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Using the Safety Cube method and a Maturity Model for Urban Mobility to assess 6 categories of Personal Urban Mobility systems in the Netherlands

by

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Abstract The introduction of new types of innovative vehicles such as the hoverboard or monowheel in urban areas can raise questions in terms of regulation, safety and the future of urban mobility. In this research, 5 personal mobility vehicles currently acting in the Netherlands are considered, as well as a category of innovative vehicles. These vehicles are considered using the Safety Cube approach for their operational, functional and structural properties. From these properties, a Maturity Model for Urban Mobility (MMUM) is designed to assess their maturity in the Netherlands and to identify influencing factors when designing urban mobility systems.
Keywords: Safety Cube, Maturity Model for Urban Mobility, Innovation, Safety, Bicycle, E-bike, S-Pedelec, Segway, Stint

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Introduction

It's not an uncommon sight: congested cities, smog or traffic accidents. The way people have travelled for commutes or recreational use in urban areas has changed little in the previous century. Advancements in mainly electronics in the last 20 years have introduced new ways for people to travel about their cities. Entirely new concepts of vehicles are being introduced to the market, with examples of self-balancing Segways or hoverboards, futuristic looking bicycles such as the YikeBike (1) and adaptations of existing technologies such as the E-bike or electric skates/skateboards (2). These vehicles, or systems, are designed to give users a new definition of Personal Urban Mobility (PUM). Often times they are designed to be sustainable, non-polluting, safe, interoperable with other modes of transportation and easy to use.

Figure 1.1: Aftermath of the Stint collision with a train (3)

There is however a turn-side to these promising technologies. On 20 September 2018, an innovative system called a "Stint", carrying 8 small children, collided with a train after a brake failure (3). Four small children died, and the vehicle was declared illegal to use until further improvement of safety features (4). The following months, investigation was done and it turned out that some technical flaws were present in the design of the Stint.

Mainly from a safety perspective, it was interesting to consider the field of PUM with a structured approach. Regulation and legislation seem to lag behind the innovative character of these systems. Systems are often times not legal for public road use, despite the benefits they could offer in terms of sustainability or congestion. Through analyzing systems currently acting in the Dutch urban regions in a structured manner, the determining factors for PUM systems were sought after. This is to ensure that designers of future PUM systems account for all important factors, such that innovative vehicles can be implemented safely and successfully into the urban environment.

2

Theory and Methodology

2.1 Methodology

Here the used methods are described. Also, further definition of the Problem Statement, Scope and Definitions is given.

2.1.1 Problem Statement

The problem that is considered in this report is that of the introduction of new, innovative, vehicles into urban areas. Introduction of new systems into the urban environment compromises many influencing factors. Some are more important than others, and it is important to consider the implications of acting systems in terms of safety, sustainability and other important factors.

2.1.2 Scope of research

As there is a limited amount of time available for this report, the scope has to be properly defined. For this report, 5 PUM systems and one category of innovative systems in the Netherlands are considered. These systems are selected as they are currently being used in the Netherlands. The choice of systems exclude walking, handicapped vehicles, public transit, recreational vehicles, cars and other systems that make use of combustion engines. For these systems, the principal attributes are considered and rated for their maturity.

2.1.3 Definitions

In this report, the following definitions will be used for these terms:

- **PUM:** Personal Urban Mobility, compromising the whole of systems and users, excluding the modes of transportation mentioned above, that are providing transportation of people in an urban setting.

- **Success:** A system is said to be successful if it is commonly used, offers benefits to the user, is safe to use and has little disadvantages for the environment it is acting in.

- **Early adapter:** The definition as used by Plötz et al. is used (5): a substantial user group that is likely to be the first that embraces the use of a certain technology or system before the system is commonly accepted.

2.1.4 Research Questions

Qualitative research was done into the topic of PUM and its success factors. Following several research questions, a literature search was performed as well as an analysis with above mentioned Safety Cube approach and Maturity Model. The research questions originally were:

- **Main question:** What are the current challenges for the future of urban mobility?

  With the sub-questions:

- How is the system currently shaped in terms of vehicles, regulations and experiences?
- What are the past experiences with this system, and how has it developed over the years?
- How does urban mobility compare to other related systems/countries?
- How does the Safety Cube model these systems?
- What direction do the EU/NL regulation want to go, which goals are set?
- How could current challenges for urban mobility be overcome?

Above questions were further investigated, and were boiled down into below sections. However, during the course of the research maturity models were further looked into as they were not part of the original questions.

2.1.5 Literature search and model validation

Research was mainly done through literature search. Use was mainly made of the Google search engine in default settings and the Google Scholar search engine in default settings. Sources were reviewed, and used when sufficiently recent, relevant or otherwise useful. Literature on the bicycle and E-bike were redundant, but for other systems use was made of news articles. Effort was made to to use governmental websites for information on legislation and regulation where possible.

For the validation of the maturity model use was made of both semi-structured interviews with industry experts and a survey. For the interviews, one employee of Trek bikes Harderwijk (NL) and the owner of Dutch bicycle factory FixieBrothers B.V. were asked to give their thoughts on the maturity model (section 2.2.2), and how they would rate the systems. Also, their views on possible additions to the model and weight factors were part of the interviews.

The survey displayed the maturity model, the 6 maturity evaluations and asked the respondents two questions per analysis: is the system rated correctly according to you, and if they had any additions to the scoring or otherwise. Additionally, respondents were asked for their opinion on possible weight factors, and if they had any additions. More information on both the interviews and the survey can be found in Appendix A.

2.2 Theory

In this section, the theory used during the bachelor assignment is further explained. Use is made of both the Safety Cube approach, and a Maturity Model is come up with.

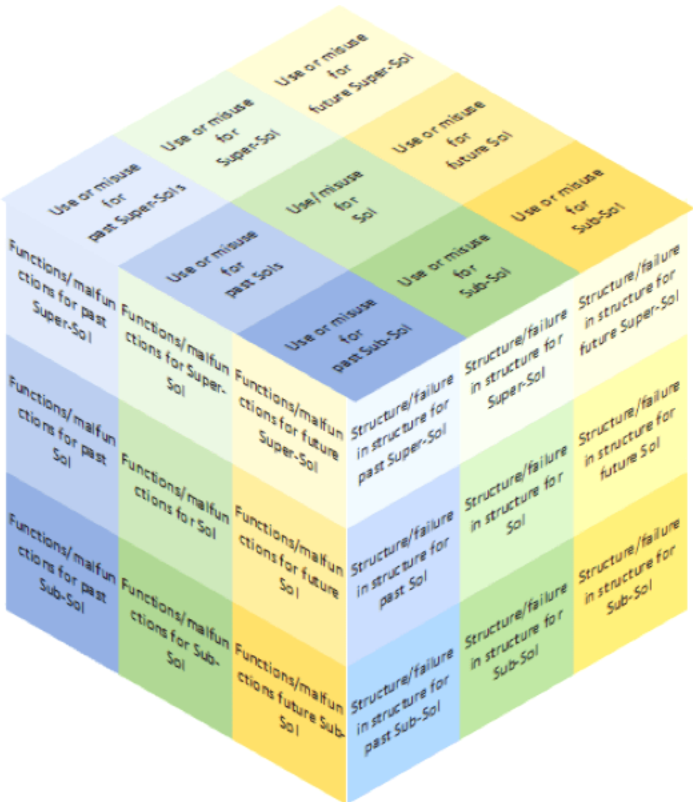

Figure 2.1: Safety Cube, with three different views (operational at top, functional to the left and structure to the right) and three columns per view for past, present and future (7)

2.2.1 The Safety Cube Method

The Safety Cube approach is a way to further incorporate safety in the design process (6). The Cube offers three distinct views over three axes, which helps contribute to safety by design, as it offers a holistic approach for designers. Although there are many models and approaches available to ensure safety of a system during the design process, safety is often regarded as a result of the design, and not a prerequisite of the design (6). Which of course, does not always yield the safest system possible. The Safety Cube approach tries to eliminate that effect, by considering the system over time and level of the system, but also the system in operation, the functional requirements and physical structure. In Figure 2.1 the Safety Cube is shown.

Axes and views of the Safety Cube

The Safety Cube offers three different views on safety by design for a system, over two axes. The Axes and the Views will be explained beneath, in addition with an analogy to a civil aircraft to further explain the functionality of the Cube.

As explained through the ISO12100 safety standard and the best-practices for safety, you can consider the system over two distinct axes: over time, and over the level of the system (8).

The Time axis can be seen as three different periods: the past, present and future. Design of systems is often for the present use, as they most likely will be used in the present or near-future. However, by including lessons learned from previous comparable systems (past), and by considering future developments or trends (future), the design can be better and more prepared for the future. In the case of the civil aircraft the time axis will describe how the system was built up in the past, how it currently is and which future trends predict how the system will look like in the future.

The System-level axis describes in what order of magnitude you're considering the system. Three distinct levels are presented by the cube: sub-system-, system- and super-system-level. The sub-system describes the components the system is comprised of. At system-level, you're only considering the system itself, the so-called 'System of Interest' (SoI). The super-system-level describes the environment the system is acting in. For the system that is the aircraft, the sub-system consists out of components of the aircraft (engines in the plane, landing gear, fuselage etc.). The super-system can then be considered to consist out of entities the aircraft is interacting with. Think of airports, flight control towers or international airspace.

Over the past, present and future, you can consider the system itself, but also the components (sub-system), and environment (super-system). This creates 9 parts of consideration for any view of the Safety Cube. For example, you can consider the past components of a system (engine technology in the 1920's) but also the future of a system (solar-powered aircraft perhaps? (9)).

Views

Next to the axes, there are also three different views of the Safety Cube. These views compromise the three elements that are common in any design or safety analysis. These elements are People, System and Environment (8). These elements respectively translate to the Operational, Structural and Functional view.

The Operational or People view describes the system structure in use. Basically, you're considering the SoI in interaction with humans. As users will not only use the system as intended, also foreseeable misuse has to be considered in the design process. For the civil aircraft analogy, the Operational view will give insight into how pilots operate the aircraft for example, or how passengers could interact with the aircraft. Misuse could include more innovative use of the system by the operators than was expected during the design phase or other.

The Structural or System view describes the system physically. The Structural view will describe the physical structure, interfaces among components and acting environment, and the competing or cooperating systems for the System of Interest. Additionally, also structural failures are discussed here. In principle, you're looking at the physical structure of the system, and its sub- and super-level. In the case of the aircraft for example, the Structural view would imply looking at the structure of the plane itself or its components, but also the physical interaction with landing strips and the luggage infrastructure. Structural failures imply looking at how the structure could fail, and what the consequences are.

The Functional view describes the functions and requirements of the system. The requirements and functions that the system will have to fulfill, play a large role in designing a system. Also attention is paid to malfunction. This view is especially useful when looking at designing systems for the future, as functions, requirements but also expectations of future systems can be easily thought of in the beginning of the design process. For the aircraft the Functional view implies looking at the things the aircraft should be able to do (fly, land, be capable of transport etc.). Here you can also set expectations for future designs (transport even more passengers on a single plane, more fuel efficient, makes use of this novel technology etc.). When looking at malfunctions, you're considering what possible malfunctions are, and how extensive they are.

Not only for the System of Interest, but also for its components and the environment it is acting in, you can consider its interaction with people, the structure of the system or the functions it should fulfill. Combining the Axes with the Views of the Safety Cube, 27 points of consideration are present.

The Safety Cube for Personal Urban Mobility systems
The above theory on the Safety Cube can be applied for Personal Urban Mobility systems. First of all, it is important to clearly define the levels of the system, and the periods in time. Underneath you can find the three views for PUM systems.

For the Safety Cube analyses, systems acting in the PUM sector are considered. These are basically the vehicles that provide personal transportation within urban areas in the Netherlands. The sub-system-level of the vehicle will therefore be the components of these vehicles, from which follows that the super-system will be the environment the vehicles are operating in. For this environment, you can think of legislation/regulation, infrastructure, driving culture or environmental requirements in urban areas.

One could also consider the whole of PUM as a definition of 'system'. Each entity in the PUM domain would then be considered a sub-system component (legislative bodies, vehicles, users, roads), the system would in turn then be the whole of components acting together. The environment will then comprise of competing or interacting systems (public transit) and other factors influencing PUM at super-system level, such as trends. This is however beyond the scope of this research, and only the first definition for the system levels will be considered.

For the time-axis, three distinct periods in time will be used. For the present, the period of the last thirty years (1990's until present) will be considered. This is due to the fact that most current-day PUM systems (mopeds, (electric) bicycles, Segways etc.) are from this period. For the future, everything beyond the present-day is considered, with a close overlap with the near-future and the present however. This is due to the fact that the PUM field is changing rapidly at the moment. Near-future vehicles and regulations are emerging very quickly, thus influencing the present system. An example would be that legislation for PUM systems have drastically changed in the past years. Germany for example is allowing all electric vehicles for last-mile solutions (10). For the past, everything in terms of PUM before the 1990's is considered.

In Chapter 4 the Safety Cube method is used for different PUM systems.

2.2.2 Maturity Models

Maturity models are a way to assess how mature (i.e. capability, level of sophistication, competency) a certain area of consideration is based on some collection of criteria (11). Often times, a five level scale is used to assess the maturity. First introduced as a framework by Humphry in 1988 (12), the Capability Maturity Model Integration (CMMI) organization adapted it for various areas such as maturity for supplier management, people capability or cybermaturity (13). Since there are many models available for different areas of consideration, choice is made to design a new model for assessing the maturity for urban mobility.

As in line with general methodology suggested by De Bruin et al. and Becker et al., several stages in developing a maturity model should be distinguished (14) (11), as seen in Figure 2.2. Both papers suggest that when designing a maturity model for a certain area of consideration the stages of design should be: defining the scope of the model, compare with relevant models, design said model such that it answers the *why, how, who, to what result* questions. After that, 5 distinct levels are set up for the maturity, and are clearly labeled. These levels are then defined, and populated with some criteria for each maturity level.

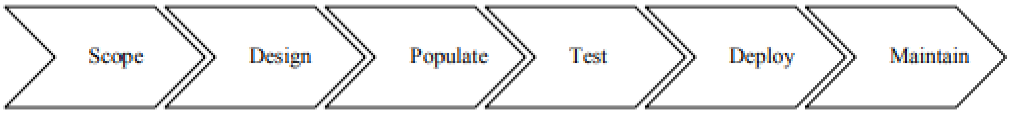

Figure 2.2: Stages for designing a maturity model, as by de Bruin et al. (14)

The Test, Deploy and Maintain stages are meant for the organizational application for the designed model. These steps ensure that the model correctly assesses maturity and will do so in future iterations. Becker describes some stages of implementation and evaluation that can lead to either the use or rejection of the model. For designing the model, only the first 3 stages are used as the latter stages are beyond the scope of this research.

As the Design stage determines how the model will look like, the Populate stage determines *what* determines the maturity of what is considered. Choice is made to follow the methodology as followed by Schumacher et al. (15). A Maturity Model for the Industry 4.0 readiness is proposed, and followed a similar methodology as with Becker et al. From comparable models and literature, attributes are found: measurable objects that influence the industry 4.0 readiness of an organization. These attributes are later grouped in categories, so called dimensions. For example, in the dimension People the attributes *ICT Competences of employees, openness of employees to new technology or autonomy of employees* are listed (15).

Similar to the dimension-attribute method is the method used by Mehmann et al., for their maturity model for crowd logistics (16). For the field of crowd logistics providers sych as Uber or Lyft, a case study and relevant models provided dimensions and attributes for those dimensions that should be fulfilled to reach a certain maturity level. For the dimension *market*, the attributes *Regional, National, International or Worldwide* are assigned to maturity levels 1 through 4. Meaning that if the crowd logistics provider operates at national level, a maturity level of 2 is attained for the market dimension.

The MMUM that is designed for this research can be found in Section 4.3. There, the *scope, design and populate* stages are gone through.

3

Description Past and Current System

When using the Safety Cube Approach, insights on the past, present and future systems are required for the analysis. In this section, a description of past, present and future urban mobility is given.

3.1 Past Systems

Personal urban transportation has seen many different forms over the past centuries. With advancing technologies came new vehicles which were safer, faster and more readily available. First examples of urban mobility came around the 19^{th} century, when the working class lived close to their working place, so the commutes where short-distance. Most of urban transportation was done by walking, and later on by the early examples of mass transportation such as the omnibus service, which was basically a horse carriage taxi service in the city (17).

Personal urban mobility came into existence around this time, with the first example of personal urban vehicles probably being the Laufmaschine, a two-wheeled wooden walking-bike in 1816 (19). Although clumsy in use, it offered greater personal mobility than walking. Over the following century, personal transportation vehicles were adaptations of the Laufmaschine with improved components such as pneumatic tires, spokes in wheels, chain driven propulsion or added wheels for balance as can be seen in figure 3.1.

In the late 19^{th} century the *Safety Bike* was introduced, which is similar to the bicycle we know today (20). The Safety Bike was safer through the use of smaller wheels and the use of a chain-driven backwheel, which made it popular for a larger portion of the population (21). Most versions of personal transportation were human-powered up until this point, meaning there was little to no use of engines, be it internal combustion or electrical. First examples of personal mobility systems with added engines would either be safety bicycles outfitted with small steam engines, or later the Butler Petrol Cycle in 1884 from England (22), or the Daimler Reitwagen in 1885 from Germany (23). These vehicles were state of the art for the time, ensuring a quicker ride to your destination than any bicycle at the time could. These vehicles evolved further over the years, becoming closer and closer to the motorcycle we know today. Although the motorcycle can be considered personal transportation, it is beyond the scope of this research as it is not urban transportation per se.

In the second half of the 20th century personal urban transportation consisted mainly out of walking, cycling or the use of mopeds, small motorcycle-like vehicles with limited engine size and fitted with bicycle pedals. The most notable moped would be the VéloSoleX, produced after the second world war by the French Solex company (24). The VéloSoleX ("Solex") offered economical and efficient personal transportation for the general public, and over the years that followed many comparable designs from different companies were produced. Generally the moped-class vehicles had a two-stroke engine of up to 50 cm^3 and limited speed of up to 45 km/h. The moped became popular, as it offered effortless and comfortable rides to your destination. Side-effects of noise and air pollution were not considered as big an issue as nowadays, where they contribute significantly to urban air pollution (25).

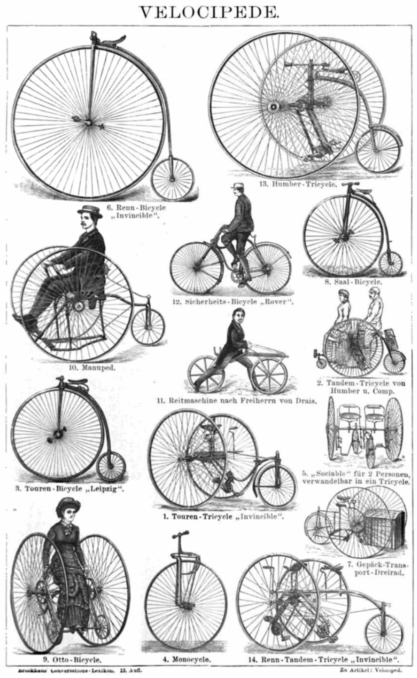

Figure 3.1: German Enclopedia from 1887 showing different varieties of bicycles (18)

The earliest form of Dutch regulation on the field of transportation would be the Motor- en Rijwielwet 1905 (26). This was general legislation which unified the legislation for Dutch road use.

After the Motor- en Rijwielwet 1905 the Wegenverkeerswet (Stb 1935, 554) was introduced, on which the current Wegenverkeerswet 1994 (WVW) is based. The latter is still in use today. The WVW is the current basis for all traffic in the Netherlands, although many regulations following the WVW are defined elsewhere. Further regulations are generally dictated by *Algemene Maatregel van Bestuur* (AMvB) in Dutch Law. These are mainly regulations on how to execute the legislation, with further details on who is authorized for certain actions, and what is meant more precisely by the general legislation. This structure is used, as the general legislation does not need to be in full detail, and AMvB's are easier to adjust quickly (27). An example for the AMvB within the WVW domain would be the regulations on Trafic Rules and Signs 1990 (*Reglement Verkeersregels en Verkeerstekens 1990*) (28).

3.2 Current Systems

In the past century, the type of vehicles have not changed much. The vehicles existed out of cars, bicycles and moped-related vehicles. In the past 20 years however, completely new types of vehicles were introduced to the global markets, and legislation and regulation have known to be lagging behind, as mentioned in the infrastructure 2018 budget (29). Primarily advancements in electrical components made two new system types possible: the electrically powered bicycle, and a category of 'new vehicles'. The electric bike comes in two flavors nowadays, the E-bike and the S-pedelec, which is further explained in Section 4.1. The 'new vehicles' can include all types of system concepts, for example the Segway, mono-wheels, hoverboards, electric skateboards, electric scooters and many more. These 'new types' primarily make use of novel technologies, and are often designed to be interoperable with public transit and to be carried along when not used.

Personal urban mobility has been traditionally focused around the bicycle in the Netherlands, and as such the infrastructure and culture is adapted to cycling-associated vehicles (30). However, when introducing new systems to the Dutch cities, some difficulties may arise. This is mostly seen in the adaptive inability of legislation. Regulation for the Segway for example changed radically in the first two years it was introduced to the Netherlands, as people were unsure how to categorize the system and what place it had in the city infrastructure. When first introduced, the Segway was only allowed on pavements, but later became illegal for almost a full year before the vehicle was allowed on bicycle infrastructure (31). The same response can be seen at this moment, but with vehicle types such as the monowheel, electric kickscooter or hoverboards, which are currently not allowed on public roads whatsoever (32). These systems could offer benefits for problems such as urban congestion and pollution, but the cities and users have not yet adapted to them.

Figure 3.2: Yikebike, an electric 'bicycle' (1)

3.3 Comparison other European systems

Comparing the Dutch system for urban mobility with other European countries, little fundamental differences are found. This is of course explained through the fact that there are conventions and standards for things like traffic rules and vehicle structures throughout the European Union. Examples would be the overview of directives applicable for vehicles (33), or the similarity of traffic rules between member states (34). The differences that are present are small, and could be explained by the fact that the culture and infrastructure of each member state is slightly different from one to another. An example is the obligatory bicycle helmet use. In some countries it is obligatory (Sweden for children under 15, in Spain outside of urban areas), and in some it is not (35).

What is interesting to compare, is the way some countries handle the introduction of the 'new type' systems. Germany for example is allowing all Personal Light Electric Vehicles (closely related to 'new type') vehicles on the public roads in 2019. In Belgium also, electric kickscooters are allowed as a new form of urban mobility, in contrary to the Netherlands (36). In the Netherlands however, little is done for these 'new types', besides a petition to reconsider just that (37).

3.4 Future systems

3.4.1 Analysis of future regulation

When considering personal urban transportation through the Safety Cube method, not only the past or present are important to consider, but also the future. Whereas the past and present can be more easily analyzed through (written) documentation or observations, the future is not. As we have not attained the technology (yet) to predict the future, we have to rely on trends and expectations to analyze what the future will look like. Through current trends in the urban transportation sector and expectations for the future, the third column on the time axle of the Safety Cube can be analyzed. In this research, use is made of several official documentations put together by (inter)national parties. Problems addressed by these papers are on the subject on urban mobilization, and the current challenges the cities face: congestion, pollution and the introduction of new technologies.

Ministry of Infrastructure and Waterways 2018 budget

Every year, the Dutch ministry of Infrastructure and Waterways (IenW) publishes their budget for the coming year. In this budget, all money budgeted by the ministry is displayed per category. Categories range from Water Policy, public transportation and railways, to Meteorology, Seismology and Earth Observation. Per category is also explained to which goals the money is budgeted, and why money is spent this way. This is especially interesting when considering this budget looking at urban mobility. For this section, the 2018 budget was considered (29).

Notable is the fact that many areas in the budget seem to evolve around sustainability. Not only sustainability in the sense that PUM should minimize the output of greenhouse gasses, but also that IenW should work towards long lasting, technologically inclusive, solutions for mobility. In the Policy Agenda, IenW states that they should strive for sustainable mobility and work towards multimodality in mobility. Multimodal mobility implies interoperability, using different modes of transportation to reach the destination. Think of using both your bicycle, a railway and bus connection for your commute.

What else is interesting to see from this budget, is that the ministry also names a few examples on how to reach that sustainability. Firstly, in the Policy Agenda IenW states that tests and pilots on public roads are important for new technologies. Without adequate testing of new technologies in real-life scenario's, benefits and risks cannot be properly identified. This is mainly done by adapting regulation locally in such a way that testing on public roads is legal. Think of testing a new type of monowheel in a city by lifting the legislative ban and track results.

Secondly, the adaptive character of laws and regulations is discussed. IenW states in Policy Article 2 that some new technologies can be the reason to 'reconsider if policy and regulation still matches the technology' (29). Additional policy or regulations can be required, if emerging technologies change the urban mobility scene.

Thirdly, many projects are named specifically in the budget. Many examples are mentioned, but for the PUM most relevant would be the 100 million euro co-financing for cycling infrastructure. Mention is made that the bicycle plays an important role in reducing the CO_2 emission and thus improving air quality, and also contributes to door-to-door mobility in a multimodal mobility system. Another mention is made of on-demand transportation as a solution for urban congestion, but that is discussed in greater detail below.

European Commission Green Paper: Towards a new culture for urban mobility

A green paper is a "*consultation document issued by the government which contains policy proposals for debate and discussion before a final decision is taken on the best policy option*". Usually after a green paper a white paper follows, which is a step towards policy implementation (38). In September 2007 the European Commission adopted a green paper, in which the future of urban mobility for the member states is to be discussed: *Towards a new culture for urban mobility* (39). The paper was aimed to identify factors that currently hinder urban mobility, and how such hindrances should be overcome. The Green Paper sheds light on five major themes: congestion, sustainability, integration of new technologies, accessibility and safety (40).

The Green Paper begins with illustrating the importance of urban mobility, firstly in an economical sense and later on in a more sustainable sense. About 85% of the gross domestic product (GDP) of Europe is created in urban areas, and it is stated that about 100 billion euros are lost every year due to urban congestion (40). This is of course not beneficial to road safety and highly undesirable from an environmental and economical point of view.

When considering PUM in combination with congestion, the Green Paper suggests that promoting walking and cycling could be a large step forward. While the benefits of walking and cycling are obvious when looking at urban congestion, the paper mainly focuses on the prerequisites for promoting walking and cycling. These modes of transportation should be fully integrated in urban policies, making sure the infrastructure can handle the load and that the general public is properly engaged in walking and cycling. Interesting to note is that mention is also made of car-sharing as a possible solution for congestion.

When addressing the sustainability related solutions for urban mobility, a lot of attention is paid to green procurement. To look not only at the cost or emission during use, but to also consider the sustainability of the manufacturing process and other lifetime costs is advised. More interesting for personal urban mobility, is that the European Commission suggests to implement the use of new technologies, and adding incentives to use these technologies. Through tighter industry standards, (monetary) incentives for clean modes of transportation and exchange of best practices new technologies can make their entry in the cities.

Not surprising is also the fact that the European Commission also pays attention to multimodal mobility, although with a slightly different angle. They imply that the user should be able to make informed choices about the mode and time of travel through information systems. Information systems can be the key to achieve '*seamless connections between networks*' (40), and by doing so the infrastructure can be used more effectively, creating an extra supposed capacity of up to 30%. Implementing information systems can be the key to reaching multimodal mobility according to the European Commission.

Attention is also paid to the accessibility of urban mobility, especially for elderly or reduced mobility citizens. Personal (on-demand) mobility could be the key in achieving independence for these citizens, as well as cheaper collective transport solutions. These solutions should both be well integrated with passenger and freight transportation and be able to reach all points of interest for a passenger. Assigning dedicated lanes for systems that deliver collective transport could offer benefits to these citizens.

While the IenW recognizes the importance of safety on the road, the European Commission also includes the user in urban mobility. First and foremost is the suggestion on safer behavior. The Commission identifies traffic behavior as a major area of improvement. By implementing special road safety campaigns and training initiatives for younger users, urban traffic behavior can be changed for safer mobility. Although it is described as perceived safety and security, improved infrastructure and enhanced visibility, (lighting and visible enforcement officers) could lead to safer urban mobility. Interesting to note is that improving cycling infrastructure and pavements for pedestrians are mentioned by name, together with smart information systems for safety-based traffic management.

The Economist Intelligence Unit report on The Urban Transit Revolution

The Economist Intelligence Unit (EIU) does research and analysis for the Economist Group, which is a sister company to the known The Economist newspaper. With over 70 years of experience, the EIU provides businesses, governments and other organizations insight on the changing world, and the risks and opportunities that follow (41). In the Report on the Urban Transit Revolution (2016), mobility challenges are reviewed within congested cities (42). This is mainly done by performing in-depth interviews with city officials or experts in the field.

In line with the IenW budget, the EIU finds that city leaders are putting not only sustainability high on the priority-list, but also liveability. Citizens should live and work in a clean environment, and are therefore encouraged to cycle and walk more in terms of PUM.

The EIU also states that city leaders should be more effective with their means. The report identifies a problem when approving sustainable urban policies, as there is not enough support for the policy. Sustainable transportation policies are more likely to be approved, if there is sufficient and timely collaboration between private and public stakeholders and that it should be clear to the public that investments in infrastructure are beneficial to the economic growth of urban regions. Not only approving a policy can be a challenge, but also the focus of a policy is important. The EIU concludes that city leaders can be more effective if they construct a long-term vision which includes the requirements for the people, environment and budget, and stick to that vision. Also, focus should lie more on improving existing infrastructure as it's already there, instead of taking on new, ambitious and costly, infrastructure projects. By upgrading existing technology, and by applying proper maintenance and traffic management, significant improvement can be reached over a shorter period of time.

Interesting to note is that the EIU also mentions on-demand mobility and pilot projects. On-demand mobility is said to be able to fill the need in the first/last-mile areas of transportation, with some success through the Mobility on Demand project by the US Federal Transit Administration (43). On-demand mobility can offer a solution, as it makes public transportation more easily available for more passengers. Testing the results for these kinds of programs require pilot testing, the EIU also points out. You can only test for the unknown, if technologies are tested in a real-life environment. The example of Pittsburgh, Pennsylvania, is mentioned, where autonomous taxi services designed by Uber are deregulated such that the concept can be tested.

3.4.2 Future trend analysis

After considering a national document, an international document by the EC and a study by an international private organization, some general conclusions on the future for PUM can be drawn. Four common denominators have been identified from these papers on a regulative level, but also some for component, system and environment level.

Regulatory

Most notably is the fact that the future systems should be sustainable (29) (40) (42). Future personal urban mobility should not only make little impact on the environment, but also be durable and be able to withstand the test of time.

Secondly, future mobility should be safe (29) (40) (42). There is no room for unsafe modes of transportation in the future, as it induces both danger and unreliability to the urban environment.

Thirdly, future mobility should be socially and technically interoperable (29) (40) (42). Personal mobility should be available for any type of person, and be able to operate in combination with other modes of transportation ('multimodal mobility').

Lastly, future personal mobility should make use of some smart combination of new and existing technologies (40) (42). Introducing new information systems, technological advancements and supporting policies could offer great benefit. Especially when designed to be used with existing infrastructure and technologies, as there are still improvements possible on that area (40) (42).

Component-level

As stated in section 3.2, components are changing rapidly. Components make the use of smarter systems possible, which in turn could offer benefits in terms of sustainability and safety. Here it is also important to consider the ease of maintenance, as illustrated by Section 4.2.

System-level

When considering above section in context of the vehicles that make up PUM, there are some new suggestions that contribute to the success of future PUM systems. To start off with, vehicles should be in line with the above conclusions: vehicles should be sustainable, safe, interoperable and have some sort of combination of old and new technologies.

However, above section also suggests that the future of PUM is influenced by other factors. To begin with, urban mobility is likely to be a success if centered around walking and cycling (infrastructure) (40). These modes of transportation are an existing and sustainable technology, and could be easily further improved on by paying further attention to the infrastructure, related information systems and user behavior.

Extending on walking and cycling infrastructure is also in line with the beforementioned side-note. Improving on existing technologies could offer greater benefit than introducing entirely new infrastructure or technologies. This is due to the fact that implementing new technologies can be exciting and promising, but is also costly and untested on the other hand, which can yield unwanted results (42).

Another factor of influence is the application of public road tests or pilots. A new form of personal urban mobility cannot be tested for success by only policymakers or manufacturers. Innovations in vehicles, policies or a combination of the two should be extensively tested in a public setting to determine all possibly implications of introducing such a novelty to cities. Then, and only then, can an informed decision be made on whether or not the new vehicle or policy deserves a place in the urban transportation system in that form (42).

Finally, designers for future PUM systems should take into account multimodal mobility (39) (42). Strengths of different modes of transportation should be combined, and connections between these modes should be seamless. Personal transporters for example can be the most effective, if they can also be taken with you on the bus or train. This way, you combine the strength for your personal transporter on the first or last mile, while using the collective transit for larger distances.

Super-system-level

Some factors can also determine the success of a PUM vehicle, but act more on the environment level than the system level. Legislation and regulation is identified as an obstacle in some cases by the IenW (29). This is often due to the fact that there is no regulation in place for emerging technologies and policies, which can lead to awkward situations when these technologies fall under existing, general, legislation. This calls for situations where regulation should be lenient and adaptive to innovation. This is mostly reached by ensuring there is enough support from across all sectors for this technology, and there is some sort of long term vision that is followed for a longer period of time.

Another environmental factor for success is closely related to multimodal mobility, namely the use of smart systems (39) (41). Strengths of different actors in a system should be combined. By combining the strengths of users, vehicles, information technologies and policies, much more can be achieved than a single actor alone could. This calls for collaboration between stakeholders, and the sharing of knowledge (41).

4

Analysis

In this section, several analyses are performed for a number of PUM systems. For each vehicle, a description will give the background information needed for the Safety Cube analysis and the Maturity analysis.

In total 6 types of vehicles will be discussed in this assignment. These system categories include: bicycles, electric bicycles, Speed-pedelecs, Segways, the Stint and the category of 'new' vehicles. These vehicles are chosen to make up an as complete overview of the current urban mobility as is. Choice is made to consider only human-powered or electrical systems due to sustainability reasons described above. Also, walking is excluded from the analysis as this research is primarily focused on PUM systems. Next to that, some more recent additions to the urban mobility scene have been added in under the category 'new' vehicles, as they can provide precious insights on innovative systems.

4.1 System descriptions

Below follow the system descriptions for each category of systems. For each vehicle, context will be given on the definition used, the context in which it is used and some legal/regulative information.

Bicycle

Definition The systems considered to fall under 'bicycle' are defined to be human-powered, have two (spoked) wheels with rubber tires. The use of a bicycle safety helmet is not required by law, and neither is a drivers license or insurance.

The bicycle is probably the best known form of urban mobility, especially in the Netherlands. Cycling is seen as part of the Dutch heritage, with one explanation being the lack of hills and mountains in the Netherlands (45). Cycling popularity can also be seen in statistics, where 27% of all trips are made by bike, and on average 2.5 cycling kilometers per capita are made each day, both recreationally as commuting (46). For comparison, Denmark is second in both statistics with respectively 18 % and 1.6 kilometers.

The bicycle can be regarded as trusted technology in the Netherlands, as it has been around for many years and is embraced as a normal way of urban mobility. People (generally) know how to control the bicycle, and are familiar with owning one, consid-

Figure 4.1: Bicycle users in Amsterdam (44)

ering on average there are 1.4 bicycles for each Dutch citizen (30). Cycling is popular due to the benefits it can offer. The Dutch consider the bicycle to be healthy, cheap, relaxing and beneficial to the environment, as found by Heinen et al. (47). Comfort and aesthetics of cycling can also weigh in the choice of riding a bike, as found by Hunt and Abraham in a literature review (48). Used for commuting as well as for recreational purposes, the bicycle is mainly intended for the function of single-person mobility. In the Netherlands, road users are used to bicycles in traffic flows, and have relatively fewer accidents when compared to other countries (46). With examples ranging from dedicated bicycle lanes, (guarded) parking facilities and connections with other modes of transportation, the Netherlands facilitate the bicycle well (49). Additionally, the infrastructure is well intertwined with other modes of transportation (30) (50). Parking of bicycles, especially in public places, can be considered a challenge as there are some examples of shortage of parking spaces (50), or large investments in bicycle parking spaces at railway stations (46).

The bicycle as a vehicle is a fairly simple concept. Components are not high-tech, so when users interact with the components the engineering concepts are simple. This makes possible maintenance easy to do yourself. What is however interesting to see, is that maintenance is not always done (properly) despite this fact. Especially among recreational cyclists and teenagers the bicycles can be poorly maintained, accounting for up to 24% of accidents for that category (51).

Of course, the system should be safe to use, or 'deugdelijk' (sound/reliable) as often described in Dutch legislation. For example in the Vehicle Rule (*'Regeling Voertuigen'*), where the word is mentioned over 450 times (52). This implies that the functions of steering, braking, accelerating and visibility should be reliable, and the structure itself is sound and complies with safety standards (EN 14764 for the bicycle (53)). All these rules can be enforced, although not all rules are enforced fully. Cases of breaking traffic rules for example are seldomly enforced, due to the fact municipal law officers do not use their legal powers to full extent (54).

Cyclists are legally not considered to be motorists, but should adhere to the basic traffic rules and signs, as described in the Reglement Verkeersregels en Verkeerstekens 1990 (28). Misuse of bicycles is however also common, as antisocial driving behavior can lead to unsafe driving characteristics or unexpected loads for the bicycle itself, illustrated by news articles on urban safety or enforcement (55). An interesting legal aspect of cycling in the Netherlands, is that motorists should always drive in such a way that "minimizes the risk of injury for pedestrians and cyclists even if they are jaywalking, cycling in the wrong direction, ignoring traffic signals, or otherwise behaving contrary to traffic regulations.” (56). Basically, cyclists and pedestrians are protected by law when involved in accidents, especially when accidents involve children or elderly.

Electric Bicycle

Definition The systems considered to fall under 'electric bicycle' or E-bike, are bicycles with auxiliary electric power, meaning they have a motor and battery. Auxiliary power stops after after reaching the speed of 25 km/h, and the motor should have a maximum nominal power of 250W. After reaching the 25 km/h barrier, the E-bike is only human-powered. This is in line with the definition by the Rijksoverheid, as higher speeds or motor power make the bicycle in question fall under speed-pedelec regulation (57). Users of E-bikes are legally considered to be cyclists in the Netherlands, and adhere to the same traffic rules as stated under the bicycle. E-bike drivers do not need a license, no helmet is required, neither is insurance or a minimum age (58). Next to the above benefits, also the comfort and aesthetics that an E-bike can offer are important to consider (48).

Figure 4.2: Elderly person using an E-bike (59)

First introduced in the 1980's in Japan, E-bikes quickly rose to success globally in the early 2000's as electronics became cheaper and more advanced (60). The E-bike offered the benefits of cycling, and added in electrical power such that riding was less exhaustive and faster. The number of E-bikes worldwide has grown significantly in the last 20 years, with China being the largest market: sales grew from 40.000 units in 1998 to 10 million in 2005 (61). Growth has also been reported in other countries such as Switzerland (62), but also globally (63).

The E- bike can be considered to be an 'improved' bicycle. As such, the E-bike is especially useful for commutes (64), as it is both healthier and cheaper than driving a car. It is less used for multimodal mobility than the bicycle, as the E-bike can often easily cover the entire commute instead of parts of it.

The electrical power, which makes the use of the electrical bike less exhaustive, offers improved mobility for elderly (65). E-bike users are primarily elderly who use it for recreation, as it offers greater mobility for this user group that otherwise would have stayed at home. Sadly, this is mostly seen in studies on accidents or news articles (66)(59)(67). The electronics are also important to consider in use, as the charging behavior of the battery can greatly determine the battery lifetime (68). Self-discharge or being empty for too long can negatively affect the battery performance.

The soundness for the structure and safety standards are similar to a bicycle. For the structural parts the same applies as with the bicycle, but for the electronics a separate safety standards applies (EN 15194 (69)).

For the bicycle and the E-bike, the same legal advantage and forms of antisocial driving behavior (misuse) are found. The latter is however, slightly different, as user groups and speed give other implications for driving behavior. For example users are often elderly and are more vulnerable than other user groups due to larger response times or insecurities (67). Also, E-bikes can look like normal bicycles, but have much higher speeds. This can lead to undesired results, as other road users do not expect these speeds from normal cyclists (64). Furthermore, cases of 'tuning' e-bikes such that they can reach higher speeds are currently raising concern as a form of misuse (70).

E-bikes have to make use of the bicycle infrastructure, which is of high quality in the Netherlands. Parking can be challenging as well for the E-bike, because of the need for charging, preferably at the point of parking.

Speed Pedelec

Definition The speed pedelec (S-pedelec) is a type of E-bike, but with higher power and speed allowed. Also, additional regulation is in place. The definition of the S-pedelec as stated by the Rijksoverheid is similar to that of the E-bike, only differences are that the motor power can be up to 4.000W and that the auxiliary power does not stop after 25, but at 45 km/h (57). The same safety standard as with the E-bike applies (EN 15194 (69). Users currently need a moped drivers license, insurance and a special S-Pedelec approved helmet (NTA 8776 standard (71)).

Figure 4.3: The Stromer ST5 S-Pedelec (72)

The S-pedelec itself offers advantages over the E-bike, but due to an ongoing regulative discussion the sales of S-pedelecs seems to be stagnating, especially since the new regulative changes since 1-1-2017 (73) (74). Before 1-1-2017 S-Pedelecs were considered to be light mopeds (*'snorfiets'*), and were required to make use of bicycle infrastructure, have a blue license plate and insurance (75). The Fietsersbond however did not agree, as the high speed differences between the bicycle lane users and the S-Pedelecs were considered dangerous, especially in urban regions where there are many children and elderly (76). S-Pedelecs are now legally considered to be mopeds (yellow license plate), which means they make use of car infrastructure in urban regions, and bicycle paths outside of the cities where specified (77). The maximum speed allowed is 45 km/h, which is part of the ongoing discussion. This is lower than the speed of the cars on the road, which makes the S-Pedelec user feel unsafe and insecure. Also, the obligated use of helmets could subconsciously make users feel less safe, because why would you need a helmet if the system is safe to use (78)? On top of that, the speed of an S-Pedelec seldom reaches 45 km/h. Both the RAI association and the Fietserbond call for a tailored (regulative) solution for the S-Pedelec, as it is promising in solving urban congestion and reach sustainable commuting because of its speed (74) (76). On the other hand, the fact that the S-Pedelec has to make use of two different types of infrastructure depending on the traffic situation is also the most notable reason for the lack of success in the Netherlands (73).

The S-Pedelec has the similar traits as the E-bike, it offers benefits over both the bicycle, car and E-bike as it is healthier than taking the car, goes faster than any bicycle without effort and has a high range. Also, comfort and aesthetics are familiar to that of the E-bike.

The higher speed of the S-Pedelec implies that maintenance is even more important than it is with bicycles and E-bikes. Additionally, a higher breaking power is necessary due to the higher speed.

Segway

Definition The Segway, or the category of self-balancing vehicles, are novelty urban vehicles which use an internal gyroscope to control the two wheels. Steering, accelerating and braking is done by shifting the weight of the user in a certain direction. The vehicle was said to revolutionize the world of personal mobility, and could prove viable in last-mile connectivity (32). Furthermore, the vehicle was said to be designed for small, urban, commutes and useful for indoor mobility (79)

Figure 4.4: Tour group using Segway Personal Transporters, from the Segway official website (80)

The Segway is an example of an entire new category of vehicles that was introduced to the Netherlands. First introduced in 2002 (80), the introduced technology of the Segway PT Transporter had no predecessor and offered a green solution for urban mobility (81). The Segway is an interesting system to consider, as it uses a whole new type of technology that legislation and regulation had not adapted for at the time of introduction. Interesting to note is that the vehicles were considered to be light mopeds ('snorfiets') up until 2007. After that, the vehicles became illegal for the public road. The vehicles were considered to be unsafe, and it did not fit into existing legislation as it uses a leaning system for braking, and no braking installation that was required for motorized vehicles (81). However, the vehicle was reintroduced in 2009, after a legal change. A new type of motorized scooters was introduced in legislation, such that more innovative vehicles can be allowed on the public roads, the so-called '*aanwijzing bijzondere bromfiets*' (82) (83). These 'special mopeds' (*bijzondere bromfiets*) require no EU type approval and can be approved by IenW, as each application for a special moped is considered individually. The Segway was allowed under this special moped regulation, meaning that the driver has to be at least 16 years old, no drivers license or helmet is required but the vehicle does need a vehicle identification number and insurance plate. Furthermore, the same traffic rules for the bicycle apply, and the Segway has to be properly visible at night and go no faster than 25 km/h (84). Additionally, it also had physical and electrical limitations that should comply with regulation as under the RVV1990 (28). Physically, the Segway uses available bicycle infrastructure, needs availability of charging locations and a place to park the system.

Although introduced in the Netherlands in 2007, EU standards did not start development in 2013 and were only finished in 2018 (85) (86). The system was a novelty to use. It used revolutionary technology at the time of introduction, and users were seen as early adapters (79). This caused the user base to be limited to a small group, until municipal services embraced the vehicle. The effortless and comfortable ride that was offered, was often seen as lazy (79). The users themselves can be considered inexperienced when compared to for example the bicycle. Also, other road users are unfamiliar with the Segways on the road.

Interesting thing to note, is that the modifying of Segways is hardly possible due to the advanced level of the components. Only examples of modified Segways are the fitting of larger wheels, thus making them go slightly faster (87).

Stint

Definition The Stint is an electric mobility solution by the Dutch company Stintum, which has 4 wheels, a standing driver position and a tub for transporting goods or up to 10 children (88). The Stint weighs about 220kg, and was able to reach a top speed of 17,2 km/h. The Stint was approved for the public road in 2011 as a 'special moped', although the vehicle's width of 110 cm was 35 cm wider than allowed (89). No drivers license is required to drive the vehicle, but it does need insurance.

The Stint was initially designed to offer a solution for transporting small groups of children from elementary schools to daycare locations, to replace often used taxi services that were expensive and congested the school areas (88). Next to that, the Stint also found use in other applications such as municipal cleaning, small mobile technical workshops and bicycle path cleaning. The Stint is, next to the Segway, an example of an innovative electric vehicle that could tackle existing problems in urban regions. Although modifying a Stint is said to be possible, documentation on the modifying of Stint vehicles was not found. Furthermore, as the vehicle was wider than any other vehicle on bicycle paths and drivers were often considered inexperienced, unfamiliarity with users and other road users was the result.

Figure 4.5: The Stint, seen here transporting children (88)

The Stint and its legislation became a subject of discussion following a lethal accident on 20 September 2018 in Oss (3). The vehicle was reported to be unable to stop in time at a railway crossing, resulting in a collision with a train and the death of four small children. Further research into the vehicle made clear that the required deacceleartion of 4 m/s^2 was not reached, and that other flaws regarding the parking brake, lack of seating for the driver and faulty wiring were pointed out as technical shortcomings. The vehicles were suspended after the accident, but after it became clear the vehicles did not adhere to regulation they were declared illegal to use (4).

In May 2019, the regulation concerning the 'special moped' was changed for a number of points, most notably it was more clearly defined who has the authority to test and approve the vehicles for the road and additional technical specifications were put in (90). The vehicle has since then been fitted with new brakes, can only fit 8 children and a drivers license is now required. At the moment of writing, the new version of the Stint is undergoing testing to be used for the coming school year (91).

'new' vehicles

Definition Under the category of 'new' vehicles, all technological innovative urban mobility solutions are meant. These are systems that came into existence over the last 10 years, and most of the times do not have fitting regulation in place, thus rendering them illegal for use on public roads (92). For this category, you can think of electric stepscooters, hoverboards, mono-wheel type vehicles or other unconventional (electric) vehicles as seen in figure 3.2 or the Monowheel by the Segway company below 4.6.

Over the past few years, many different varieties of electric vehicles have been developed. Some are adaptations of existing systems, and can be readily found online (such as electric stepscooters or electric skateboards on for example the Eboarders website (94). On the other hand, also entirely new concepts are found on the market. Examples include the concepts by the Segway company such as the Segway Drift, a pair of skate-like mini boards you can stand on, or the previously shown monowheel (2). Another example would be the YikeBike that, although has similarities with the bicycle,

Figure 4.6: The Monowheel by the Segway company (93)

redefined how you use it (1).

Although this category is a collection of different systems, there are many similarities between the vehicles. First and foremost, all these vehicles are relatively new, and are considered to be novelties in the mobility sector. These systems are tested and rated for safety and performance by the same rules as for example mopeds and e-bikes, but cannot adhere to the same standards as they are entirely new concepts. Often times the vehicles cannot be type-approved, as the way of steering and braking by leaning for example is considered to be unconventional and unsafe (81). Secondly, these systems seem to heavily aim for sustainability, as concepts are exclusively electric. The future of urban mobility has no place for combustion engines, as often implied by different manufacturers. Thirdly, these systems seem to all tackle the same problem: urban mobility, and more precisely that of the last-mile problem. The systems should be able to be carried with you on trains, and bring you to your final destination. Lastly, the systems often times remain untested in urban regions, which leaves the safety and implementation of such systems to discussion.

As there is no legal framework for these vehicles, they have no assigned place in the urban setting. This makes that users can gain little experience with interacting with these systems, and as such large unfamiliarity on use and interaction follows. These systems are currently seen as cool to use novelties, and using these systems seem solely for early adapters.

4.2 Safety Cube Analyses

In this section, the safety cube method is applied to each system. The systems are looked at from a operational (use/misuse), functional (function/malfunction) and structural (structural/structural failure) point of view. For each level of component, system and environment the three points of view are used. Information stated under 4.1 is used to generate the safety cube analyses. Within the tables, all factors influencing different system-levels or views are displayed. For each system, the safety cube analysis is shortly discussed before continuing to the Maturity Model.

The time axis is not included in these cubes, as it will unnecessarily complicate the tables. The systems are considered at the present moment in time, and lessons learned from the past systems are included in this present view. Future challenges are included where applicable.

Bicycle

The filled in safety cube for the Bicycle can be found in Figure 4.7. Many of the characteristics of the bicycles are seen back in the Safety Cube: users and the environment are familiar with using a bicycle, it is readily available for everyone and it should be build and function in accordance with safety standards and regulation. Some of the characteristics of the bicycle are collected under 'easy entry': the bicycle is cheap, readily available, easy to learn and requires no safety precautions such as helmets. As such, the bicycle is easy to start using ('easy entry').

	Component level	**System level**	**Environment level**
Operational view (use/misuse)	-Understandable engineering -Maintenance	-familiarity -healthy -cheap -'easy entry' -antisocial driving -comfort -aesthetics	-legal advantage -driving culture -substance abuse
Functional view (functions/malfunctions)	-braking -accelerating -steering -lights	-sound structure -human powered -single person mobility	-uses bicycle infrastructure -combine with other modes -commuter use -recreational use
Structural view (structure/failures in structure)	-affordability / availability components -reliability	-physical limitations -structure complies with standards	-availability infrastructure -bicycle parking

Figure 4.7: Safety Cube analysis of the bicycle

Not only the positive sides of the views are important, but also the negative sides: misuse, malfunction and structural failure. Misuse is concentrated around (the lack of) maintenance and the way it is driven. Driving behavior, but also driving culture and substance abuse, can be considered misuse if they are not in accordance with laws and regulation, as can be the case.

Malfunctions are found to be concentrated around the component level: often through poor maintenance, some functions are not in working condition and are considered to be malfunctioning. Think of broken lights or barely working brakes.

Failures in structure can also happen, but mostly at component or system level. Failures in structure can considered to be the breaking off of components (a light falling off), or a system structure failure, in which the bicycle frame breaks. The latter is however unlikely, as the human-powered system is only exposed to limited loads and standards account for these loads.

Electric Bicycle

The filled in safety cube analysis for the E-bike can be found in Figure 4.8. The E-bike is very comparable to the bicycle, but the addition of electronics add a few considerations. This is seen across all points of view, with the examples of the E-bike being less exhaustive, different functions from the bicycle and electrical limitations.

	Component level	System level	Environment level
Operational view (use/misuse)	-modifying electronics -maintenance -charging behavior	-healthy -'easy entry' -cheaper than car -less exhaustive than bicycle -comfortable -aesthetics -antisocial driving	-legal advantage -driving culture -vulnerable users (elderly) -unexpected speed when interacting with road users
Functional view (functions/malfunctions)	-braking -accelerating -steering -lights -charging battery	-single person mobility -auxiliary power until 25 km/h	-uses bicycle infrastructure -commuting -recreation
Structural view (structure/failures in structure)	-availability components -integration (electrical) components	-physical limitations -electrical limitations -sound structure -structure complies with standards	-availability infrastructure -charging availability -E-bike parking availability

Figure 4.8: Safety Cube analysis of the E-bike

For the misuse of E-bikes, the modification of the electronics, damaging charging behavior or antisocial driving behavior can be considered. Driving behavior can be considered a greater factor than with the bicycle, as speeds are both higher and more unexpected.

Malfunctions can include one or more of the components not working properly, going faster than intended or using the E-bike on unintended infrastructure. The latter also falls under misuse.

Structural failures are the same as with the bicycle, either on component or system level, although failure at system level is unlikely.

Speed Pedelec

Closely related to the E-bike, the S-pedelec could be considered the big brother of the E-bike. Effects that came into play with the E-bike are still present, with an added in regulative debate. The Safety Cube analysis can be found in Table 4.9. This regulative debate can be seen back through no 'easy entry', perceived unsafety and use of both car and bicycle infrastructure

	Component level	System level	Environment level
Operational view (use/misuse)	-modifying electronics -maintenance -charging behavior	-healthy -no 'easy entry' -cheaper than car -less exhaustive than bicycle -comfortable -aesthetics -antisocial driving	-percieved unsafety -interaction with cars and cyclists -regulative discussion
Functional view (functions/malfunctions)	-braking -accelerating -steering -lights -charging battery	-single person mobility (high range) -auxiliary power until 45 km/h	-use car and bicycle infrastructure -commuting
Structural view (structure/failures in structure)	-availability components -integration (electrical) components	-physical limitations -electrical limitations -sound structure -structure complies with standards	-availability infrastructure -charging availability -S-Pedelec parking availability

Figure 4.9: Safety Cube analysis of the S-Pedelec

Because of the above, the S-pedelec is comparable to the E-bike in terms of misuse, malfunction and structural failure. Only side-note here is that the higher speed of this system gives possible more dangerous driving behavior and more risk if malfunctions or structural failures were to take place at this speed.

Segway

After the more conventional systems as the different types of bicycles, the Segway is the first to be considered with innovating technologies. The filled in safety cube for the Segway can be seen in Figure 4.10.

	Component level	System level	Environment level
Operational view (use/misuse)	-modifying electronics/parts -maintenance -charging behavior	-no 'easy entry' -not exhaustive -comfortable -aesthetics -antisocial driving	-interaction with cars and cyclists -inexperienced users
Functional view (functions/malfunctions)	-braking -accelerating -steering -lights -charging battery	-single person mobility (high range) -fully electric	-fit into urban infrastructure -commuting -recreation -indoor mobility
Structural view (structure/failures in structure)	-availability components -integration (electrical) components	-physical limitations -electrical limitations -sound structure -structure complies with standards	-availability infrastructure -charging availability -parking availability

Figure 4.10: Safety Cube analysis of the Segway

Although innovating in the use of technologies, the safety cube of the Segway is very similar to that of the previous cases. As all these systems are urban mobility solutions, functions and structures are not surprisingly very similar. Only difference here is that the Segway is fully electric and not exhaustive, and was also designed for indoor functions. Misuse on the other hand is slightly different, as the controls of the Segway are very innovative. Users and people interacting with users can be considered inexperienced, with undesirable operational interaction.

Stint

The filled in Safety Cube for the Stint can be found in Figure 4.11. On component level, it is the same as the Segway, besides the modification. Furthermore, the Stint served a large need as mobility solution for groups of children, which accounts for some system- and environment-level factors.

	Component level	System level	Environment level
Operational view (use/misuse)	-maintenance -charging behavior	-effortless -aesthetics -comfort -cheaper than alternatives	-unfamiliarity -vulnerable passengers -inexperienced users
Functional view (functions/malfunctions)	-braking -accelerating -steering -lights -charging battery	-novelty, serves large need -different applications -complies with regulation	-use bicycle infrastructure -mobility for small children, cargo, public services
Structural view (structure/failures in structure)	-availability components -integration (electrical) components	-physical limitations -electrical limitations -sound structure	-availability infrastructure -charging availability -parking availability

Figure 4.11: Safety Cube analysis of the Stint

Misuse in terms of antisocial driving behavior is considered as very unlikely, due to the children. What is however a form of misuse for the Stint, is inexperience among users. This is due to the Stint being a novelty, and users are often described as inexperienced (89).

Malfunction for the Stint is more interesting to consider, especially after the tragic accident in Oss. The braking system malfunctioned during that accident. Other malfunctions for the Stint can include using the Stint for unintended purposes, non-compliant Stint vehicles or function on other than bicycle infrastructure.

Structural failures are as previously discussed; unlikely due to structural standards.

'New' vehicles

Last but not least, is the safety cube analysis for the category of 'new' vehicles, which can be found in Figure 4.12.

Misuse for this category of vehicles is difficult to describe. Malfunctions and structural failures depend on the system itself, and are often well designed. Malfunctions are then closely related to misuse; when the user comes into play.

	Component level	System level	Environment level
Operational view (use/misuse)	-maintenance -charging behavior	-'cool' to use -effortless -aesthetics -comfort -antisocial driving	-inexperienced users -unfamiliarity other road users
Functional view (functions/malfunctions)	-braking -accelerating -steering -lights -charging battery	-new concepts -single person mobility -electric	-uncertain place in infrastructure -design for multimodal mobility
Structural view (structure/failures in structure)	-availability components -integration (electrical) components	No regulation on: -physical limitations -electrical limitations -sound structure	-availability infrastructure -charging availability -parking availability

Figure 4.12: Safety Cube analysis of the 'new' vehicles

Misuse depends on the user, and as the use of this system is currently not approved little factual can be said about it. Presumptions include that users are often young, and that antisocial driving and unfamiliarity when interacting with these users can lead to undesirable situations.

Combining the safety cubes

From the performed safety cube analyses many similarities between the different systems can be seen, but also differences are found. System attributes often influence the safety cube of a system on multiple system levels, and comparing the vehicles via this method can be challenging. As such, a Maturity Model is devised to make the comparison more explicit.

4.3 Designing the Maturity Model for Urban Mobility (MMUM)

As described under the theory in 2.2.2, the Maturity Model is designed.

Stage 1: Scope The MMUM to-be is aimed for assessing the maturity of systems that are capable of transporting people in urban regions, excluding systems that make use of combustion engines and walking.

Stage 2: Design The Model should answer some questions, so that it should be clear on what the model is meant for, and for whom (14). Also, comparable models are sought after.

- *Why* should the model be applied?
  As can be seen from the example of the Stint, and the future challenges of urban mobility, current systems are not optimally fulfilling their goals. By applying this model, constraints and areas of improvement for urban mobility systems can be identified.

- *How* can the model be applied for different uses?
  The model should offer a framework or method that can assess the sophistication of urban transportation systems in the Netherlands. The model as used below

could be used in other fields as for example rural transportation or public urban transportation with some adaptations where needed.

- *Who* needs to be involved in applying the model?
  This model should be applied by all stakeholders in urban mobility. As the use of the Safety Cube implies, urban mobility systems have many parts of consideration. As such, all relevant stakeholders should be included in applying such a model. This means that not only designers of vehicles, but also for example policymakers, users of the vehicle, other road users or other authorities on the field should be included.

- *What* can be achieved through the use of this model?
  The use of this model should give designers or other stakeholders in urban mobility a hand in identifying areas of improvement for the systems. By doing so, a more safe, sustainable or pleasant future for urban mobility could be achieved.

Comparable models Maturity Models in the field of Urban Mobility Systems could not be found through literature research. However, some comparable or interesting models have been found.

- Mehmann et al. (16) devised a model for crowdsourcing transportation services, and made use of the dimension-attribute method. This model is interesting to consider, as it made use of only 4 maturity levels instead of the usual five, and used attributes that could be considered business achievements instead of measurable quantities.

- Schumacher et al. (15) devised a model for industry 4.0 readiness for an organization. Interesting to consider due to the large number of literature considered (3400 findings) and large number of attributes and dimensions (62 and 9 respectively).

- Pöppelbuß and Röglinger (95) found several design principles for both descriptive and prescriptive purposes for maturity models. The principles are in line with the methodology described under Section 2.2.2 by De Bruin et al. and Becker et al. (14) (11).

- Silvius and Schipper (96) developed a maturity model to integrate sustainability for project development. Through the dimensions People, Planet and Profit organizations are presented a practical tool that can integrate the abstract concepts for sustainability into practice.

- Safety by maturity models, such as Goncalves Filho et al. for the safety culture in petrochemical companies in Brazil (97), Foster and Hoult for safety planning in the UK coal mining industry (98) or Law et al. for assessing the safety culture in a hospital setting (99).

Stage 3: Label and Design Maturity levels Choice is made to make use of 5 maturity levels, as this will ensure differentiation and is able to give a neutral, middle, level. A level that is not either immature or mature. Levels are given from low to high maturity:

1. **Initial:** There a little to no signs of a matured system. Dimensions are at their initial level, and there is much room for improvement.

2. **Developing:** The system is developing, and shows its first signs of maturity. There is still much room for further maturing.

3. **Intermediate:** The system is not either mature or immature, but intermediate in maturity. Dimensions show signs of maturity, but have not matured fully yet.

4. **Advanced:** The system has advanced to a mature system, but the maturity has not yet reached its optimum.

5. **Optimal:** The system is optimally matured, and dimensions are optimized for the use.

4.3.1 MMUM dimensions and attributes

Stage 4: Define the model with Dimensions and attributes Now that the maturity levels have been defined, dimensions and corresponding attributes for their maturity levels can be selected. A dimension influences the maturity of a system in a certain category. Choice is made to follow the Safety Cube approach and define three categories of dimensions: People, System and Environment, as seen in Figure 4.13. Per category, dimensions are selected from sections 3.4 and 4.2. Factors are selected on the base that they have a large influence on the maturity of a system. The choice of dimensions is further explained below, after which the model is shown (Figure 4.14) and further attention is paid to what the dimensions and their attributes entail.

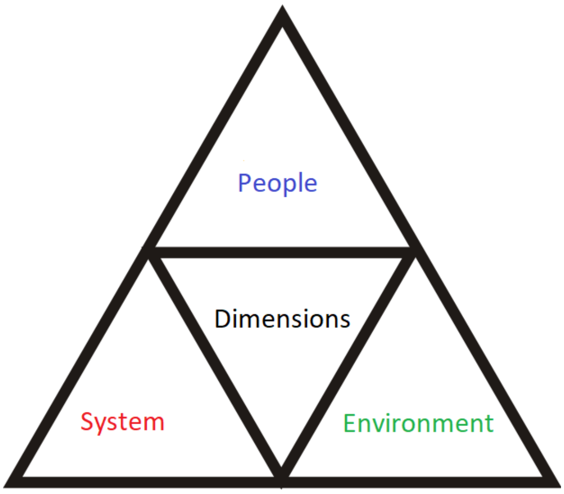

Figure 4.13: Maturity dimensions in three categories: People, System and Environment

In the dimension category 'People' 5 dimensions have been identified. When considering the systems with the Operation view, their use and misuse some recurring factors can be found. First and foremost the 'easy entry' is found in all but the more innovative vehicles. This is closely linked to the user benefits. The benefits that a system offers greatly determines the use of it, as can be seen when comparing the bicycle with the S-Pedelec or Segway for example. The use of the S-Pedelec offers more benefits than the Segway, and can be considered more matured because of that.

Interaction with the user and the system is best displayed in how the system is driven, and what the driving culture looks like. Driving the system is the largest part of the use and misuse of a system, and as such can greatly determine the maturity of use. For example, the bicycle maturity is more determined by how the people drive it than how the people park or dispose of it. What is considered to be normal in terms of driving a system is part of the driving culture, and the whole of users driving the system also determines the maturity from a People perspective.

Familiarity is something that follows from the maturity perspective in section 2.2.2. How familiar the user is with the use of, and interaction with, the system determines how competent/sophisticated the user is, i.e. mature. Unfamiliar users can be considered less mature than familiar users. Although closely related to the Driving Culture and Behavior dimensions, Familiarity also includes non-users' perspective on interacting with the system.

The last dimension in the 'People' category can be considered obvious: the user group. *Who* uses the system can tell something about the maturity of a system. The number of user groups that make use of a system can determine the maturity, for example if you compare the use of the bicycle (almost all user groups) with the use of the S-Pedelec (almost exclusively used by the working class for commuting).

In the dimension category 'System' 3 dimensions have been identified. These dimensions tell something about the maturity of the system itself. Maintenance is the first dimension to be selected, as it recurred in every single Safety Cube analysis. Although maintenance is performed by the user, choice is made to put it in the Environment category. The likely state of maintenance and ease of maintenance influence the overall maturity of a system. A system that is very easy to maintain can be considered more sophisticated than systems that are not easy to maintain.

Secondly, the Sustainability of a system can also influence the level of sophistication. This dimension did not only follow from section 3.4, but also from comparing the selected systems with the moped for example. Clearly, the considered systems are more sustainable than the moped due to the fact they have no combustion engine. As future systems should aim towards sustainability, the level of sustainability in all stages in the lifecycle of a system can have an influence of the maturity.

Thirdly, the Safety is considered to be a System category dimension. The safer a system is, the more sophisticated and mature it can considered to be. Unsafe systems should improve on their safety features, and as such have not fully matured yet. Although Safety is closely related to how the system is driven, it is defined to be a System dimension as the physical structure of a system can greatly influence the safety features.

In the dimension category 'Environment' 3 dimensions have been identified: Infrastructure, Legal Environment and Interoperability. Infrastructure is selected due to the fact that it is prominently present in the safety cubes. Apparently, the availability and quality of present infrastructure influences the maturity of a system. More dedicated and high-quality infrastructure could be linked to more matured systems, and the other way around. The S-Pedelec is interesting to consider here, because the lack of dedicated infrastructure makes the system less competent in use.

Legal environment is also selected. From the section on future trends one can see that the legal environment can play a large role in the development of future systems. Also, from the safety cubes it is apparent that systems that have a beneficial legal environment are more integrated into the urban regions, and could be considered more mature as such. This is best seen when comparing the E-bike with the S-Pedelec, where the legal requirements of the S-Pedelec can be considered limiting the use.

Lastly, Interoperability is selected in this category. Section 3.4 identified several factors for future systems, with Interoperability one of them. The possibility to combine one system with other systems for urban mobility is identified as vital for especially future systems. Systems that cannot be integrated with other forms of urban mobility could be considered less mature.

4.3.2 The Maturity Model for Urban Mobility

The attributes for each dimension are found by using the definitions of the different maturity levels. For each dimension, the initial and most mature attribute are identified. After that, the levels 2 through 4 are defined as having attributes that fall somewhere in between the levels 1 and 5. Below is the Maturity Model for Urban Mobility in figure 4.14, the different attributes are explained in more detail below the model.

Dimension	1:initial	2: Developing	3: Intermediate	4: Advanced	5: Optimal
'easy entry'	Impossible entry to system	Learning, helmet, insurance, drivers license	Learning, helmet, insurance	Learning, helmet or insurance	Inviting environment
User benefits	No benefits	Cheap	Cheap, healthy, comfortable, exhaustive	Cheap, healthy, comfortable, slightly exhaustive	Cheap, healthy, comfortable, not exhaustive, aesthetics, accepted use
Driving Behavior and culture	Severe antisocial driving behavior, major traffic violations	Severe antisocial driving behavior, traffic violations	No severe antisocial driving behavior, traffic violations	Minor antisocial driving behavior, minor traffic violations	No antisocial driving behavior, stick to traffic rules
Familiarity	Unfamiliar, never heard/seen the system	Heard/ read about the system	Has used the system, knows about the system	Familiar to use and interaction, possible ownership	Very familiar to use and interaction, likely ownership
User group	Unavailable for all users groups	Available to some user groups	Available for normal user	Available for normal user and elderly	Available for every user group
Maintenance	No structural integrity	Low structural integrity, some functions in order	Structural integrity, some functions in order	Structural integrity, all functions likely in order	Pefectly maintained, cannot be tempered with
Sustainable	Harmful system lifecycle	Improper disposal, toxic materials	Neutral lifecycle, some toxic materials	Sustainable lifecycle, no disposal programs	No impact lifecycle, disposal programs
Safety	Very unsafe, safety	Generally unsafe, many accidents	Both somewhat safe and unsafe	Generally safe, some accidents	Very safe, few accidents
Infrastructure	No available infrastructure	Not suitable for available infrastructure	Suitable for available infrastructure, no dedicated Infrastructure	Suitable for available infrastructure, dedicated lanes	Dedicated, high quality infrastructure, accepted
Legal Environment	Illegal to use	Requirements, undesirable place, limited speed	Requirements, undesirable place	no requirements or limitations	Favorable legislation, legal protection
Interoperability	Not interoperable	Parking at transit hubs	Parking at transit hubs, no need for interoperability	parking at transit hubs, can be carried	Extensive interoperable support

Figure 4.14: Maturity Model for Urban Mobility, with categorized dimensions and corresponding attributes

Easy entry tells something about how easy it is for a user to start out with a certain system. At initial level, it is virtually impossible to start using the system. At the highest level, it is very easy to start using the system and the environment can be considered inviting for the user. Level 2 is reached if it is possible to learn to use the vehicle, but also practical requirements of a helmet, insurance and drivers license are needed. Level 3 is reached if you'll need to learn how to use it, and use of the helmet and insurance is required. For level four, only one requirement is needed and there is some need to learn how to use it. At level five, it is really easy to start using the system, and as such requires little learning and no requirements.

User benefits tells something about how beneficial the use of a system is to the user. For example, the system could be cheaper to use than others, offer health benefits, can be considered as accepted to use in the Netherlands, comfortable or good-looking (aesthetics). The lowest level is defined to have no benefits to the user. The highest level is attained when the system is very cheap, healthy, comfortable, aesthetic and integrated well into the environment. The levels 2 through 4 are attained when different benefits are provided by the system such as exhaustiveness. A system can be not exhaustive (fully electric, no human input), slightly exhaustive (auxiliary electric power, human input) and exhaustive (human input only).

Driving behavior and culture tells something about how the system can be (mis)used while driving. How likely is antisocial behavior, and how severe is the possible antisocial driving behavior? Driving in such a way that can cause lethal accidents is considered to be more severe than small traffic rule violations. As such, the lowest level of driving behavior is defined as likely to cause lethal injuries to others. The highest level is unlikely to cause lethal or minor accidents, and as such no traffic violations are allowed for level 5. The levels 2 through 4 fall in between that range, including some severity of traffic violations, in which severe antisocial driving behavior means with possible lethal outcome due to major traffic violations as running a red light, and minor traffic violations such as using only one hand to steer.

Familiarity tells something about how used/familiar people are with using the system and having the system around. Is it a novel technology that users have not even heard of, or are they familiar with using and interacting with the system in the urban environment? The levels in between are defined to have some degree of familiarity with use, but also interaction. Familiarity is scaled to how well you know the system. Have you never heard of it, have you read about it, have you used it or do you own a system? The same goes for interacting with a system, as familiarity determines how well a user interacts with different systems.

User group tells something about who can make use of the system. Hoverboards are for example great for children, but not so much for elderly. The lowest level is defined such that the system in unavailable to any user, with exceptions such as the producer. The highest level is then defined to be available to all user groups. Level 4 is reached when vulnerable users such as elderly can make use of the vehicle, and so on. Handicapped users are not taken into account here, as they have a separate category of vehicles as described in the RVV (28). A normal user is defined to be any person in good health, not being elderly, a child or otherwise special user.

Maintenance tells something about the likely state of being of a system. Structural integrity and the likelihood that all functions can operate normally are discussed here. Costs of components, ease of maintenance and the ease of tempering with a vehicle influence this dimension. The lowest level is defined such that there is a low structural integrity and no functions are working properly. The highest level is defined as a perfectly maintained system, where all functions are working properly and tempering with the vehicle is virtually impossible.

Sustainability tells something about the sustainability of the lifecycle. Use of toxic, wasteful, materials influences the lifecycle, but also the way they are disposed of. The lowest level is defined to be harmful to the environment, and the highest level has no impact on the environment in any point in its lifecycle. Attributes will then be considering how the vehicles are likely to be disposed, and to what extent toxic materials are used.

Safety tells something about the perceived safety of a system. Is the system considered to be safe in its current form and environment, for different users? The vulnerability of users and perceived safety through the use of safety precautions (helmets) is used here. The lowest level is defined to be very unsafe, and is used by vulnerable users with safety precautions. The highest level is defined to be very safe, and no precautions are needed.

Infrastructure tells something about the roads you can use with the vehicle. Not only the physical condition of the road is important, but also if the system fits in there, if it is accepted by the other road users and if it is suitable. Also, parking and other physical places are taken into account here. The lowest level implies there is no physical place for the system at hand. The highest level supports high-quality, dedicated, infrastructure. The levels in between are determined by how well the system fits into the physical infrastructure, and is accepted there.

Legal environment tells something about the legislation and regulation that is in place, and how much it favors the use of a certain system. Level 1 is defined to be fully illegal to use. Level 5 is defined to have legislation in favor of the system. Limitations such as undesirable place on the road, requirements (helmets, insurance, license) or allowed speed determine the other levels.

Interoperability tells something about how well the system can be used in combination with other systems. The lowest level is not compatible with other modes of transportation, and the highest level supports interoperability extensively. How well you can park your system at public transport hubs, if the system can be carried with you are attributes for this dimension. Some systems can be used without use of other modes of transportation, as they sometimes fulfill all the user needs.

Please note that dimensions are not mutually exclusive per se. A dimensions that is found to be under one category, might as well also influence another category. Maintenance for example is categorized as a System dimension, but the way the user maintains his/her system is a substantial component of maintenance. This makes that Maintenance could be considered both in the People and System category.

4.4 Maturity analyses

In below figures the different systems are rated for their maturity by the author. As with the maturity model by Mehmann et al., the overall maturity level of a system is the same as the lowest scored maturity level (16). Relevant information for this analysis can be found in the respective sections under 4.1 or 4.2. For each system, the maturity evaluation and notable conclusions are given. Also outcomes of the interviews and survey are discussed, displayed in different colors in the figures.

Weight factors for dimensions The three categories are considered to have the same level on influence on the maturity level of a system, results from the survey and interviews found (100) (101) (102). As there are more dimensions in the People category than the System and Environment category, choice is made to even out this difference with the use of weight factors. Below can be found that up to 5 points per dimension can be attained, and as such the total scores of the categories System and Environment are multiplied with a factor of 5/3.

Dimension	Maturity Level	Description
'easy entry'	5 (4)	Inviting environment for cyclists (lower because you have to learn to ride)
User benefits	5 (4)	very cheap, easy and accepted to use (lower because it is exhaustive)
Driving Behavior and culture	4 (3)	cause lethal accident, traffic violations (lower because of antisocial culture)
Familiarity	5	Cycling is part of Dutch culture
User group	4	Users with lesser physique do not cycle
Maintenance	4 (3)	Easy to maintain, although not all bicycles are always properly functioning (lower because of low maintenance level)
Sustainability	4	No toxic materials, but no disposal programs
Safety	3	Human powered, little severe accidents. No safety precautions needed
Infrastructure	5	Dedicated and high-quality infrastructure
Legal Environment	5	legal protection in case of accident
Interoperability	2 (3)	Parking shortages, cannot be carried, not ideal for commutes (higher because often used in combination with train etc.)

Figure 4.15: Maturity evaluation for the bicycle. Total maturity: 61,3/75, People maturity: 23/25, System maturity: 18,3/25, Environment maturity 20/25.

Bicycle

The maturity analysis as by the author for the bicycle can be found in Figure 4.15, in black. The overall maturity level is 2, as Interoperability has the lowest score. In the People category, the bicycle scores relatively high, which is probably due to the fact that the bicycle has been around for a long time and the Dutch are familiar with using it. In the system category the bicycle scores only 18,3 points, mostly due to the safety. Mainly because it is human-powered and can only go so fast. In the Environment category the bicycle familiarity can be seen again, as the infrastructure and legal environment score the highest possible maturity level.

From the survey and interviews some dimensions were scored differently. Learning to ride caused 'Easy entry' to be considered as a four and exhaustiveness implied that level 5 was too high for the user benefits. Behavior in terms of driving was found to be more antisocial by the survey, and this was also seen in the Maintenance, where it was found to be more poorly than initially thought. Interoperability has improved, since it was found that the bicycle is used frequently in combination with the train and also used for entire commutes.

E-bike

The maturity evaluation of the E-bike can be found in Figure 4.16 The lowest scored maturity level is 3, which is higher than that of the bicycle. The E-bikes maturity is also very similar to that of the bicycle with comparable total maturity's in the different categories. What is interesting to see is that through the use of electronics on bicycle technology, the dimensions Driving Behavior, Familiarity and Sustainability score lower than with the bicycle. The electronics increase the antisocial driving behavior, make users less familiar with the use and the battery influences the disposal stage of the lifecycle negatively.

Dimension	Maturity Level	Description
'easy entry'	5 (4)	No requirements and also inviting environment (lower because of relative high price)
User benefits	5 (4)	Cheaper compared to car, offer increased benefits over bicycle (still relatively expensive)
Driving Behavior and culture	3 (4)	More likely to cause accidents than bicycle due to speed, traffic violations (users not seen as antisocial drivers)
Familiarity	4	E-bikes are often seen, but user is less likely to own one than a bicycle
User group	5 (4)	Available for all sorts of users, except for young children (lower because of exclusion of young children and reduced mobility users)
Maintenance	4 (2)	Same as normal bicycle (can't be done yourself, more expensive than bicycle)
Sustainability	3	Battery materials, no disposal programs
Safety	3 (2)	Comparable with bicycle, but with higher speed and older users (lower because of vulnerable users)
Infrastructure	5 (4)	Dedicated and high-quality infrastructure (charging and high speed difference)
Legal Environment	5	legal protection in case of accident
Interoperability	3	Parking shortages, cannot be carried, ideal for commutes

Figure 4.16: Maturity evaluation for the E-bike. Total maturity: 60,4/75, People maturity: 22/25, System maturity: 16,7/25, Environment maturity 21,7/25.

On the other hand, the dimensions User group and Interoperability are increased. The electronics make the E-bike available to all users, and due to the auxiliary power the E-bike is ideal for commutes, making interoperability less of a factor.

Generally the survey found the E-bike to have scored too high. The price was considered more of a limiting factor for the E-bike entry, as is the case with the user benefits. User group was seen as not available to all, and the type of users (commuters, elderly and such) were found to be less antisocial in their driving, but also more vulnerable as can be seen under Safety. Maintenance also scored lower compared to the bicycle, but even lower because of the expected complexity and high price of E-bike maintenance. The lack of charging availability and the speed difference with other bicycle path users lowered the Infrastructure score.

S-Pedelec

The maturity evaluation for the S-Pedelec can be found in Figure 4.17. As can be seen from the categorized scores, the S-Pedelec scores much lower than the E-bike in People and Environment maturity, but is comparable in terms of System Maturity. For the People category, this is explained due to the fact that the S-Pedelec has many practical requirements to fulfill in terms of helmet, insurance and drivers license. This, in combination with the current regulation that the S-pedelec has to make use of both car and bicycle infrastructure, makes that the user experiences less benefits from its use and is only interesting to use for a select group of users.

Dimension	Maturity Level	Description
'easy entry'	2	Helmet, insurance and license required
User benefits	4 (3)	Less comfortable and accepted than E-bike (much more expensive than E-bike)
Driving Behavior and culture	3 (4)	Intermediate as there is too little information available (less antisocial due to user group and drivers license)
Familiarity	3 (2)	S-pedelec relatively known, although not many people use it (very little people know it what it is)
User group	3	most often used by middle-aged users, not for everyone available
Maintenance	5 (4)	Higher (moped) standards, electronics secured (complex, more expensive maintenance)
Sustainability	3	Battery materials, no disposal programs
Safety	4 (3)	Generally safe, as users are careful due to sharing road with car (due to cars)
Infrastructure	2	Shares two types of infrastructure, does not belong on either
Legal Environment	2	Requirements in place, awkward place on the road, limited speed
Interoperability	3	Comparable to E-bike, little need for interoperability due to range

Figure 4.17: Maturity evaluation for the S-pedelec. Total maturity: 46,7/75, People maturity: 15/25, System maturity: 20/25, Environment maturity 11,7/25.

The fact that the S-Pedelec has scored the highest as of now for the System category is explained through the Maintenance dimension. As this system falls under the moped category, higher safety standards apply. Also, it is only reasonable to assume that the S-Pedelecs are better maintained and driven safer than E-bikes, as they have to interact with cars and unsuitable infrastructure.

The S-Pedelec scores very low in the Environment category. This is due to the ongoing regulative discussion on where the S-Pedelec should be used. This makes for an awkward situation where users have to use two types of infrastructure, and feel generally unsafe. Also, in combination with the moped rules that are in place for a vehicle that seldom reaches the allowed speed of 45 km/h, the legal environment is less than inviting.

Interviews and the survey show that very little people have heard of or know what a S-Pedelec is, which can be seen back in Familiarity. As with the E-bike, the expected high price and complexity of the system lowered the User benefits and Maintenance scores. The requisite of a drivers license made the driving culture less antisocial than expected. From the survey. also the regulative discussion can be seen back as the Safety scores lowered due to the interaction with cars.

The S-Pedelec can be seen as an example of a system that is well designed for a certain use, but mainly due to out of place regulation and inexperienced users the S-Pedelec scores low on the maturity evaluation.

Segway

In Figure 4.18 the maturity evaluation is given for the Segway. With a total maturity of 43, the lowest score is 1. Interestingly enough, the Segway scores in a comparable fashion as the S-Pedelec. Although relatively matured in terms of the System category, mainly the Environment but also the People category score relatively low.

Dimension	Maturity Level	Description
'easy entry'	4 (3)	Insurance required, learn new way of driving (learning to drive)
User benefits	2 (3)	Not cheap, although it could offer benefits in terms of e.g. comfort (comparable to S-Pedelec in price)
Driving Behavior and culture	3 (4)	Intermediate as there is too little information available (conscious driving behavior)
Familiarity	2	Although known concepts, few have actually used it
User group	2 (3)	Theoretically for everyone (exception for users with reduced mobility)
Maintenance	5	Only known case of tempering is larger wheels
Sustainability	3	Battery materials, no disposal programs
Safety	3 (2)	Intermediate as there is too little information available (limited braking power)
Infrastructure	3	Bicycle infrastructure, no dedicated lanes
Legal Environment	3	Some requirements, no dedicated place on the road
Interoperability	1 (2)	No information on interoperability, cannot be carried (could be driven to train station, interoperability less needed)

Figure 4.18: Maturity evaluation for the Segway. Total maturity: 43/75, People maturity: 13/25, System maturity: 18,3/25, Environment maturity 11,7/25.

Although the Segway is easier to start out with due to fewer requirements, it offers less user benefits than the S-Pedelec mainly due to its higher cost. The User base score can be explained through the fact that the S-Pedelec is relatively new in the urban regions, and users are only a select group of early adapters. This also accounts for the Familiarity score, as users are less used to interacting with the S-Pedelec.

In the System category, the Maintenance scores the highest. This is due to the fact that the only known case of tempering is with putting on larger wheels, and that due to the more complicated technology the Segway is more likely to have all functions working properly. On Safety it scores lower, mostly due to lack of data but also again due to familiarity with the system. As users are not yet adapted for the new way of controlling this system and it being in the environment, it can cause unsafe situations.

Environmentally, the Segway scores the same as the S-Pedelec, although higher on both Infrastructure and Legal Environment, due to the S-Pedelec's regulative discussion. The Segway is not designed for Interoperability, as it cannot be carried and was meant to be able to use for all sorts of trips.

From the interviews and survey the Segways innovative character can also be seen. The system design caused 'easy entry' to score lower due to the learning curve, and Safety due to the expected low braking power (102). Some dimensions also changed positively: Pricing was comparable to the S-Pedelec, driving behavior was expected to be more conscious and the use was found to be for everyone, with the exception of users with reduced mobility. Also Interoperability changed, as the survey expected that it was either less needed or it should be possible to use in combination with a train.

Stint

Figure 4.19 gives the maturity evaluation for the Stint system. With the lowest score being a 1 for Interoperability, the total maturity becomes 47, comparable to the S-Pedelec.

Dimension	Maturity Level	Description
'easy entry'	4	Learning to ride and insurance required
User benefits	4	Many benefits, although not healthy and accepted after the accident
Driving Behavior and culture	5 (4)	Small chance for antisocial driving behavior due to children transportation (width antisocial for other users)
Familiarity	2 (3)	Limited user group (known due to Oss accident)
User group	2	Available for select purposes, no private use
Maintenance	5	No information on tempering, due to purpose likely to be in good state
Sustainability	3	Battery used, no disposal programs
Safety	3	Technical shortcomings and Oss accident, little further information
Infrastructure	2 (3)	Wider than normally allowed on bicycle paths, (as wide as two cyclists, high availability bicycle paths)
Legal Environment	3	special moped' rules and limitations
Interoperability	1	Not interoperable, although also not needed due to purpose

Figure 4.19: Maturity evaluation for the Stint. Total maturity: 47/75, People maturity: 17/25, System maturity: 20/25, Environment maturity 10/25.

When considering the People category, there is a much easier entry than for example with the S-Pedelec. The Stint offered many benefits for the user as it was designed to be a much cheaper way of transporting groups of small children. This accounts for the high score for the Driving Behavior, as drivers of the Stint will probably be driving much more cautiously when children are on board, even though it is a new way of controlling a vehicle. The survey expected however that the large width is antisocial to other users (100). The new way of controlling a vehicle also contributes to the low score for Familiarity, next to the fact that few people have actually used it or interacted with it in traffic situations. The survey showed however that the Oss accident caused a large awareness for the Stint. As for the User Base, the Stint was designed for a select number of purposes and has little private use because of that.

The System category shows comparable scores to the Segway. Maintenance scores exceptionally high, due to a presumable high state of maintenance to ensure the childrens safety and no known cases of tempering with a Stint. Sustainability is comparable to that of any electric system, and for Safety a 4 was given. Although there was only one accident with the system, research into the cause of the system showed a few technical shortcomings which made the vehicle less safe.

The Environment category is interesting to consider. Exception was made to allow the Stint even though it was too wide, which resulted in extra difficulty when using the bicycle infrastructure. Physically, the Stint was unfit to use on bicycle infrastructure, as they can be relatively narrow at times. This was not in line with findings from the survey, as the width can be considered as wide as two cyclists cycling next to each other (100). Legally, it adheres to the special moped regulation, meaning some limitations are in place. Furthermore, the Stint was designed for a dedicated purpose, and as such there is no need for interoperability. A score of 3 could be argued, but when taking into account the physical dimensions of the Stint the parking quickly becomes an issue.

'New' vehicles

The maturity evaluation for the category of 'new' vehicles is given in Figure 4.20. This category has the lowest total maturity of all considered systems, with the lowest score also being a 1 for Infrastructure and Legal Environment. From the interviews, a grading was done assuming an 'ideal situation' (102) (101). This is in displayed in blue, and assumes that the new type vehicles have been legal for some time, and make use of bicycle infrastructure.

Dimension	Maturity Level	Description
'easy entry'	5 (5) (4)	No requirements needed as they are still illegal (only for 'trendy' people, no reduced mobility, also illegal)
User benefits	2 (4) (3)	Generally cheaper than other systems, but offers little other benefits (cheaper than all alternatives)
Driving Behavior and culture	3 (3)	Intermediate, as little is known
Familiarity	2 (4) (3)	Unfamiliarity, often seen online but seldom used (stepscooters often seen)
User group	2 (3) (3)	Only used by early adapters (more users if legal)
Maintenance	4 (4)	Unlikely to be tempered with
Sustainability	3 (3)	battery, no disposal programs
Safety	2 (3) (3)	although not fully road tested, no safety standards are in place (safer dan S-Pedelec)
Infrastructure	1 (4) (3)	Has no assigned place (yet) (bicycle paths available, but illegal)
Legal Environment	1 (3)	No legislation in place (yet)
Interoperability	5 (5)	Often designed for interoperability, can often be carried

Figure 4.20: Maturity evaluation for the 'new' vehicles. Total maturity: 40,7/75, People maturity: 14/25, System maturity: 15/25, Environment maturity 11,7/25.

From a People point of view, the user group and Familiarity were expected to score higher by both the survey and the interviews. This is due to the fact that some new type systems are frequently seen, and are more available for everyone if legal. Also, User benefits were expected to score higher, as they could reach the 'Advanced'-level requirements if legal, at a relative low price.

Also System maturity is low compared to other systems. Generally, vehicles that fall under this category are hard to temper with due to advanced electronics and have comparable Sustainability impact due to the batteries. Safety on the other hand scores much lower. Unfamiliarity with controlling the vehicle, and also the current illegal status of these systems make that unsafe situations can arise quickly. Users are both not used to controlling a vehicle, and not used to interacting with one. However, the survey and interviews expected similar safety to the S-Pedelec. (100) (101).

As was also the case with the Stint, these category scores poorly on Environmental dimensions in the current state. In the ideal state, it could score 'Intermediate' for Legal environment as there would probably be some limitations (102), and 'Advanced' for the Infrastructure due to the bicycle paths. This is somewhat in line with the survey, although only a 'Advanced' maturity level is reached due to the assumed illegal status of the category. This category of systems scores great on the Interoperability dimension as found in both the current and ideal state.

4.5 Comparing the maturity assessments

After assessing the maturity of the six systems for 11 dimensions, conclusions can be drawn as to how these compare to each other. An overview of the attained scores is given in Figure 4.21. In total, 75 points could have been earned, 25 for the People dimensions, 15 for the System dimensions and 15 for Environment dimensions. System and Environment scores were multiplied by a factor of 5/3 to ensure all dimensions influence the total score equally, and reach the total of 75. Again, black is scored by the author, blue indicates the scores for the new type systems for an ideal situation, and green/red/black in brackets indicate the survey and interview outcomes.

Several interesting things can be noted from below figure. Both the bicycle and the E-bike have matured in comparable ways in the Netherlands. Both score exceptionally well in the Environment dimensions compared to the other systems. This can best be seen in Figure 4.22. This is explained through the fact that both types of bicycles have been around for some time, and infrastructure and regulation have had ample time to adapt. From this same reasoning, the high scores for People dimensions is also explained. Users are familiar with using and interacting with the bicycles. As such, systems that make use of existing technology that people are used to, in an environment that is fit for those systems, the success of a system is greater.

	Maturity category			
	Total	**People**	**System**	**Environment**
Bicycle	61,3 (58,4)	23 (20)	18,3 (16,7)	20 (21,7)
E-Bike	60,4 51,7)	22 (20)	16,7 (11,7)	21,7 (20)
S-Pedelec	46,7 (42,4)	15 (14)	20 (16,7)	11,7 (11,7)
Segway	43 (45)	13 (15)	18,3 (16,7)	11,7 (13,3)
Stint	47 (48,7)	17 (17)	20 (20)	10 (11,7)
New	40,7 (55,7) (51)	14 (19)(16)	15 (16,7) (16,7)	11,7 (20) (18,3)

Figure 4.21: Total Maturity scores of all systems

Another interesting conclusion that can be drawn from this figure, is that the S-Pedelec, Segway, Stint and 'New', which make more extensive use of electronics than the E-bike, score very low on the Environment category. The legal environment and infrastructure have not adapted for these systems, and as such the vehicles are either placed on awkward places on the road (S-Pedelec) or have no place at all ('new'). Apparently the environment plays a large role in the maturity of new technologies in PUM.

Not only the Environment is important to consider for the use of new technologies in urban mobility, but also the People and System. Both figures show that the new technologically advanced systems such as the S-Pedelec, Segway and Stint score generally well on System dimensions. These systems are comparable to the bicycle for example in terms of Maintenance, Sustainability and Safety, but seem to be less matured than the bicycle. This follows from the People dimensions. These systems score lower due to the use of newer, more unfamiliar, technologies and this makes the driving behavior unpredictable, the user base often limited and easy entry uncertain due to changing legislation. Apparently, not only the environment plays a large role for these new technologies, but also the People category.

Lastly what is interesting is to consider in Figure 4.22 is the category of 'new' vehicles. The survey showed a large difference, namely due to different assumptions

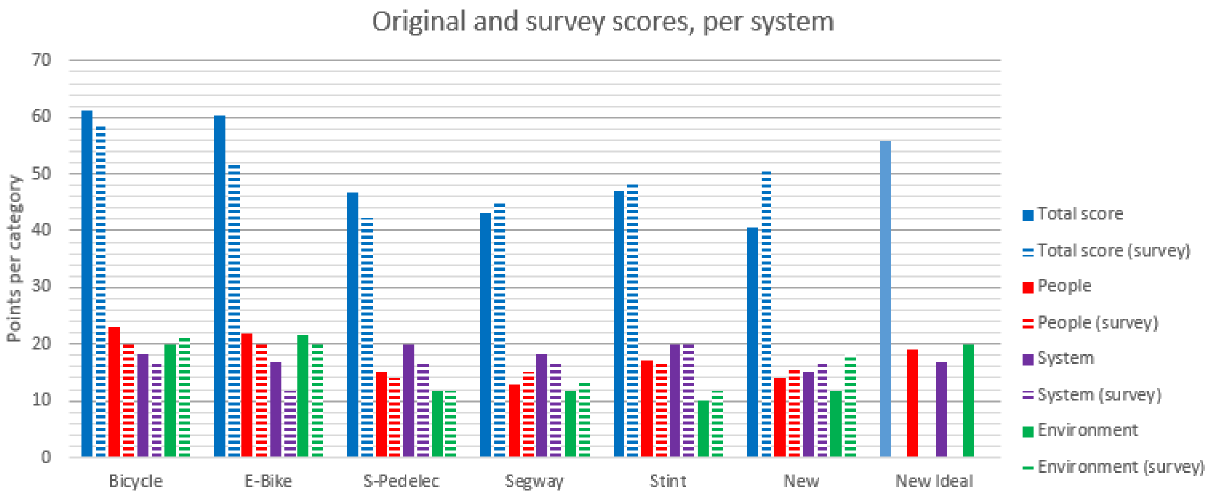

Figure 4.22: Graphic representation of categorized scores per system, including the 'ideal situation' for the new category

with the Environment dimensions. Interestingly enough, the ideal situation ('New ideal') indicates that the system matures greatly if proper legal framework is in place. As the vehicles are currently illegal to use, people cannot become familiar with it and reap the benefits it could offer for the user. It seems that the problem for this category of vehicles is concentrated around its regulation, and by introducing public road tests for example a lot can be gained in terms of system maturity and use. This is also in line with the case of the S-Pedelec: changing and unsuited regulation contributed to the low use of an otherwise promising way of commuting

5

Conclusion and Discussion

5.1 Conclusion

In this bachelor assignment, research was done into systems that currently act in the field of Personal Urban Mobility (PUM) in the Netherlands. The current and future challenges for PUM systems were identified to give designers of such systems insight in to what is important to the success of a PUM system. The bicycle, E-bike, S-pedelec, Segway, Stint and a collective category of 'new' vehicles were considered. The current state of PUM and its future was looked into using literature review, semi-structured interviews and a small survey. The systems were compared using the Safety Cube approach and from that a Maturity Model for Urban Mobility (MMUM) was designed.

From three different policy documents on the future of PUM, it turned out that the systems that act in it should be *safe*, *sustainable*, *interoperable* and make smart use of *old and new technologies*. Systems that fulfill these requirements, are more likely to be a success.

Other conclusions from these policy documents include that future systems that are focused around walking and cycling infrastructure have a larger chance of success, designers should not be afraid to improve on existing technologies and infrastructure, and that public road tests are vital in taking informed regulative decisions. Additionally, systems should take into account the possibility for multimodal mobility.

From the Safety Cube approach and the MMUM, several conclusions can be drawn. The bicycle and E-bike are an example of matured PUM systems in the Netherlands. Both systems have been around for some time which makes for adapted infrastructure, inviting (legal) environment and familiarity with using and interacting with these systems.

From the MMUM followed some challenges for the use of innovative PUM systems. Mainly in the People and Environment categories, these systems fall short. The systems themselves can be considered adequately designed for use and safety, but not for its environment or the people using it. As there is often no (adequate) legal framework for these systems, unfamiliarity, limited user benefits, no 'easy entry' and limited use follow. The challenge for these vehicles is to create an inviting environment where people can become familiar with the systems and where lenient regulation is in place. Public road tests could prove important for this challenge, as well as sufficient support across stakeholders and a long-term vision that is followed.

5.1.1 Recommendations for future research

Future research on this subject should also account for several other factors. As limited time was available for this assignment, some things were not included in this report. That does not mean they are not important for the subject. An overview of recommendations for future research on the field of PUM, MMUM or Safety Cube, can be found in Appendix B.

5.2 Discussion

A critical look at the course of research and methods used is also important.

Some dimensions had too little information available to make a worthwhile comparison in the MMUM. For example, no statistics but only some (subjective) 'perceived' safety references where used for the Safety dimension. Also Driving Behavior was hard to display objectively, as little information was available. Triangulation of information could have been better, if more (scientific) references for the newer category of systems were used. By considering more literature on the subject, more accurate analyses can be performed. Also, using interviews and surveys more extensively could prove a solution here.

The relative success of a system is sometimes mentioned, but no accurate measure has been defined. The popularity of a system among users can say a lot about how well designed the system was for its Operation, Functions and Structure. However, without mention of relative use per capita or other relevant statistics, little objective comparisons between systems can be made.

The validation of the MMUM was only limited, and full objectivity cannot be guaranteed. Use was made of only two interviews with industry experts and a survey with 24 respondents. More interviews and higher count of respondents would more accurately validate the MMUM. Validation for the Safety Cube analyses could also improve the objectivity.

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[101] Semi-structured interview with Tamor Hartogs, owner of FixieBrothers B.V., held on 31-7-2019;.

[102] Semi-structured interview with Ivar Hartogs, Customer Service Representative at Trekbikes Harderwijk, held on 31-7-2019;.

Appendix A

Interviews and survey for the validation of the MMUM

Interviews and a survey were performed to validate the MMUM ratings by the author for each system. The outcomes were combined, and gave adjusted (validated) scores for each MMUM analysis.

A.1 Interview

Two semi-structured interviews were held to confirm the findings of the MMUM. The two interviewees were selected for their experience with urban transportation systems. Transcripts of both interviews can be requested from the author.

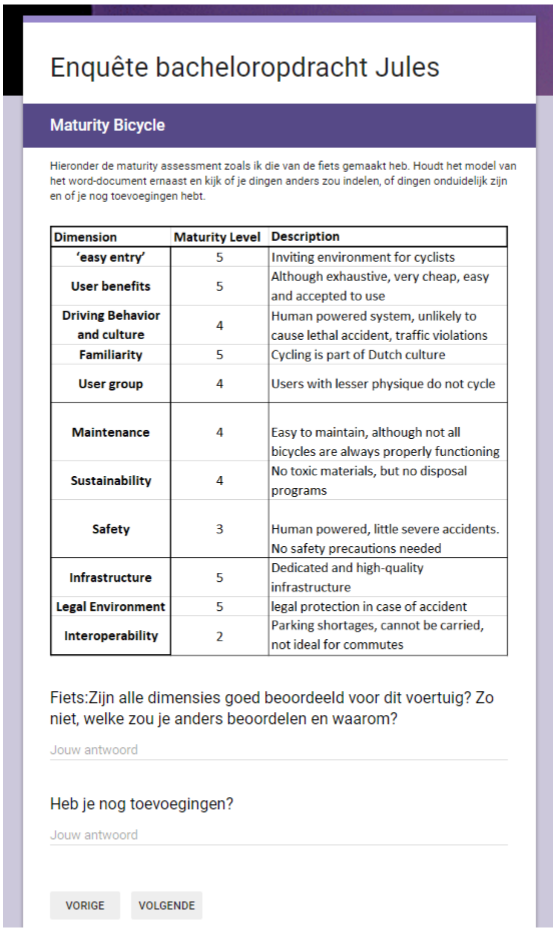
The first interview was held with Ivar Hartogs. He is currently an employee at Trek Harderwijk, and works as a customer service representative. Before that, he engaged enthusiastically in cycling competition and was employed as a bicycle repairman.

The second interview was held with Tamor Hartogs. He is currently the owner of FixieBrothers B.V., a Dutch bicycle brand. FixieBrothers B.V. currently has two bicycle repair shops in the Amersfoort region, a large fleet of rental bikes and is known to offer tailored solutions for customers bicycle needs.

Both interviews followed a similar structure. First, a small introduction on maturity models, the systems considered and the designed MMUM was discussed. At this point, both interviewees were asked if dimensions were accurately described, and if other dimensions could be at play. After establishing a basic understanding of the MMUM, the maturity analyses for each system as done by the author were discussed with the interviewees. Reasoning behind each score was discussed, and they were asked if they would score certain dimensions differently, and why. These comments were later combined with the outcomes of the survey, to come up with validated scores for the dimensions.

A.2 Survey

Similar questions were asked during the online survey. Respondents were given a PDF in which a basic explanation for a maturity model, the MMUM, and explanation of dimensions were given. In the PDF, a link for a Google Form environment was given for the respondents. For each rated system, the respondents were asked for their views on the given scores, and if they would rate something differently themselves or why. An example of the questions asked is given in Figure A.1.



Enquête bacheloropdracht Jules

Maturity Bicycle

Hieronder de maturity assessment zoals ik die van de fiets gemaakt heb. Houdt het model van het word-document ernaast en kijk of je dingen anders zou indelen, of dingen onduidelijk zijn en of je nog toevoegingen hebt.

Dimension	Maturity Level	Description
'easy entry'	5	Inviting environment for cyclists
User benefits	5	Although exhaustive, very cheap, easy and accepted to use
Driving Behavior and culture	4	Human powered system, unlikely to cause lethal accident, traffic violations
Familiarity	5	Cycling is part of Dutch culture
User group	4	Users with lesser physique do not cycle
Maintenance	4	Easy to maintain, although not all bicycles are always properly functioning
Sustainability	4	No toxic materials, but no disposal programs
Safety	3	Human powered, little severe accidents. No safety precautions needed
Infrastructure	5	Dedicated and high-quality infrastructure
Legal Environment	5	legal protection in case of accident
Interoperability	2	Parking shortages, cannot be carried, not ideal for commutes

Fiets:Zijn alle dimensies goed beoordeeld voor dit voertuig? Zo niet, welke zou je anders beoordelen en waarom?

Jouw antwoord

Heb je nog toevoegingen?

Jouw antwoord

VORIGE VOLGENDE

Figure A.1: The format in which questions were asked for each system (Dutch).

Additionally, at the end respondents were asked for their views on the weight factor for each category of dimension. Respondents were asked if the three categories should equally make up the overall maturity, or if one category is considered to be of more influence than another. Additionally, respondents were asked to give additional (general) comments were applicable. Figure A.2 shows the final questions.

The survey was filled in by 24 respondents. Respondents were mainly University of Twente students, both bachelor and master level. Responses were automatically collected in an Excel file, which can be requested from the author.

The outcomes of the survey and interviews were interesting to consider. Scores were often times done well according to the respondents, although some dimensions were often pointed out by a larger number of respondents as being incorrectly graded. Respondents often only gave minor corrections (one point up or down), and often used similar reasoning. If a dimension was pointed out several times, with similar reasoning, the adjusted score was put into the validated MMUM scoring.

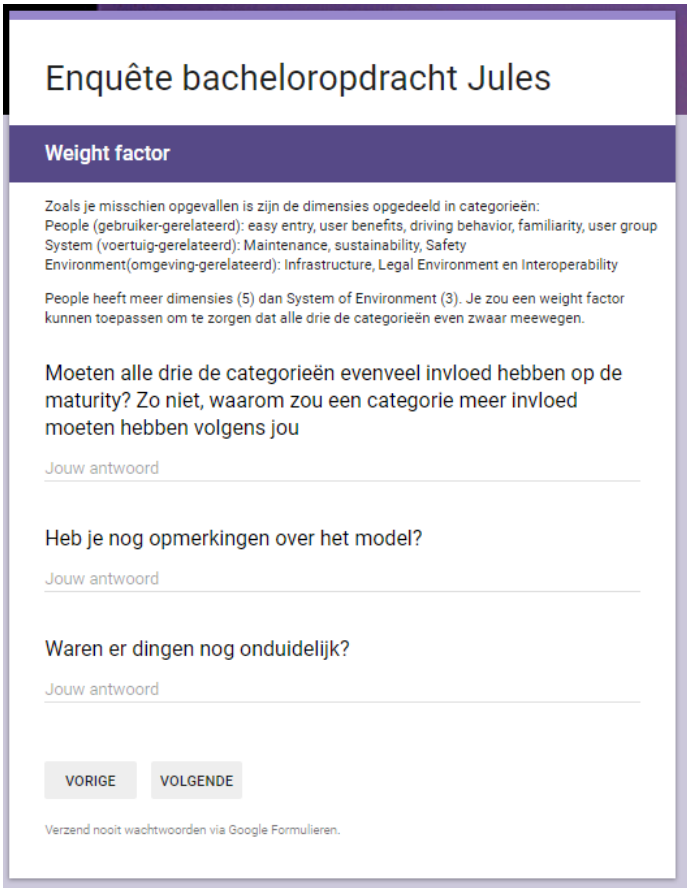


Figure A.2: Final question of the survey, on the weight factor and additional comments (Dutch).

Appendix B

Recommendations for future research on PUM

In this appendix, recommendations for future research on the subject of PUM, the Safety Cube or MMUM are given.

First and foremost, is the fact that this analysis is done for urban regions in the Netherlands. It might be interesting to design a maturity model for urban mobility for more general use. This could lead to different dimensions all together, but also other decisions in terms of weight factors or level definition. By doing so, relevant comparisons can be made between systems in different environments.

To construct some sort of measure for how 'future-proof' a system is, can also be viable. The considered policy documents gave some insight into what is important for a future system. A system that is matured today, is not necessarily adapted for the future. A measure on how sustainable, safe, interoperable or road-test ready for example a system is, can give new insights for future designers.

Furthermore, the comparison of systems currently excludes some other modes of transportation. It could be interesting to also consider the use of walking and combustion engine vehicles such as mopeds or cars. Even including handicapped vehicles could give new insights, as there is often differentiation in legislation for this category.

More in depth recommendations include the dimension 'safety': often times mention is made of 'safety'. The way people perceive *safety* and how safe a system really is depends on general opinion, but also some form of accident statistics. To analyze a systems safety features (safety, driving behavior, structural integrity etc.), more information has to be sought after. Including more references in the form of relevant accident statistics, surveys for general opinion or structural analysis with for example crash tests can give new information.

Also the possibility of misuse is something that needs to be considered further. People using the system seem to contribute largely to how well it is maintained, driven, and interacted with. As this is something that is hard to quantify, it might be interesting to qualify the (mis)use. Looking further into how people (mis)treat the system in different ways can give valuable insights for design choices. By finding a way to qualify misuse, more relevant comparisons can be made. Defining a scale for different kinds of misuse, and validating by survey or otherwise could prove insightful.

The sustainability dimension would also benefit from extra attention. Currently, only differentiation is made between systems with or without toxic materials. When you take into account the entire lifecycle of a system, including the production and disposal stages, the sustainability of a system can be more accurately determined.

Outcome of the survey also suggested it might be worthwhile to look into differentiation in weight factors between dimensions. Some dimensions can be considered more important than others, depending for what problem you're optimizing for. If optimization for safe road use is the case, the dimensions 'safety', 'infrastructure' and 'driving behavior' are more important to consider than the others, and should have a larger weight factor.

Legislation and regulation often times turned out to be crucial to a systems use. Looking more into *why*, *how* and *in what context* some regulative decisions are made, can give insight on how to identify challenges for not only designers, but also legislators.