because PUMA is an expensive vehicle
Urban travelers	Very High(10)	Very High (10)	They have a very high influence and very important stakeholders because one of the main functions of PUMA is that they offer faster urban transportation
People with mobility problems	High(8)	High(8)	They are highly important and have a high influence because PUMA provides an easier way of transportation.
Government	Very High(10)	Very High (10)	They have a very high influence and are very important because

			they want to have sufficient law and regulations to ensure the safety of the urban vehicle and of the passengers
Regional Authorities	Very High(10)	Very High (10)	They have a very high influence and are very important because they want to ensure that no traffic offenses and regulations are violated, endangering the life of pedestrians and of the passengers.
Municipalities	Very High(9)	Very High (9)	They are highly important and have a high influence because they want to ensure the safety of the environment.
Public mobility operators	Very High(10)	Very High (10)	They are highly important and have a high influence because they are in direct contact with the customers and need to provide the necessary services.
Infrastructure management agencies.	Very High(9)	Very High(9)	They are highly important and have a high influence because these stakeholders determine the type of road and traffic regulations, in combination with authorities, which the vehicles have to comply with.
Maintenance companies	High(8)	High(8)	They are highly important and have a high influence because during the use of these vehicles, maintenance is the largest share of the costs.
Mobility dealerships	Very High(9)	Very High(9)	They are highly important and have a high influence because these stakeholders distribute and sell and or rent vehicles to customers or public mobility operators.
Technology suppliers	Very High(9)	Very High(9)	They are highly important because these companies and organizations are interested in delivering the most optimal and cost-efficient technologies for the manufacturer.
Vehicle	Very High(10)	Very High(10)	They are highly important and

manufacturers			have a high influence because they are interested in fabricating the most market-suitable and cost effective product for the consumers.
Energy suppliers	Very High(10)	Very High(10)	They are highly important and have a high influence because the nature of the electric vehicles, energy suppliers, in the form of (renewable) power supply are crucial for the working principle of these vehicles.
Insurers	Very High(9)	Very High(9)	They are highly important and have a high influence because given the new nature of these vehicles, insurance companies are interested in setting up policies, regulations and insurances for users as well as producers.
Car industry	Very High(10)	Very High(10)	They are highly important and have a high influence because of the resemblance to car vehicles
Distributors	Very High(9)	Very High(9)	They are highly important because they act during a wide variety of the stages of the process, including production supply, retail supply, delivery, maintenance accessibility and waste management supply
Recycling plants	Very High(9)	Very High(9)	They are highly important and have a high influence because given the nature of the system, a number of components are suitable for the recycling of the parts.
Waste management	Very High(10)	Very High(10)	They are highly important and have high influence because they manage waste streams during production as well as at the later stages of lifetime.

3. System (Safety) Objectives

Rules and regulations concerning the legislation

Regulations based on the European Union (Approval of the PUMA in European Legislation).The diagram below describes briefly the procedure of how the legislation works in the European Union.

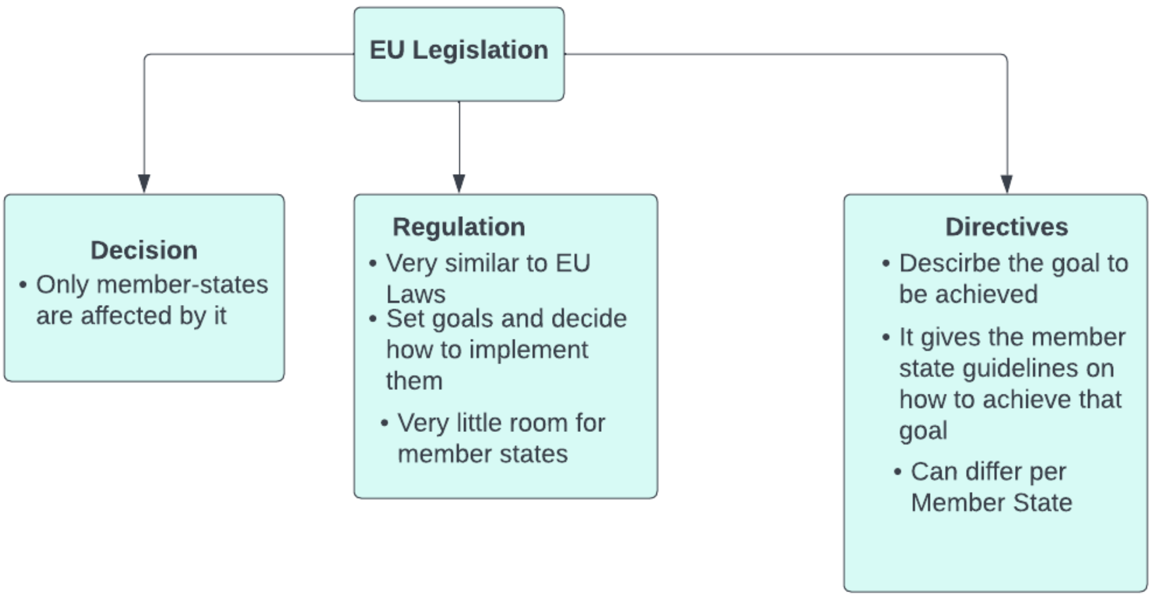

Figure 2: EU Legislation Chart.

More specifically:

- **Decisions** can only applied to the Member States that are described in the decision part
- **Directives:** Is the preferable way of the European Union, since it describes the goals that need to be achieved and it provides specific guidelines to each Member State.
- **Regulations:** It is a standard procedure where specific guidelines, laws and regulations must be followed by each Member-State.

Rules regarding bringing a new product to the market

When a company or entrepreneur wants to put forward a product to the market, the product has to meet certain regulations and laws which are set up by the European Union to ensure the safety of products but also encourage trading between EU countries.

In order to simplify the procedures, a guide named Blue Guide has been created by the European Union, which has become the main reference document explaining the procedures regarding EU Legislation. To be more precise, the procedure that the Blue Guide describes in order to follow EU Legislation Rules is described in the following parts:

Part 1:

First of all, the manufacturer has to carry out a risk analysis which is required to be in the technical documentation of the product. Then the manufacturer has to describe how the product will apply the essential requirements to fulfill the legislation procedure. The manufacturer chooses whether or not to apply and refer to harmonized standards. Furthermore, he needs to prove that the product is safe under the specific laws, regulations and standards of the Blue Guide.

The safety (present and future) goals of the PUMA are to be within the standards of the EU, by assessing possible hazards, and by identifying and mitigating risks.

Part 2:

The biggest part is the conformity assessment which contains a lot of procedures and technical documents. The technical documentation will be finished in the end and the conformity assessment will be complete. The second part takes place in the design and production phase and it is the manufacturers main responsibility to address all the requirements and directives.

The main parts of the procedure is described below:

Technical documentation: It is compulsory for a manufacturer because it contains information about the design, ways it was manufactured and operation of the product. The document must be kept for 10 years when the product is placed on the market. In the document it also has to register in detail which standards the manufacturer has applied.

EU Declaration of Conformity The manufacturer or the authorized representative has to sign the declaration of conformity and must contain all information to identify all parties. This happens before the product is on the market but at the end of the production and the design phase. The EU declaration of conformity must be kept 10 years unless it is otherwise indicated.

CE Mark It indicates the conformity of the product. The Union legislation provides for the CE Mark. It is a key indicator (but not necessary proof) of a product's compliance with the EU legislation. For this documents are made up which help by affixing the CE mark. Some products need other markings, such as marine equipment. The manufacturer or authorized representative affixes the CE mark. With the CE mark the manufacturer declares that the product conforms to all applicable Union Legislative requirements, and that the conformity procedures all have been completed. The CE marking may not be affixed until the conformity assessment procedure has been completed.

Part 3

When everything seems finished and checked, the manufacturer draws up the declaration of conformity which he declares his responsibility for the product. After a product is put on the market, the market surveillance will control that the product still meets the requirements and safety as it should be in the time when it was approved. When a product seems unsafe, market surveillance will make a recommendation of measures which ought to be taken. Safe guard will then judge this and take measurements if needed.

4. Risks during lifecycle

To identify the most important risks that the PUMA currently has, there can be looked at different types of stages in the lifetime. This is done in order to check all risks associated from start to end in a structured way. The risks are identified in order to check the feasibility of implementing the PUMA in the current market in a safe environment. For this, five stages have been chosen in the life cycle of the PUMA: Production, packaging and distribution, operation, maintenance and support and the disposal or retirement phase. Since the PUMA has not yet been implemented in the current market and there is not a lot of technical data available online, similar vehicles will be stated at first in order to determine the risks the PUMA would have if it were to be used in real life environments.

4.1. Comparable vehicles

First a check is done on what comparable vehicles that already exist might be out on the market in order to learn from the past. The hazards and risks that may be caused by these vehicles may also apply to the risks involved in the lifecycle of the PUMA. Therefore, six vehicles are looked at and briefly explained in table 2.

Table 2: Comparable vehicles to the PUMA.

	**Segway E110 Electric scooter** These types of scooters are small urban traditional scooters that can achieve similar speeds to the PUMA. It can carry two persons and is not very well protected from collisions. Therefore, these urban transportation vehicles can be seen as similar to the PUMA prototype.
	**Flinc-Ev Beach V5** This vehicle has 4 wheels, however can carry 2 people and in addition can only be used in urban areas due to a similar maximum speed limit as the PUMA. These vehicles are compact and are relatively similar to the PUMA, however these have 4 wheels.

	**Micro Microletta** This is a prototype scooter that has three wheels and can also carry 2 persons. It is compact and stable due to its three wheels and therefore does not depend (heavily) on stability control software, which may malfunction. It is in the similar speed range of the PUMA and is meant for urban use as well.
	**Lit motors C1** This vehicle also has two wheels and has software which enables it to balance on its two wheels. It is in the similar speed range as well, which makes it all very similar to the PUMA whilst rotating the axis of the wheels.
	**Segway PT i2 SE** The well-known Segway where the same control stability software is used as in the PUMA, however now the user is standing instead of sitting and it can only carry one person at the time. The similarity lies in the design of the two wheels next to each other and the stability control. These vehicles are banned in a lot of countries from the open road.

	**Segway Ninebot One S2** There is an upcoming market for the monowheels as well. Although it can carry only one person at the time, it is very small and compact and may achieve speeds of the PUMA as well. These types are already used in public roads where they also go through the safety checks, so it is interesting to look at the rules and regulations around monowheels as well.

4.2. Hazard Identification

A comparable, technical , functional and operational hazard analyses will be identified by using tables 3,4,5 & 6 by looking into the past, present and probable future risks. A comparable hazard analysis will be made on the Segway since the technology is very similar to the PUMA and may cause the same hazards. The technical hazard will focus on physical aspects and interfaces of the Segway. The functional hazard looks more into the working of the PUMA and all technical aspects associated with these functions. The operational hazard focuses on the aspects when the PUMA is being used and all effects it will have on or from the environment. These hazards will use different levels as the environment, the PUMA self and possible subsystems of the PUMA.

Since the PUMA does not yet exist on the public road (only in a practice test), one can look at similar vehicles to learn from the past. The Segways are the most common vehicles on the road since they are mainly vulnerable in the open road. However, they are (mainly) not used in places where the speed limit is above 30 km/h. Therefore, the possible hazards of mopeds and scooters are also taken into account in the comparable hazard analysis in order to correct for the speed limit that Segways do not encounter in their life cycle.

Comparable Hazard Analysis:

Table 3: Hazard analysis of comparable vehicles.

Comparable hazards of other similar vehicles	**Past**	**Present**	**Future**
Environment of similar vehicles	- Driving into pedestrians, because of crowded sidewalks. - Weather conditions cause wheels to spin. - Death by being hit by a car. - Falling off due to misuse of the product without wearing a helmet. - Driving off an altitude.	- Banned from most countries for road use. - Sidewalks may be crowded and can cause running into pedestrians. - Bad road maintenance causes accidents. - Person could not get a fine because of no laws or regulations when riding a Segway while being intoxicated.	- Crowded sidewalks may cause accidents with pedestrians. - Weather conditions may decrease performance. - Bad road maintenance may cause accidents. - Users may drive into restricted areas. - People not wearing a (proper) helmet.
Similar vehicles	- Malfunctioning stability control may cause people to fall off. - Display may not function properly. - Speed limiter does not work properly. - Reduced performance due to cold weather affecting the battery.	- Malfunctioning stability control may cause people to fall off. - Display may not function properly. - Speed limiter does not work properly. - High center of gravity may cause instabilities in the user of the Segway losing control. - Reduced performance due to cold weather affecting the battery.	- Malfunctioning stability control may cause people to fall off. - Display may not function properly. - Speed limiter does not work properly. - Reduced performance due to cold weather affecting the battery.

Technical Hazard Analysis:

Table 4: Technical hazard analysis of the PUMA.

Possible hazards of the PUMA related to technical aspects.	**Past**	**Present**	**Future**
Environment of the PUMA	- Death by driving off a cliff. - Broken bones when driven through a porthole. - Death after being hit by a car. - Rain can cause slippery roads, which makes the braking distance longer.	- Personal vehicles are banned in a lot of different cities throughout the world. - Rain can cause slippery roads, which makes the braking distance longer. - Chance of collision with road users or other drivers of a PUMA. - Chance of collision in a crowded environment with pedestrians.	- Rules & regulations have to be made. Whilst other countries already banned scooters and Segways. - Driving when it is windy may cause instabilities. - Large water displacement on the street may affect the performance. - Rain can cause slippery roads, which makes the braking distance longer. - Change of collision with road users or other drivers of a PUMA. - Change of collision in a crowded environment with pedestrians.
PUMA	- Death by falling off a Segway. - Brain damage from falling off without a helmet on. - Malfunctioning stability control software causes people to fall off.	- Temperature dependency of the battery. - The PUMA has a high center of gravity and therefore the driver can have less control of the PUMA. - A low seating for the driver can cause additional blind spots.	- Emergency brake system failure. - Speed control system failure. - Not fast enough emergency braking - The PUMA has a high center of gravity and therefore the driver can have less control of the PUMA. - A low seating for the driver can cause additional blind spots. - Incorrect assembly of parts causing

			accidents.
Any subsystem PUMA		- Bad visibility on surroundings by no or bad mirrors. - Due to poor maintenance structural failure can occur, for instance bad tire profile.	- Bad visibility on surroundings by no or bad mirrors. - Due to poor maintenance structural failure can occur, for instance bad tire profile.

Functional Hazard Analysis:

Table 5: Functional hazard analysis of the PUMA.

Possible hazards of the PUMA related to functional aspects.	**Past**	**Present**	**Future**
Environment of the PUMA	- Cold weather can cause less performance of the battery, this can lead to reduced performance of the PUMA.	- Cold weather can cause less performance of the battery, this can lead to reduced performance of the PUMA.	- Cold weather can cause less performance of the battery, this can lead to reduced performance of the PUMA.
PUMA		- Overloading can cause longer braking distances. - Can drive without a seatbelt. - The power supply cannot be stopped. - Brakes do not work, so the PUMA can be stopped driving. - Electric shock due to high voltage electrical components.	- Overloading can cause longer braking distances. - Can drive without a seatbelt. - The power supply cannot be stopped. - Brakes do not work. - Electric shock due to high voltage electrical components.

Any subsystem PUMA		- Lights are not working, which can cause dangerous situations when road users cannot see the PUMA. - Power cable does not work, therefore driver cannot adjust driving speed and power steering does not work.	- Lights are not working, which can cause dangerous situations when road users cannot see the PUMA. - Power cable does not work, therefore driver cannot adjust driving speed and power steering does not work.

Operational Hazard Analysis:

Table 6: Operational hazard analysis of the PUMA.

Possible hazards of the PUMA related to operational aspects.	**Past**	**Present**	**Future**
Environment of the PUMA	- No training required - Bad weather conditions like fog can cause less visibility for the driver. - Other road drivers do not pay attention during driving which can cause dangerous situations.	- No training required - Bad weather conditions like fog can cause less visibility for the driver. - The driver has less focus, because of an incoming call, this can cause a collision. - Other road drivers do not pay attention during driving which can cause dangerous situations.	- Training (e.g. driver's license required). - Vehicles make less noise in the future. - Faster traffic can cause more serious accidents. - Bad weather conditions like fog can cause less visibility for the driver. - The driver has less focus, because of an incoming call, this can cause a collision. - Other road drivers do not pay attention during driving which can cause dangerous situations.

PUMA	- The driver has less focus, because of tiredness, this can lead to longer response time and longer braking distance.	- The driver has less focus, because of tiredness, this can lead to longer response time and longer braking distance.	- The driver has less focus, because of tiredness, this can lead to longer response time and longer braking distance. - Due to bad maintenance the PUMA can malfunction.
Any subsystem PUMA	- The driver does not use his seatbelt.	- The driver does not use his seatbelt. - The navigation system can be not user friendly and does not need to be used.	- The driver does not use his seatbelt. - The navigation system can be not user friendly and does not need to be used.

The different hazard assessments will be analyzed in chapter 6 for the present and future time frame. Thereby, also a fault tree is made which can identify hazards and risks. This is done for a collision with other vehicles and objects, because a significant number of hazards can cause a collision. A fault tree for a collision is presented in figure 3.

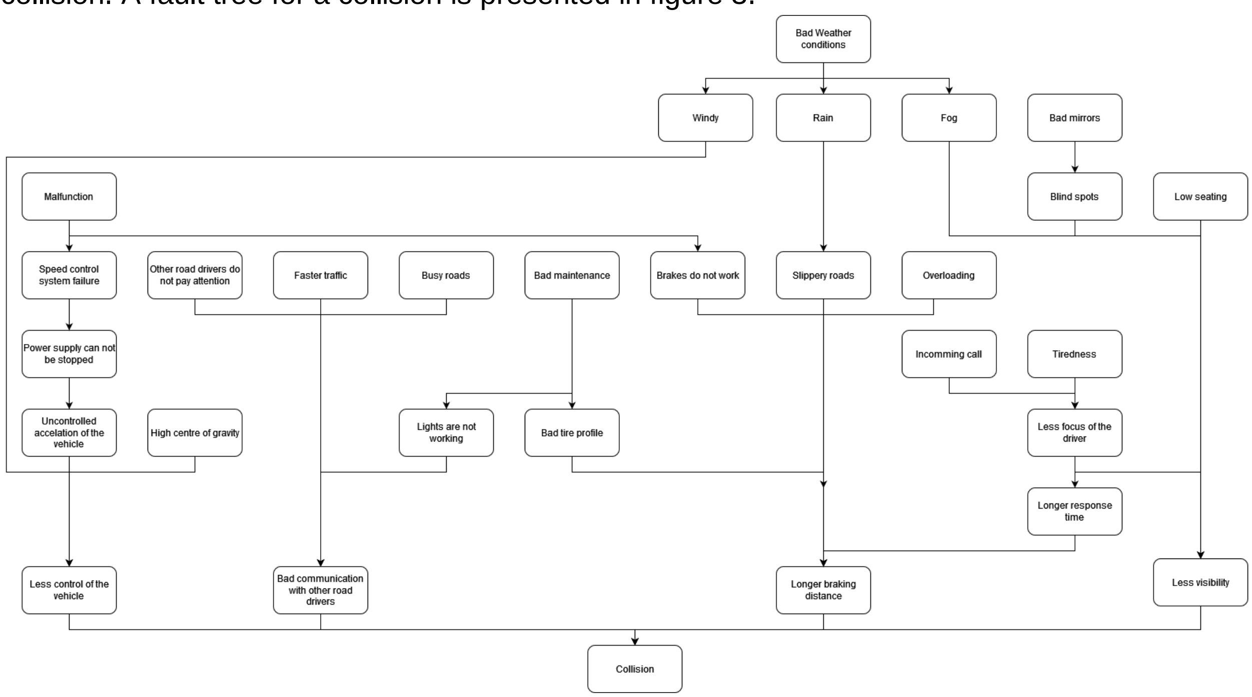

Figure 3: Fault-tree of causing a collision with the PUMA in its environment.

4.3 Production, Distribution, Maintenance and Disposal

During the different phases besides the operational risks that have been discussed before, risks and hazards may also occur in the whole lifecycle of the PUMA. Starting with the production phase, where mainly the assembly of the PUMA will be taken into consideration. These risks may be:

- Objects falling on top of one of the employees (by another employee)
- Malfunctioning machinery that causes an injury
- Electric shock
- Fire hazard
- Getting compressed
- Collisions with vehicle or crane with employee
- Chemical hazards with paints or battery fluids
- Fatigue of employees
- Bacteria/viruses contamination of other employees

Also during the maintenance of a PUMA vehicle, the employees are endangered to certain risks:

- Malfunctioning machinery that causes an injury
- Electric shock
- Fire hazard
- Chemical hazards of e.g. battery
- Fatigue
- Possible bacteria/viruses contamination of other employees

There has to be noticed that most of these hazards are not related to the design of the PUMA itself (instead of the battery and paint), but more to the design of the working environment. The PUMA still handles the production and maintenance environments and is therefore relevant to mention in the overall risks involved in the lifecycle of the PUMA.

For the disposal phase of the lifecycle of the PUMA, the main dangerous component is the battery which contains hazardous materials. The disposal of lithium ion batteries should be handled with care and must be stored in a safe space. The batteries should be packaged in safe materials in order to make sure that the battery does not rupture, catch fire or explode. Recycling of the batteries must be performed by educated professionals with the use of specified insulated tools. If recycling of a battery is done improperly, the specialist may be exposed to harmful and toxic gasses and fumes coming out of the battery casing. So the main risks of the disposal phase can be summarized:

- Toxic release of contents battery to environment
- Toxic release of harmful fumes or gasses
- Fire hazard
- Electric shock hazard
- Explosion hazard
- Contamination of groundwater or soil

5. System (Re)design

The Segway PUMA has many technologies to maintain the occupants safe, but all the systems depend on one feature in the car, the balance. The balance is important due to maintaining the occupants in a correct posture and providing the correct stabilization for handling. This balance is made by a dynamic stabilization system. This is the sub-system that will be analyzed.

This system (also called body-sensing or Segway) is based on a two-wheel self-balancing vehicle, and has a simple structure, with flexible movement and an essay driving (in many cases and also in Segway PUMA, the driving is autonomous). Also, meets the needs of energy saving and environmental protection. To have a correct function of the system, it's based on "dynamic stability", this system has a gyroscope (device containing a rapidly spinning wheel or circulating beam of light that is used to detect the deviation of an object from its desired orientation) and acceleration sensor in order to detect the change of vehicle attitude, and also a servo system (used in a variety of application such as robotics, industrial automation, and others) is used to adjust the motor for a balance system.

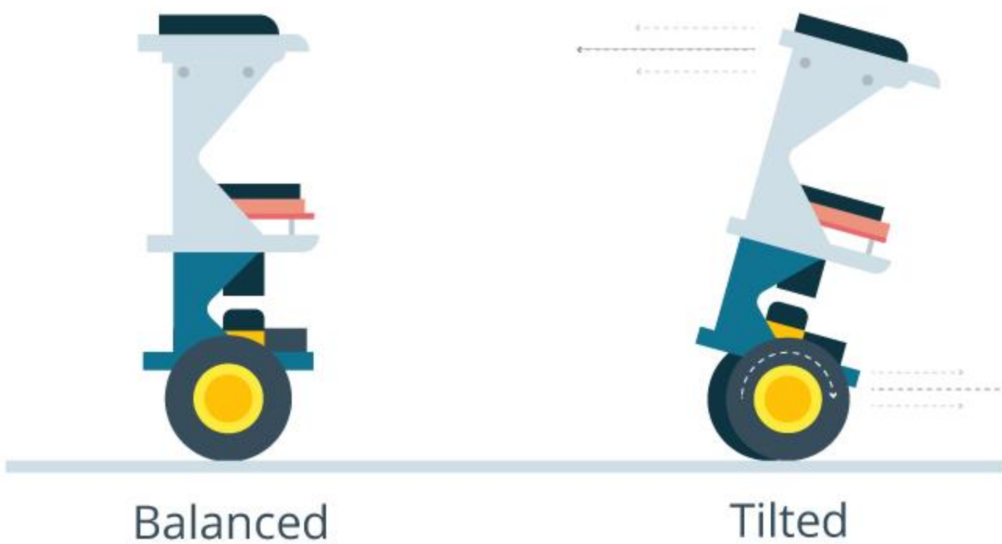

Figure 4: Balancing system.

To have a better comprehension of how the system works, everything starts with the gyroscope which detects the change in the gravity center of a human body (being in the case of the Segway PUMA the occupants). After the fast calculation by a single-chip microcomputer, the motor is driven to make the balance vehicle advance or retreat with the turning realized by direction calculation. This means that the motor works to go backward/forward/in the left and right direction to get the balancing vehicle.

But there is no system exempt from failure, and there are situations where this system can malfunction, and the PUMA can lose its balance and cause an accident. To reduce this or eliminate it, 2 different actions will be implemented.

First of all, is the utilization of various dynamic stabilization systems. There are going to be 3 of this system, just in case the first one fails, it's another backup, and so on. Also, if these 3 systems fail, a mechanical system is going to be put in.

This system is comparable to the one that has the luxury brand of the Japanese car manufacturer Nissan (In terms of decreasing the malfunction). The development of a steering without mechanical linkage like the steer-by-wire system.

Figure 5: Scheme of the steer-by-wire system of Infiniti.

This technology will permit a quicker and more precise steering response, keeps vibrations from the road from annoying the driver, and improves the car's active lane control system. Eventually, it will offer weight savings, reduce maintenance costs, and make designing autonomous cars a lot easier. Moreover, the electronic boxes that manage the control system are placed in three or four identical copies, connected in parallel, to avoid any loss of signal or malfunction. (Like the dynamic stabilization system in PUMA)

In addition, in an environmental way, the creation of a modular structure with constantly updated parts reduces planned obsolescence and extends the life of a product. That will permit easy maintenance and future improvements to comply with updated ISO standards and future environments. This system was inspired by the Mobilize Duo, a future city way of personal transport managed by a branch of the French car manufacturer Renault.

Figure 6: Mobilize Duo

This future electric powered quadricycle will be proposed only by long-term rental to constantly update the components in the future and most of all to reduce the pollution impact in the environment. As the vehicle has to come back to the company at the end of a rental the company will control its complete recycling in contrast to a traditional car wreck.

6. Risk Assessment

This section focuses on the mapping of risks, their frequency, severity and detectability. This provides the system designer with an overview of the hazards so targeted solutions to these safety hazards can be applied appropriately by the designer.

6.1. Risk assessment and acceptance criteria

In order to classify risks and to conclude if hazards will occur, a so-called Failure Mode Effect Analysis is performed (FMEA). Three distinct indicators are set-up and values assigned to each indicator. This is done by first constructing a risk severity matrix; How impactful and severe is a risk and what are the consequences. Secondly, a risk occurrence matrix; How frequent do risks occur. These range from very frequent to impossible. Finally, a risk detection matrix is constructed to display the chances of detecting hazards. All of these matrices produce a single value which is multiplied to quantize the final ‘risk’ value. A higher value corresponds to a serious risk issue, whilst lower values are less significant. Loosely following ISO 26262 as a checklist for the FMEA, possible hazards and risks were identified. Note that these matrices only attribute to a very general and superficial classification of risks and are subject to variability and subjectivity.

Table 7: Risk severity matrix.

Severity	Implications	Factor
Negligible	Not resulting in a loss of workday / working hours. Financial losses < €10,-. Minimal environmental damage.	S1
Low	Loss of workday / working hours. Financial losses between €10,- and €100,-. Repair necessary, very mild injuries. Low environmental damage.	S2
Moderate	Loss of workday / working hours. Financial losses between €100,- and €1000,-. Repairs inevitable, small injuries. Medium environmental damage.	S3
Critical	Loss of workday / week. Financial losses between €1000,- and €10000. Repair or new vehicle necessary. High injury probability. Significant environmental damage. External injuries	S4
Maximum	Loss of life, chronic injuries, Financial losses up from €10000,-. Vehicle totally crashed. External casualties. Total environmental destruction.	S5

Table 8: Risk detection matrix.

Detectability	Implications	Factor
Impossible not to detect	Blatant obvious warnings to help detect.	D1
Easy to detect	In plain sight, easily recognizable.	D2
Hard to detect	Requires investigation but accessible for the user. Maintenance should detect this.	D3
Extremely hard to detect	Requires specific knowledge of the user. Maintenance can miss this.	D4
Impossible to detect	Not visible/detectable. Maintenance will miss this.	D5

Table 9: Risk frequency matrix.

Frequency	Implications	Factor
Infeasible	Never occurs, impossible to occur. Risks that are not possible or eliminated entirely	F1
Improbable	Might not occur during the lifetime of the product and/or user. Very unique cases, extremely unlikely to happen	F2
Occasional	Plausible to occur during lifetime of product and/or user.	F3
Probable	Plausible to occur multiple times during lifetime of product and/or user.	F4
Frequent	Will most likely happen multiple times during the lifetime of product and/or user.	F5

Analyzing the FMEA shows the most important failure modes, which are loss of control of the PUMA, less visibility, less focus of the driver and bad communication with other drivers. All these failure modes have significant high RPN value, because of their high severity. Thereby, the potential causes of these failure modes will occur often during the lifetime of the product. Besides, the detection of these potential causes is also very hard.

Table 10: FMEA of the PUMA.

Function	Potential failure mode	Potential effect of failure mode	Severity	Potential causes	Occurrence	Means of detection	Detection change	RPN
Weather	Los of control of the Puma	Collision, go off the road or tumble over	4	Windy weather conditions	5	Movement sensor	3	60
Weather	Less grip of the wheels	Collision, go off the road or tumble over	4	Rainy weather conditions	5	Rain sensor	2	40
Weather	Less visibility	Collision or go off the road	4	Fog	5	-	4	80
Weather	Battery life will decrease	Collision	4	Cold weather	5	Temperature sensor	2	40
Design	Blind spots	Collision	4	Bad mirrors	3	-	4	48
Design	Blind spots	Collision	4	Low seating	3	-	4	48
User	Less focus of the driver	Collision or go off the road	4	Incoming call	5	-	4	80
User	Less focus of the driver	Collision or go off the road	4	Tiredness	5	-	4	80
User	Longer braking distance	Collision	4	Overloading	4	Weight sensor	2	32
System	Brakes do not work	Collision	4	Malfunction sensor braking system	2	Backup sensor	2	16
System	Brakes do not work	Collision	4	Power loss	2	Measure resistance over wire	1	8
System	Brakes do not work	Collision	4	Hardware failure	2	-	4	32
System	Uncontrolled acceleration	Collision	4	Malfunction sensor speed control	2	Backup sensor	2	16
System	Uncontrolled acceleration	Collision	4	Power loss	2	Measure resistance over wire	1	8
System	Uncontrolled acceleration	Collision	4	Hardware failure	2	-	4	32
System	Uncontrolled driving	Collision or go off the road	4	Malfunction sensor power cables	2	Backup sensor	2	16

Function	Potential failure mode	Potential effect of failure mode	Severity	Potential causes	Occurrence	Means of detection	Detection change	RPN
System	Uncontrolled driving	Collision or go off the road	4	Power loss	2	Measure resistance over wire	1	8
System	Uncontrolled driving	Collision or go off the road	4	Hardware failure	2	-	4	32
System	Air condition does not work	Overheating	2	Malfunction sensor temperature	2	Backup sensor	2	8
System	Air condition does not work	Overheating	2	Power loss	2	Measure resistance over wire	1	4
System	Air condition does not work	Overheating	2	Hardware failure	2	-	4	16
System	Heating system does not work	Freezing	2	Malfunction sensor temperature	2	Backup sensor	2	8
System	Heating system does not work	Freezing	2	Power loss	2	Measure resistance over wire	1	4
System	Heating system does not work	Freezing	2	Hardware failure	2	-	4	16
System	Fire	Die or get injured	4	Battery overheating	3	Temperature sensor	2	24
System	Fire	Die or get injured	4	Motor overheating	3	Temperature sensor	2	24
System	Fire	Die or get injured	4	Short circuit	2	Ground breaker	3	24
Maintenance	Bad communication with other drivers	Collision	4	Bad maintenance lights	4	Frequent quality check	3	48
Maintenance	Less grip of the wheels	Collision, go off the road or tumble over	4	Bad maintenance tires	4	Frequent quality check	3	48
Environment	Bad communication with other drivers	Collision	4	Other drivers do not pay attention	5	-	4	80
Environment	Bad communication with other drivers	Collision	4	Busy roads	5	-	4	80

6.2. Residual safety risks

In this section, an overview is given of the residual risks of the system under consideration. A categorization is made based on the following risk types: Eliminated risks, which should absolutely not occur and the designer should strive for a 100% guarantee that these risks occur during the entire lifecycle of the product. To be controlled risks are hazards that have a chance of occurring but should be dealt with accordingly. These risks should be controlled such that the consequences are minimal and solutions are in close proximity. To be communicated risks are part of the designer-user interaction and act as an information source of knowledge, expertise and skill to the experienced designer to the inexperienced user.

Eliminated risks (by the designer):

- Material failure. (Due to mechanical failure modes)
- Toxic chemical release of the product during production, operation and disposal.
- Not complying to prescribed regulations and certificates regarding safety.

To be controlled risks (by the designer):

- Crash safety protection mechanism. (seatbelt, airbag, distress signal, GPS tracking)
- Risk of environmental pollution during production, operation and disposal.
- Availability for maintenance part. (manufacturing route, availability of resources, accessibility of maintenance)
- Detection of failed vehicles during quality control.

To be communicated risks (to the user):

- Operation of the vehicle whilst driving. (Speed, controls, direction indication, breaking)
- Storing conditions for the vehicle. (Humidity, temperature)
- Refueling/charging the vehicle. (Which type of power/fuel, how to charge)
- Basic maintenance operations for the user.
- Maintenance recognition by the user. (identifying hazards)
- Digital safety of the vehicle. (Passwords/Locks, WiFi connections, software updates)

There is a large gradient in severity of the abovementioned risks. As stated previously in Section 6.1, the most severe, frequent and undetectable risks should be eliminated e.g. material failure. It is also trivial that a portion of the risks are inevitable and thus have to be dealt with by means of reduction, communication or solutions to consequences.

7. Risk monitoring and human factors

In this section, possibilities of risk monitoring are considered as well as human and socio technical aspects of risks are addressed.

7.1. Safety risk monitoring

It is never possible to resolve all safety related issues. Random chance, human error and several other factors contribute to a number of failure modes. Therefore, it is of importance that the system is monitored in order to act quickly and precisely whether the system fails. A distinction can be made between leading and lagging indicators. The former are used to address a problem or safety issue before the system fails and the latter indicates if the system has failed.

Under the leading system indicators we can share:

- Clear and extensive user manual of the system
- Proper training in order to use the system
- Registrations of location data and AI machine learning
- Implementation of real time monitoring system for the user
- Crash prediction and warning systems for the user

Under the lagging system indicators we can share:

- Registration of accidents by severity and frequency
- Analysis of testing and training accidents
- Customer complaints, requests and feedback
- Root cause analysis of the failed system

Investing in both a proper leading as well as lagging system indicators can benefit the safety of the system. Newer systems, such as real time monitoring and AI machine learning principles are from recent times and are at the disposal of the technology implementations and manufacturers. These could provide a new and better insight into the safety of the system. Big data analysis of accidents and incidents with the system could also benefit the total safety of the system. Note that these technologies will increase the complexity of the system, which will make analysis more complicated. In general, prevention is better than healing so the main focus should be on the leading system indicators.

7.2. Human factors and culture

The concept of a small vehicle that aims to transport people and optionally goods over small to medium distances is at the time of writing an understandable concept, especially in urban areas. Nowadays, streets are filled with speed-pedelecs, electric skateboards, Segways and comparable tiny vehicles. However, these are often not used correctly, misused or abused. Several accidents with fast moving people on these vehicles in combination with unaware fellow road users are notable. Especially in the Netherlands where e.g. helmet use is very uncommon, this can be a severe problem.

Geographical location is of great importance to be taken into account during the implementation phase of the PUMA. The most suitable locations are distinguished by their already existing and functioning infrastructure. Countries in Western-Europe, developed Asia, Oceania and North America are more compatible with the goal of the PUMA as a vehicle and means of transportation. To further zoom in, countries such as The Netherlands, Belgium, Denmark, UK, Japan and South Korea are most suitable for implementation of the PUMA given their level of infrastructural development and customer applicability.

A key player in the safety of the PUMA is the driver itself. Therefore, it should be determined if any required pre-knowledge is necessary in order to drive the vehicle, comparable to a driver license test for a simple car. Should the driver of the PUMA be in possession of a Dutch B driving license? And do neighboring countries agree to the level of skill of a driver license? Or should additional training be required for driving in a PUMA vehicle? These are all questions which are of importance when distributing a product over a number of countries and even continents.

On top of that, fellow road users have to get used to the presence of PUMA vehicles in traffic. They have to estimate the speed of the vehicle, its maneuverability, and driving style in order to make decisions when encountering PUMA vehicles. Just with the adoption of electric bikes under elderly citizens in the Netherlands, which causes an increase of road accidents, proper education and integration is required from both the user as well as the interactors of the system.

Possible misuse of the PUMA is exceeding the speed limit or road type on which the vehicle is supposed to drive. Neglecting functions such as direction indication and proper use of the (head)lights at poor visibility, such as evening and night-conditions, could be labeled as misuse. A number of cases of misuse of previous, comparable vehicles is extensive and a special case is the death of the owner of the Segway Company, who allegedly passed away after sustaining injuries from falling off a cliff using the Segway.

With the implementation of a futuristic looking vehicle comes a number of extra challenges to overcome safety-wise. Similar to self-driving cars, which are carefully monitored and scrutinized because of their new nature and unfamiliarity on the road, the PUMA will have to comply with strict safety regulations. Otherwise, parties such as the government and the media will (rightfully) target these vehicles, which can come at the expense of the development and implementation into society.

The increasing number of autonomous vehicles on the traffic scene, is a future scenario with which the PUMA vehicle has to deal with. However, the responsibility of autonomy lies within the autonomous vehicle itself and not with the PUMA vehicle. Further scenarios include special training for inexperienced drivers, such as people without a driver’s license, in the form of a practical test and or written examination.

8. Conclusion

Personalized urban vehicles are upcoming and the future of transportation of people and goods in urban areas and more specifically in narrow infrastructures so the safety aspects are of great importance. For this reason, the system in this report was based on ADAS (Advanced driver-assistance system) which includes a human-machine interface which will inform on road data and detect nearby obstacles or human error and will respond accordingly. In order to improve the safety of the vehicle the system's functions were built in such a way, to minimize the possibility of an accident. Furthermore, to reduce any unforeseen problems due to the vehicle all the vital information about the power supply, etc. are collected in order to reduce negligence. In addition, the main (past and future) stakeholders were identified, analyzed and categorized according to their influence on the system under design. Moreover, the rules and regulations concerning the legislation were identified and analyzed. Additionally, the risks of introducing PUMA in the current market were identified and a hazard analysis of comparable vehicles was conducted. Moreover, a redesign of the system was presented where Mobilize Duo a future electric powered quadricycle only for long-term rental to constantly update the components in the future and most of all to reduce the pollution impact in the environment. Additionally, a risk assessment was conducted, where the risks were mapped, as well as their frequency, severity and detectability. Finally, possibilities of risk monitoring were considered as well as human and socio-technical aspects of risks were addressed.

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