TRAFFIC MODELLING AIMED AT ASSESSING WELL-BEING

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Summary

Background: Traffic micro-simulation models are an important tool for assessing (future) traffic scenarios. A trend has emerged in which there is more attention towards well-being (Dutch: 'brede welvaart') in policy-making. Including well-being in mobility-related policies is likely to become a requirement for future policies. Many analyses regarding mobility are executed using traffic micro-simulation software. Therefore, there will be a need for a possibility to assess well-being using this type of software. At the moment there is no such method available, which is why a framework is set up to allow for an assessment of well-being using traffic simulation models.

Method: As well-being is a very broad term first it is investigated what the mobility aspect of it actually entails. This mobility aspect consists of four dimensions, which are living environment, accessibility, safety and health. For the assessment of well-being, seven indicators are defined and a relation between the indicators and the simulation software is defined. These seven indicators represent three of the four dimensions directly, with the missing dimension of health indirectly involved in multiple indicators. These seven indicators are emissions – gases, emissions – noise, paved surface area, travel time loss per person, the attractiveness of public transport, the attractiveness of active modes, and traffic safety. Using a survey among traffic engineers it is investigated whether the seven indicators are regarded as equally important. Due to the great variance between responses and the fact that different situations require different rankings of indicators, it is necessary to establish a dedicated ranking of indicators for every study area. There is no general relative importance between indicators available that can be applied universally.

Framework: The framework that is created consists of three separate parts, although for each part a distinction is made whether results for an indicator can be obtained using traffic simulation software or not. For the simulation indicators, different variants for the same study area need to be compared. The first part for simulation is gathering results for the seven indicators by making use of traffic simulation software. These results need to be normalized so they can be compared to each other. The second part is the establishment of the relative importance of indicators. This should be achieved by communicating with local authorities, local residents and the input of an experienced traffic engineer. The third and final part is combining the results of the first two parts to obtain a well-being score for the simulation part.

For the non-simulation indicators, the three parts are very similar. For the first part data needs to be gathered instead of obtaining results. The second part is a priority list of indicators, rather than a list of factors per indicator. The third part also combines the outcomes of the first two parts to obtain the well-being score for the non-simulation indicators.

The overall score resulting from the framework for well-being is the combination of both the simulation and non-simulation indicators.

Discussion and conclusion: Well-being is a very broad term which makes it difficult to assess, even though only the mobility aspect of it is investigated. Seven indicators are a low amount to make a proper assessment. However, the seven indicators are well spread across the different dimensions of the mobility aspect. This makes the outcomes of the simulation part of the framework useful to gain insight into the impact of different variants on well-being. For the case study that is performed as an example of how the framework can be applied several assumptions are made that need closer inspection before the actual implementation of the framework. The impact of heavy traffic and the effect of variants on the modal split are not taken into account properly for the case study.

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1. Introduction

Traffic simulation models play a major role in transport engineering. These models can be used to assess a whole range of goals. They allow for an analysis of a current situation or potential future scenarios. Traffic models are often used to assess the performance of such situations. They can for example be used for an analysis in minimizing travel time loss, for determining the emissions in a network, or to gain insight into the traffic safety of a network. Traffic simulation results are often used in transport-related policy-making decisions. For example, if the outcome of a traffic study into travel times results in one proposed solution with only half the travel time loss as another proposed solution, the first option is more likely to be chosen as the final solution. There are more factors influencing the decision-making process, but traffic simulation results often influence the final decisions.

In the policy-making domain in the Netherlands, a new trend is emerging. Well-being[1] is becoming increasingly important, as is backed by the fact that a political party has included well-being in its party program for the 2023 national elections (NOS, 2023). Furthermore, well-being is incorporated into the national budget of the Netherlands (CPB/PBL/SCP, 2022). The aim of including well-being in policymaking is to improve the living standards for everyone in the Netherlands. The literal translation of well-being in Dutch shows that prosperity is shared on a broad level, so for as many people as possible. In this context, well-being not only includes proper financial stability, but also health and happiness for example.

The inclusion of well-being into policy documents is a big step towards improving well-being. However, the mobility aspect of well-being is not captured to its full extent in current mobility policies (Snellen et al., 2021). Most striking is that there are no suggestions for assessing well-being regarding mobility. Thus, it is unclear how well-being, specifically its mobility aspect, can be improved upon, as it is unclear what the current situation is. Nevertheless, there is a desire to assess the well-being of mobility-related policy issues.

Since the attention towards well-being is relatively new, no method of assessing mobility-related well-being has been developed yet. There are, however, many studies that examine individual aspects of well-being like traffic safety or the impact of transport-related emissions, although none of these studies combine different aspects intending to assess well-being. Well-being has many aspects to it which makes an analysis of it very complex. When the current trend towards improving well-being continues, there will be a need to assess well-being before the implementation of a (construction) project. To prevent having to perform multiple studies, each aimed at a different indicator for well-being, a framework for an overarching study into mobility-related well-being should be created. Such a single study would not only result in a better insight into well-being, but it will also save time since only one study is necessary rather than multiple ones. Furthermore, because all studies into well-being are performed using the same method the results of the studies can be compared in a more trustworthy way than when results of different types of studies need to be compared.

[1] In Dutch: ‘brede welvaart’, literally ‘broad prosperity’ in English

Traffic simulation models are an interesting means to assess mobility-related well-being. Simulation software could be used to not only examine travel times but other factors of well-being as well. Traffic safety and vehicle emissions are two examples of aspects of well-being that can be assessed using traffic simulation software. It is therefore likely that more aspects of well-being can be assessed using this type of model. The more aspects of well-being can be assessed via traffic models, the more complete an analysis of mobility-related well-being is. Nevertheless, it is unfeasible to assume that every aspect of mobility-related well-being can be assessed using traffic models. Therefore, in a framework, it is necessary to also include space for aspects that cannot be assessed via traffic simulation models.

In the next section, the research questions are introduced. To answer these questions a literature review is performed, which is the first chapter of this report. After that, the methodology of the research is explained. Next, the survey that is held is explained. The outcome of the survey is elaborated on in the chapter for the survey as well. The software that is used for the case study is introduced in chapter 5, followed by the chapter in which the case study is presented. Not only is the case study introduced, but also the results of the case study are in this chapter. In chapter 7 the framework that is set up for this research is introduced. Finally, the report ends with a discussion and conclusion.

1.1. Research questions

Concluding from the introduction, there is a need for an analysis, or at least a framework for an analysis, that allows for the assessment of well-being regarding mobility. Therefore, the following research goal is formulated:

Create a framework for the assessment of mobility-related well-being that uses indicators that can be derived from a traffic simulation model

To achieve the goal as stated above the main research question is as follows:

Main research question

How can traffic simulation results be used for an analysis of a study area when assessing people's well-being is the main criterion?

To make sure that the main research question can be answered the research needs to be well-structured. This will be done by answering the following sub-questions first, which are each divided into sub-questions again. This further subdivision is done to make sure that all aspects are investigated, as well as ensuring that the research is guided in the right direction.

1. What is the role of mobility within the overall concept of well-being?
2. How can results be obtained for indicators for the mobility aspect of well-being using a micro-traffic simulation model?
3. How can indicators of the mobility aspect of well-being be applied in a framework for assessing well-being?

2. Literature review

As the research is originally aimed at a Dutch context, the Dutch term ‘brede welvaart’ is considered for the literature review. However, since this is a relatively new term there is no consensus yet on how this should be translated into English. There are multiple suitable translations to English, and which translation is used differs per source. Dutch sources citing English articles generally contain either ‘beyond GDP’ or ‘well-being.’ Therefore, both these terms are used for the literature review and are interchangeable.

2.1. What is ‘beyond GDP’ or well-being?

Well-being in general

Beyond GDP was a relatively unknown topic until the report by Stiglitz, Sen, and Fitoussi (2009). This report aims to determine how economic performance and social progress can be better examined, since only considering the GDP does not provide enough statistical insight into the state of a country. In this report, not necessarily many new insights are presented. Instead, it is an overview of the then-existing knowledge and applying this knowledge to obtain useful tools for future use of beyond GDP (Michalos, 2011; Vanoli, 2010). However, there already was a conference in November 2007 by the European Union at which the main discussion was about why looking beyond GDP is necessary for the future (European Commission, 2007). A major problem of beyond GDP is that many indicators are necessary to determine the actual values for well-being (OECD, 2014). These indicators are not the perfect solution, but they are a good approach for determining well-being, as long as proper attention is paid to the relative importance of indicators (Fleurbaey, 2009).

Beyond GDP (Gross Domestic Product) is a very broad term of which there is no single definition in literature (Stolwijk, 2010). The term ‘beyond GDP’ clearly implies that it goes further than just GDP. Beyond GDP is not just a single number that describes the (financial) performance of a country or area, which is what GDP is used for (OECD, 2023). Beyond GDP encompasses multiple indicators that represent the level of well-being of people. The main disadvantage of using GDP to describe well-being is that it can give a very skewed image, as it does not reflect the situation of individual people, but rather of an entire population. GDP itself was never designed to be an indicator of well-being in a country (Aitken, 2019). For example, if in a country the upper 75% of people are financially very well off, while the bottom 25% are struggling to make a living, the GDP of that entire population will still be relatively high. In other words, the GDP does not accurately represent the level of well-being of every citizen (Badir et al., 2017). With beyond GDP the heterogeneity of a population is much better taken into account. This is because the individual or household situations are addressed rather than putting the situations of an entire population in just a single value (Aitken, 2019). Within a population there can be major differences in living conditions, which is taken into consideration in beyond GDP, but is left out of the scope of GDP. Beyond GDP, or well-being, therefore represents an improved image of the quality of living for a population.

Well-being in European context

Stiglitz et al. (2009) researched beyond GDP, but they did not come up with a definition of it. In fact, there is no consensus on a definition of beyond GDP in literature. The definition of beyond GDP differs per source and is generally dependent on how and why beyond GDP is used. Nevertheless, Stiglitz et al. (2009) came up with a list of items that they think should be included when setting up a definition of the multidimensional concept of well-being:

i. *Material living standards (income, consumption and wealth);*
ii. *Health;*
iii. *Education;*
iv. *Personal activities including work;*
v. *Political voice and governance;*
vi. *Social connections and relationships;*
vii. *Environment (present and future conditions);*
viii. *Insecurity, of an economic as well as a physical nature.*

> *All these dimensions shape people's well-being, and yet many of them are missed by conventional income measures.* (Stiglitz et al., 2009, p. 14)

One of the definitions of well-being that can be found in literature is as follows: "A broad concept which is not confined to the utility derived from the consumption of goods and services, but is also related to people's functioning and capabilities (i.e. the freedom and possibilities they have to satisfy their needs) (Smits & Horlings, 2019, p. 6; UNECE/Eurostat/OECD, 2014, p. 5)." The most important aspect of this definition is that not only should be assessed what people own or have but also what they can do to improve their lives. This is not limited to physical assets only, as the mental aspect is an often overlooked part of well-being that should also be taken into account (Boelhouwer, 2016).

According to the European Social Partners (ESP), well-being can be subdivided into three important categories, namely social, economic, and environment (European Social Partners, 2021). This can be seen in Figure 1. Considering sustainability the same three factors are sometimes called the 'three Ps': People, Profit and Planet (Bingen et al., 2021; Snellen et al., 2019). These three Ps are directly connected to the categories set up by the ESP. The factors Social, Economic and Environment are replaced by/connected to People, Profit and Planet, respectively.

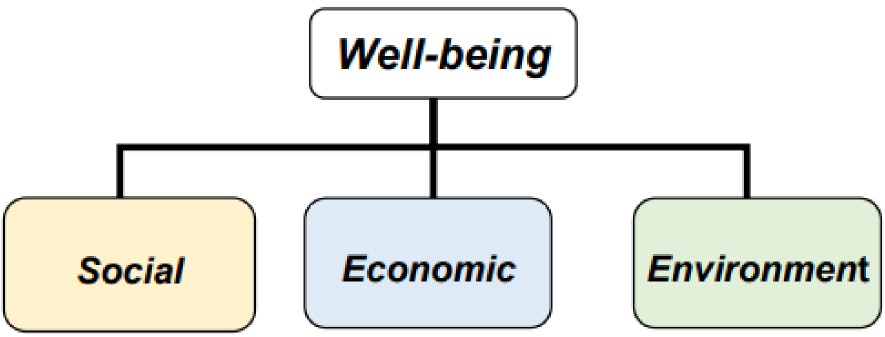


Figure 1 - Factors of well-being (European Social Partners, 2021)

Well-being in Dutch context

The CBS (Dutch Statistical Agency) uses a different approach to well-being than the European as mentioned in the previous section. The translation of the definition by the CBS is: "Well-being considers the quality of life in the here and now and the extent to which this would be at the cost of future generations and/or of people elsewhere in the world (CBS, 2021, p. 33)." Interestingly to note is that the CBS considers the quality-of-life aspect but does not mention which elements should be assessed to determine this like Stiglitz et al. do.

Of the three categories depicted in Figure 1, the category of Environment gets the most attention in the Netherlands (PBL/CPB/SCP, 2018; PBL/SCP/CPB, 2017; Raspe et al., 2019). However, Terzi (2021) also mentions that sustainability is an important factor to keep in mind when making policies. The report by PBL/CPB/SCP states that their attention should not only be on the here and now but also on what effects might be in other places in the world and how current behaviour affects future generations. They argue that events that occur in the present should not negatively influence the future. A solution that could improve the welfare and well-being of people living now but would imply that future generations cannot live under the same standards as now is not a viable solution. Instead, there should be looked at an option that might be a little worse for now so that future generations can thrive as well.

Policymakers in the Netherlands are increasingly interested in implementing well-being in their policies. Evidence of this is that in 2021 three Dutch planning agencies started looking into possibilities to incorporate well-being into the national budget (CPB/PBL/SCP, 2022). The agencies look into the consequences of well-being-oriented policy-making. The Netherlands is not the first country to focus on well-being, but there are very few that have done it before, especially regarding infrastructure (Bartelet & de Gooyert, 2021).

According to Goudappel, well-being consists of five main goals, as depicted in Figure 2 (Goudappel, 2023). Although according to Goudappel there are five main goals, three goals are enough to fully describe well-being if they are subdivided according to the division in Figure 1. Social inclusivity can be considered as a social factor. Equally, economic vitality can be considered as the economic factor and quality of the living environment can be considered the environment factor. For the other two factors, namely health and energy transition it is a little more complicated. Health can be considered as both social and environment because the environment can cause diseases or illnesses, while the social aspect of health should not be underestimated. Energy transition can be both economic and environment, as the transition will have high investment costs (economic), but should improve the state of the environment, as the transition is aimed at doing just that.

Figure 2 – Main goals of well-being according to Goudappel (Goudappel, 2023)

Assessing well-being

There are many different methods for assessing the level of well-being (Hoekstra, 2019). One of these was created by researchers from Rabobank and Utrecht University, which is called the Brede Welvaartsindicator (BWI). The BWI is a single number that represents the level of well-being for a certain area (Badir et al., 2017; Bavel et al., 2019). For setting up this indicator 21 different variables are examined across 11 dimensions. Although these are quite some variables, it can be assumed that many aspects of well-being are not fully considered in the BWI. This assumption is possible since from other sources it becomes clear that well-being can be much broader than what can be captured with 21 variables. Nevertheless, the fact that there are 11 dimensions means that the BWI has a solid foundation, although a higher number of variables and dimensions would result in a more accurate representation of well-being.

Following the approaches to well-being and the subdivisions as shown in Figure 1 and Figure 2 it can be concluded that no general consensus exists on what well-being means or how to describe it, even though there are similarities between them. This lack of consensus does not mean that no efforts are made to try to assess overall well-being, as is shown by the BWI. Nevertheless, across the different sources, the main line becomes clear on how a definition should be set up. Included in a definition should be the many different factors that influence living situations. Not only monetary assets are important, but also other factors influencing people's lives like social contacts and health for example. Furthermore, well-being should not be at the cost of others, not for people living elsewhere in the world nor for people in future generations. A general consensus on well-being is important for an assessment of well-being since it needs to be known what such an assessment should actually assess.

2.2. Well-being and mobility

The current assessment methods for mobility and accessibility are focused too much on capacity and travel time reduction, which often leads to a decrease in well-being (Voerknecht, 2021). Furthermore, the Dutch environmental assessment agency (PBL) explored what well-being means for mobility in the Netherlands (Snellen et al., 2021). In this document, Snellen et al. outline multiple implications for policies regarding mobility and well-being. The most important implication they recognize is the problem that considering every factor of well-being is practically impossible. This is why it is important to carefully consider what factors influence a certain policy and should thus be included in an analysis. According to Virág et al. (2022) expanding the mobility infrastructure network hardly improves well-being in the Netherlands. They advise that new policies should therefore aim to reduce resource use and stimulate active modes and public transport. For public transport, it is necessary to focus more on connections with bordering countries, as those facilities are currently insufficient (RLI/ROB/RVS, 2023). Another study suggests that attention should be paid to policies addressing the mobility situations of people who are (at risk of being) transport disadvantaged (Currie et al., 2010).

Deciding on which policy is best for an area also implies choosing what type of ethical decision you are going to make (Snellen et al., 2021). There is a difference between improving something for most people (utilitarianism) and making sure that the minimum level of existence is increased (sufficientarianism). There even is a third option which aims to reduce inequality differences among people (egalitarianism). When well-being is spread unevenly across a country the inequality will likely lead to lower overall well-being, and it can even undermine national objectives (OECD, 2014; RLI/ROB/RVS, 2023). This is because if well-being is spread unevenly people will move to places where well-being is high (often cities), causing the more rural areas to become less interesting to live, thus decreasing the well-being in those areas even further.

Dimensions of mobility in well-being

There is an abundance of indicators that could be considered to determine well-being. Not all indicators are equally important, especially when only the mobility aspect of well-being is considered. Some indicators are subjective and will therefore have different values according to the perception of people. Even when a set of indicators is established the relative importance might differ between regions (OECD, 2014; RLI/ROB/RVS, 2023; Thissen & Content, 2021). Rural regions in the Netherlands have seen (governmental) institutions disappear in the past years, which decreases the liveability in those regions. This is partially done with the idea that creating strong regions will eventually cause other regions to grow accordingly. However, the opposite effect is reached via this policy (RLI/ROB/RVS, 2023). The economically weaker regions only get weaker due to people and activities moving to the economically stronger regions, which causes people in the weaker regions to have to travel further to activities. A side effect of this is that the trust in the government decreases in the weaker regions.

Snellen et al. (2021) mention four dimensions of well-being that are important for mobility, which are visualized in Figure 3. Not all factors of these four dimensions have a positive effect on well-being, as follows from the health dimension where harmful emissions have a negative influence, as opposed to the positive influence of exercise. Increasing accessibility is another dimension with mixed effects since a higher accessibility could result in higher transport costs or the removal of a nature area (RLI, 2021). These four dimensions are different from those set up by Goudappel or the ESP, although there is a clear overlap between some dimensions. Health and living environment can directly be connected to the same dimensions as mentioned by Goudappel. Accessibility is mostly comparable to social inclusivity, whereas safety is broad and can be subdivided into almost all categories from Goudappel. The differences in dimensions can be explained by the fact that for the dimensions, as seen in Figure 3, the focus is only on the mobility aspect of well-being. Since mobility is only one aspect of well-being it is possible to narrow down on the dimensions that are relevant for the mobility aspect specifically.

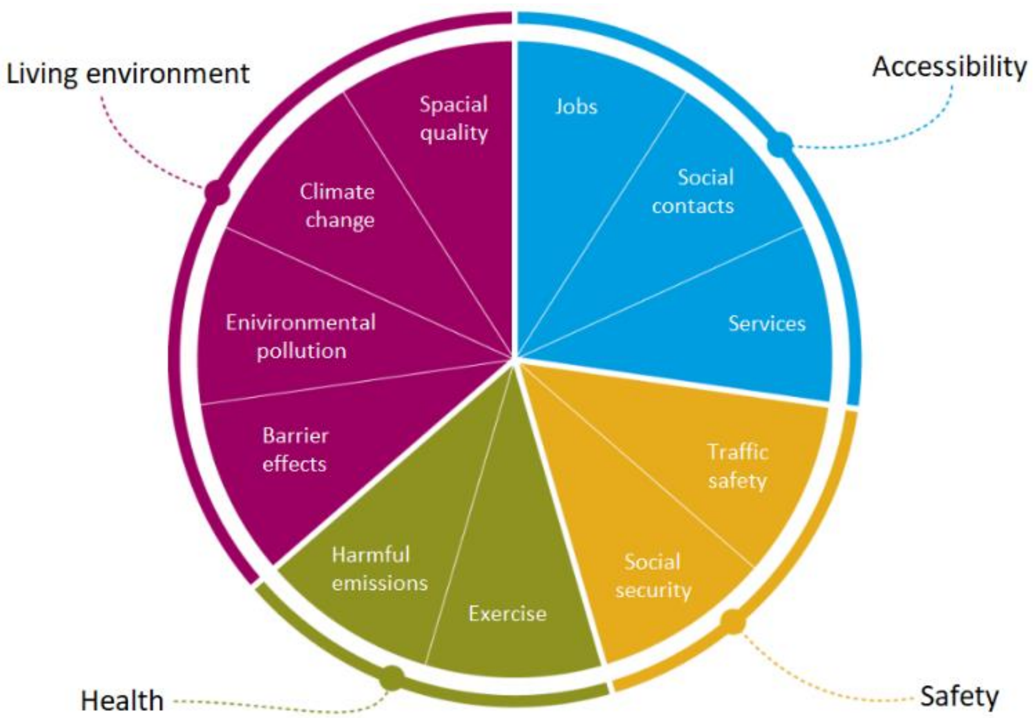


Figure 3 - Dimensions of well-being concerning mobility (Snellen et al., 2021)

Monitoring well-being

Although the Monitor Brede Welvaart (CBS, 2021) is a good outline of the situation considering well-being in the Netherlands it does fall short for the mobility aspect specifically (Visser & Wortelboer-van Donselaar, 2021). Visser and Wortelboer-van Donselaar, who work for the Kennisinstituut voor Mobiliteit (KiM), also note that there is attention only to reducing travel times and reducing congestion regarding the mobility aspect of well-being. However, they find that the Sustainable Development Goals (SDG) set by the United Nations consider the mobility aspect better, although this is still not sufficient. Currently, only the costs of mobility are included for the well-being aspect in the SDGs, which is also the case in the Monitor Brede Welvaart (MBW). Therefore, Visser and Wortelboer-van Donselaar suggest that the benefits of mobility in the form of accessibility should be evaluated as well. This addition is supported by Thissen and Content (2021), especially regarding the subjective value that is perceived accessibility. After all, in cities other activities might be perceived as important than would be the case in rural communities. To address accessibility, from 2022 onwards the Dutch national travel survey (ODiN) contains a question of what the perceived accessibility is of a destination. It is not yet possible to spot trends in the data achieved from this, as only the data from 2022 is known and no data from other years yet. The perception of accessibility is comparable to the travel experience, as negative experiences can also negatively influence well-being due to stress for example (Vos et al., 2013).

Not only (perceived) accessibility is important to consider for mobility, but also the living environment and safety are necessary for a good analysis. Examples of indicators for these factors are noise pollution for the living environment and traffic safety for the safety factor. Both the values for these indicators are improved by lowering the speed limit (Baat et al., 2021). However, both these factors, and thus the indicators as well, are currently left out of the MBW. These factors should be addressed when assessing the state of well-being for an area. Currently, the assessment of well-being in general is done by setting up a Social Cost-Benefit Analysis (SCBA). However, at the moment, this method is not sufficient to determine the mobility aspect of well-being accurately (Visser & Wortelboer-van Donselaar, 2021).

Furthermore, according to Vonk Noordegraaf et al. (2021), the mobility aspect of well-being is currently used incorrectly in SCBAs. In the report is stated that although there is attention to mobility, there is no attention to what it means for well-being. This is because mainly the financial effects of changes in mobility policies are inspected. It is not possible to determine for every effect what the monetary impact is. This is supported by the RLI (Dutch environmental and infrastructure advisory agency) who state that it is difficult for some relevant mobility aspects to be put into monetary value (RLI, 2021).

Another negative influence of the use of SCBAs is the fact that it excludes possibly viable options early on in the decision-making process. In practice, most traffic solutions are evaluated on goal realisation (does it solve the bottleneck?) and costs of implementation. By only looking at these two aspects the effects on well-being are mostly left out of the decision-making. The result of this is that good solutions for improving well-being are not even considered after the first stage in the process (RLI, 2021). In April 2022 the Dutch government acknowledged that changes are necessary to, among others, SCBAs to include a better well-being perspective, especially regarding the role of public transit (Ginneken & Bouchallikh, 2022).

2.3. Indicators for the mobility aspect of well-being

There is an exploration by TNO that focuses on defining indicators for well-being in the mobility domain (Vonk Noordegraaf et al., 2021). However, the presented list of indicators is still insufficient according to the authors. Not only do they think that the presented list is incomplete, but some of the presented indicators are not properly measured yet. This is partly due to the lack of consensus on the definition of well-being, as well as the fact that transport and mobility are still evolving. Examples of this evolution are that more people will live in cities in the future, and more information on travelling can be found online (digitalization). Furthermore, for many factors of well-being, there is not enough data available (yet) to be able to use those indicators. This lack of data is mainly because the indicators are new and no effort has been made to gather data for these indicators. When simulation software is used the results for indicators are created. Therefore, there is no problem with the lack of data for indicators for which results can be obtained using traffic simulation software. The exploration can be used as a source for establishing indicators useful for this research.

For this research indicators for the mobility aspect of well-being can generally be divided into two groups. The first group consists of indicators for which results can be retrieved using traffic simulation models, while for the second group, it is not possible to use traffic simulation models to obtain results. The exploration by Vonk Noordegraaf et al. (2021) contains indicators for both categories. Most indicators in this exploration are not suitable for simulation. For example, it is impossible to determine the emotional impact of a trip using traffic simulation software.

Most attention in this research is towards the group of indicators that can be assessed using traffic micro simulation software. The goal of this research is to find a method for assessing well-being using this type of software. Therefore, a list of indicators suitable for simulation purposes needs to be created. The document by Vonk Noordegraaf et al. (2021) is used as an inspiration for some of the indicators, although not all indicators follow from this document. Table 1 contains the list of indicators for which the traffic simulation software can be used. The indicators are sorted by the four dimensions of the mobility aspect of well-being as described in section 2.2.

Table 1 - Overview of indicators per dimension of the mobility aspect of well-being suitable for simulation purposes

Dimension	Indicator
Living environment	Emissions – Gases
	Emissions – Noise
	Paved surface
Accessibility	Travel time loss per person
	Attractiveness active modes
	Attractiveness Public Transport
Safety	Traffic safety

The chosen indicators that are shown in Table 1 are suitable for simulation purposes. There are many traffic studies into these indicators, although no studies exist in the literature that combine these indicators intending to assess well-being. There are, however, studies that consider multiple indicators at the same time. For example, some studies combine both emissions and traffic safety, although these indicators are considered separately (Possel et al., 2018; Song et al., 2020). Other research focuses on the effects of emissions (Chen et al., 2022) or uses indicators separately for an assessment of turbo roundabouts (Anagnostopoulos & Kehagia, 2018). In conclusion, there are no studies that look beyond, let alone combine, multiple factors for an assessment of well-being.

The indicators in Table 1 are suitable for micro-simulation purposes. However, when the scale of the simulation is different, a macro-simulation study for example, these indicators are not necessarily suitable. Especially the accessibility indicators could be changed to the number of destinations that can be reached within a certain amount of time. The attractiveness of the alternative modes should also use this type of accessibility at a macro level. Since this research focuses on micro-simulation the indicators will be worked out further for that type of simulation study.

With the focus on indicators that are suitable for micro-simulation purposes, it might seem that non-simulation indicators are not important for the assessment of well-being. However, for an assessment of such a broad concept as well-being both simulation and non-simulation indicators should be taken into account. The non-simulation indicators are therefore incorporated in the final framework for assessing well-being. Nevertheless, the exact application of how these indicators can be used for an assessment is outside of the scope of this research.

The seven indicators set up for simulation purposes are spread across the different dimensions of the mobility aspect of well-being. Therefore, the elaborations on these indicators are sorted per dimension in sections 2.3.1 to 2.3.3. Even though there is no direct indicator for health it is still indirectly involved in multiple indicators, which is explained in section 2.3.4. For all seven indicators suitable for simulation there is an elaboration on why they are chosen and what their effects are on well-being. For the health dimension, the indirect involvement in some indicators is given instead of the elaboration on the relevant indicators for that dimension. Chapter 5 explains how results for each indicator are obtained from the simulation software.

2.3.1. Living environment

Emissions – Gases

One of the indicators taken from the list of indicators as set up by Vonk Noordegraaf et al. (2021) is the emission of gases. There are many different gases which all have an effect on the environment and/or the health of people. However, only three different emission gases are considered in this research: CO_2, Nitrogen and particulate matter. These three gases are the most influential gases resulting from transport (Johnson, 2015; Vonk Noordegraaf et al., 2021).

Many different gases can influence the climate, but the most well-known of these is the greenhouse gas CO_2. This gas is considered the most important greenhouse gas due to human activity (EPA, 2023). Because this is such an important greenhouse gas the effect of other greenhouse gases is compared to CO_2. This CO_2-equivalent differs per type of gas. For example, the CO_2-eq of methane is 28, meaning that the greenhouse effect of methane is 28 times as strong as an equal amount of CO_2 would have.

Recently, nitrogen has become a hot topic in the Netherlands. Not necessarily nitrogen itself is meant here, but rather gases that contain nitrogen like nitrogen oxides (NO_x) and ammonia (NH_3). Ammonia is mostly an agricultural emission, whereas nitrogen oxides are a result of transport and industry (RIVM, 2023). An excess of nitrogen oxides in the air is harmful, especially for people who already have lung issues or who suffer from asthma. Nitrogen also impacts biodiversity by making the soil rich in nutrients where this normally is not the case. This causes plants that do not like nutrient-rich soil to lose out to plants that thrive in such soils. Furthermore, nitrogen oxides could cause acid rain (Boningari & Smirniotis, 2016).

Not necessarily a gas, but still part of the emissions from vehicles is particulate matter. Particulate matter can consist of many different types of materials and sizes, but for this research particulate matter up to 10 microns is considered. These particles are so small that they float in the air and can therefore be inhaled into the lungs. There they can cause pulmonary and cardiovascular diseases, as well as different types of cancer (Sacks et al., 2011; Schwarze et al., 2006).

For all three emission gases, the exact effects on humans differ. However, they do have in common that an increase in emissions would lead to adverse effects on human health. Thus, it is assumed that for all three emission types a reduction in emissions is beneficial for well-being.

Emissions – Noise

An excess amount of noise can cause many different health problems. These problems are not limited to physical problems, but can also include psychological issues (Geravandi et al., 2015; Goines & Hagler, 2007). Noise from transportation, in particular noise coming from road traffic, is the most common source of noise pollution in cities (Murphy & King, 2022). Although there have been some improvements in reducing noise nuisance, these measures have mostly been to increase driver comfort. Drivers experience increasingly less engine noise while driving, but noise nuisance reductions for people outside of vehicles are lagging.

The two main types of noise created by vehicles are engine noise and tyre noise. Other sources of noise include air resistance noise, which is mostly for vehicle occupants, and brake noise, which for passenger vehicles is negligible on well-working brakes (Schlagner & Wagner, 2009). For heavier vehicles like buses and trucks braking noise could be a factor, but how much is dependent on the state of the brakes as well as how heavy a vehicle is. Engine noise consists of noise coming from the combustion engine, whereas tyre noise is the noise following the interaction between the road and the tyres. Both are dependent on the speed of a vehicle. Tyre noise is less impactful at low speeds, but when the speed of a vehicle is increased the tyre noise will eventually overtake the engine noise as the main noise contributor (Murphy & King, 2022). It has been known for a long time that the type of road surface directly influences tyre noise, as is already shown by Sandberg and Descornet (1980). Furthermore, it is important to note that electric vehicles have practically no engine noise. This is interesting as the share of electric vehicles in the Dutch fleet is increasing (RVO, 2023).

Paved surface

This indicator is to determine the amount of space that is used for paved surface dedicated to motorized vehicles. There are multiple aspects to this indicator, although not all aspects affect the well-being directly and are therefore out of the scope of this research. However, the concept behind the indirect effects is explained.

The first aspect is the amount of material used for a studied network. If fewer materials are used the impact on the environment is smaller. Generally, resources are obtained at a different location than the study area, meaning that the impact at the source will be less. This is especially important when non-renewable resources are used, as unused resources will still be available in the future (CBS, 2022). Furthermore, if less construction material is used the impact of transport of these construction materials will also be less since there are fewer goods to transport.

The second aspect is that when less space is used for the road surface of motorized vehicles more surface area remains to be used for other purposes. More space could be allocated to active modes by adding a (wider) bicycle lane or by expanding the sidewalk, which could lead to an increase in the attractiveness of transport by active modes (Timms & Tight, 2010). Another option is to use the space for greenery, a tree for example. Not only will the addition of green space make the area more appealing, but it will also improve resilience towards nature. Precipitation can infiltrate the ground better, and the provided shade will reduce heat stress in a city (Ketterer & Matzarakis, 2014). However, as it is unknown what will be done with the additional space if the paved surface area is smaller, this aspect should be considered as an indirect effect.

According to the two aspects mentioned above, well-being increases when reducing the paved surface. However, a reduction of the paved surface could lead to a decrease in accessibility because the capacity of a road might be reduced as there is less space for cars available. Therefore, it is necessary to keep accessibility in mind and not only strive to have as little paved surface as possible. Moreover, the quality of the paved surface is of influence to many other factors of well-being. For example, the type of road surface affects noise emissions resulting from tyre noise.

2.3.2. Accessibility

Travel time loss per person

This is a very traditional indicator for traffic simulations, as this is one of the main indicators for assessing the performance of a studied network. The travel time loss in this study is defined as the additional time it takes for a vehicle compared to a situation in which there is no interference for that vehicle. If there is no interference, the vehicle can go at the desired (or allowed) speed, also at intersections. Generally, a network is deemed to perform better when the total travel time loss is lower. After all, people have to wait less in traffic and can therefore reach their destination quicker. Clearly this results in an increase in accessibility. However, an increase in accessibility might have implications for other factors that influence well-being. Traffic safety, for example, might decrease due to vehicles travelling faster. Vehicle emissions will increase when vehicles travel at a higher speed or for a longer distance.

Travel time loss in simulation software is generally acquired on a vehicle basis. However, not all vehicles have an equal number of people on board. This means that travel time loss results can be very skewed if a bus full of passengers would count the same as a passenger car with only the driver as an occupant. To make travel time loss results more equal the vehicular delay should not be the indicator, but rather the travel time loss per traveller. To do this the vehicular travel time loss should be multiplied by the number of occupants of that vehicle. The effect of this is that a bus that is stuck in traffic has a bigger effect on the total travel time loss than a regular vehicle. This makes it more interesting to design for better public transport, which likely increases its ridership, resulting in fewer vehicles on the road and thus even less travel time loss. According to van Oort (2014), it is even important to consider the number of occupants rather than the number of vehicles when public transport is considered for travel time loss.

Attractiveness active modes

The likelihood of a trip being made by an active mode depends on the attractiveness of active modes. Ideally, people should choose to take a trip using an active mode rather than taking a car, as this would lead to a decrease in car trips. There are many factors influencing the decision of a traveller which mode to take, but the more attractive a trip using an active mode is the more likely a trip using such a mode will be made. More trips by active mode will very likely lead to a reduction in nuisance from motorized vehicles. There will be less emissions from vehicles, which leads to cleaner air, as well as less nuisance from noise. Fewer cars on the road should also lead to fewer accidents, which should improve road safety. Moreover, when people use an active mode they get some exercise which has many health benefits.

One way of improving the attractiveness of active modes is by improving their experience at intersections (Friel et al., 2023). The safety of cyclists differs per intersection design (Anne Harris et al., 2013), which is why it is important to design with cyclists in mind. At signalized intersections, this can be achieved by giving cyclists and pedestrians a green light sooner than they would usually get. At priority intersections there generally is not that much waiting time as there is little traffic that should be waited for. However, at roundabouts active modes should be in priority, meaning that they do not have to wait for cars, but instead, cars have to wait for them. In the Netherlands, this already is the case within built-up areas, but they are generally still out of priority outside of city limits. However, giving more priority to active modes has to come at the cost of other traffic. Motorized traffic will have to wait longer at intersections when active modes are given priority. A balance needs to be found to ensure that active modes are made more attractive while limiting the (negative) effects for other road users.

It is safer to cycle in a place that is dedicated to cyclists. When it is safer to cycle somewhere it becomes more attractive to do so (Bialkova et al., 2022; Hull & O’Holleran, 2014). Cyclists being in the same place on the road as vehicles could lead to dangerous situations, especially when the speed difference increases. Therefore, the realization of dedicated cycle lanes, but ideally separate cycle paths, will increase the safety of cyclists. With separate bike paths, there are very few places where an accident with a motorized vehicle could occur, as they both have their own space. Only at intersections their paths could cross.

When the amount of space dedicated to active modes is increased this will increase the attractiveness of these modes (Friel et al., 2023; Skartland, 2016). When more space is available the risk of an accident decreases. A wider cycle path allows for easier overtaking, which is important due to the rise in e-bike popularity and thus the increase in speed differences between cyclists. A wider pavement means that there is more space to walk freely and pass other pedestrians. Extra pavement space also allows for additional bicycle parking for example. Nevertheless, when the spaces for cyclists and pedestrians are combined, the attractiveness can be negatively impacted (Berghoefer & Vollrath, 2023).

Attractiveness Public Transport

As is the case with active modes, an increase in the attractiveness of public transport should result in an increase in its ridership. There are many ways to improve the attractiveness of public transport, but not all are possible to implement in a static traffic model. The cost of a ticket is impossible to implement in such a traffic model for example. There are, however, other options to make public transport more attractive, which ideally reduces the number of private vehicles on the road. People will be more willing to take public transport if it is a quick, reliable alternative (van Oort, 2014).

A way to increase the reliability of public transport is by giving them priority at intersections. Especially at signalized intersections, it can save a lot of time when buses or trams can immediately cross the intersection without having to wait for a green light (Dumbliauskas et al., 2017). This ensures that public transport vehicles have an advantage over other traffic who have to wait until the public transport vehicle has passed the intersection. According to Dumbliauskas et al. (2017), this should not lead to significant delays for other traffic when implemented properly. In the Netherlands, this absolute priority for public transport is already implemented at signalized intersections. When public transport vehicles can go right away their time table becomes more predictable, which increases the reliability.

Increasing the frequency of public transport has a positive impact on ridership (Brechan, 2017; Jenelius, 2018). This is because with an increase in service, it is more likely that a vehicle suits one's travel needs. There will be less waiting until a vehicle arrives and when a transfer is necessary it is also more likely that another line has a good connection to minimize waiting time due to transfers.

When public transport has a dedicated lane for themselves, a bus lane for example, public transport vehicles will not have to wait for other traffic. They can always continue on their journey while the rest of the vehicles might be stuck in traffic. This measure would therefore increase the reliability and the speed of public transport vehicles, making them a more attractive option to take (Arasan & Vedagiri, 2010). However, the realization of a dedicated public transport lane would require a big investment, and would also increase the total paved surface area. On the other hand, if a multi-lane street is changed so that one of the lanes becomes a dedicated public transport lane the paved surface area would remain the same. However, this would likely harm the flow of regular traffic (Szarata et al., 2021).

2.3.3. Safety

Traffic safety

People want to be able to travel safely, which makes traffic safety an important aspect of well-being. For every mode of traffic safety is important, as it should not matter what mode is taken, people will always want to travel safely. Many aspects influence traffic safety, but not all are possible to take into account in a traffic model.

In order to assess traffic safety in traffic simulation models the amount of conflict points at intersections can be determined. Conflict points are areas where different vehicle trajectories meet. This mostly applies to intersections, since that is where the paths of multiple routes cross each other. These crossing points are potential areas of conflict, meaning that accidents are most likely to occur there.

Incidents between two cars can have very different outcomes than incidents between a car and a cyclist. This is because cyclists can be considered vulnerable road users. Pedestrians and people on mopeds are other examples of vulnerable road users (VRU). Special attention should be paid to these VRUs, as the likelihood of an injury is much higher for them than for people in a car. It is not possible to model single bicycle crashes but crashes between cyclists can be modelled and should therefore be considered in the research.

The maximum allowed speed on a road is of influence on the number of incidents that happen on that road, but also on the severity of incidents. Especially when multiple modes use the same roadway the difference in speed between modes is a factor in crash risk. The lower the speed differences, the better people can adjust to prevent incidents from occurring. Moreover, the mass of a vehicle influences traffic safety. Especially when there is a large difference in vehicle mass the perceived risk for the traveller with the lower mass is increased (Llorca et al., 2017).

2.3.4. Health

Even though there are multiple indicators, there is no direct indicator for the health dimension of well-being, which explains why health is absent from Table 1. Although there is no direct indicator for health, it is indirectly involved in many other indicators.

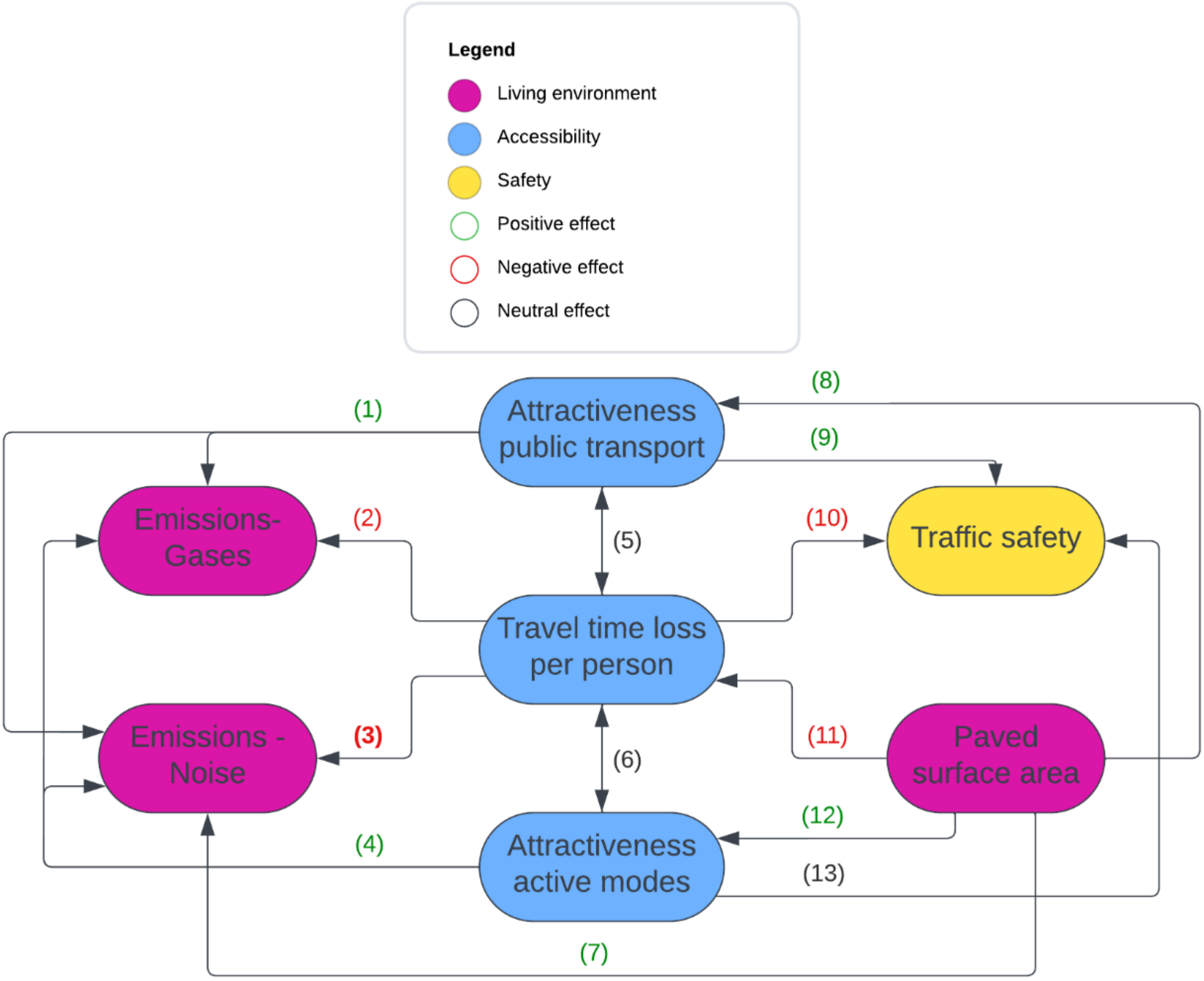
The emission of gases from vehicles leads to polluted air that people breathe. This has a negative effect on the health of people. Even though the effects might be really small per time unit, in the long haul the breathing of polluted air can lead to lung diseases. It especially affects people who already suffer from asthma. Noise can have a negative influence on health as well since it could lead to increased stress or poorer sleeping (Geravandi et al., 2015). On the contrary, a reduction of paved surfaces resulting in an increase in greenery should have a positive effect on people's health. This is because the plants will take up some of the emitted CO_2, as well as provide a positive impact on mental health since it will be a more pleasant place to be.

Traffic safety is another indicator which has an indirect, but rather big, impact on health. When no accidents occur, traffic safety would not be an issue and its impact on health would be zero. However, this is not the case and accidents do occur. Minor accidents might only result in property damage only but there are many accidents which lead to injuries. In really bad accidents even death can be a consequence. Vulnerable road users in particular have very little protection and can easily become injured as a result of an accident.

On the other hand, the use of active modes is considered beneficial for the health of people. The exercise that comes along with active modes ensures that people stay fit. A drawback of active modes might be the exposure to traffic accidents and pollution, however, the benefits easily outweigh these risks (Mueller et al., 2015). City design should be aimed at encouraging people to walk, cycle or use public transit to their destinations. When this is done appropriately there is a smaller risk of people getting diseases due to pollution or getting involved in accidents (Genter et al., 2008; Giles-Corti et al., 2016; Turrell et al., 2018). Not only do people get sick less often, but their health in general will improve when commuting in an active mode (Bopp et al., 2013). Jacob et al. (2021) investigated mental health as well and found that this improves when switching to active modes for commuting.

2.3.5. Indicator relations

Most of the indicators are related to each other. In the previous sections about the individual indicators, some of these relations are already mentioned. Figure 4 visualizes how the different indicators relate to each other. The direction of the arrows shows which indicator influences which other indicator. For every arrow in Figure 4, there is a specification in the accompanying table of what effect each arrow represents. If the number is green there is a positive effect on well-being, for red numbers the effect is negative, while for black numbers the effect can both be positive and/or negative. This is because the influence on well-being can go both ways for some effects. For example, for arrow number 13 from attractiveness active modes to traffic safety the increase in the attractiveness of active modes can lead to both an increase and a decrease in traffic safety. On one hand, there will be fewer motorized vehicles on the road with an increase in active modes, thus reducing the chance of an accident. On the other hand, there will be more vulnerable road users on the road, thus increasing the likelihood of injuries in case of an accident.



(1)	More public transport → less emissions (Glock & Gerlach, 2023; Jing et al., 2022; King et al., 2011)
(2)	• Lower travel time loss → higher speeds → more emissions (Fergusson, 1994) • Higher travel time loss → start-stop traffic → more emissions (Khalfan et al., 2017) Both effects are opposite, so a positive optimum can be found in between the effects.
(3)	• Lower travel time loss → higher speeds → more emissions (Freitas et al., 2012) • Higher travel time loss → start-stop traffic → more emissions (Jahandar et al., 2012) Both effects are opposite, so a positive optimum can be found in between the effects.
(4)	More active modes → less emissions (Glock & Gerlach, 2023)
(5)	More people in public transport → less congestion → lower travel time loss (Das et al., 2021; van Exel & Rietveld, 2010)
(6)	More people using active modes → lower experienced travel time loss (Panter et al., 2014)
(7)	Better road surface type → lower noise emissions (Sandberg & Descornet, 1980)
(8)	Presence of a bus lane increases attractiveness public transport (Arasan & Vedagiri, 2010)
(9)	Public transport is safer than automobile travel (Litman, 2016)
(10)	Higher average speeds → bigger impacts at accidents → less safe (Vorko-Jović et al., 2006)
(11)	Less pave surface area → less space for cars → lower road capacity (Szarata et al., 2021)
(12)	More space for active modes increases its attractiveness (Friel et al., 2023; Skartland, 2016)
(13)	• More active modes → less vehicles → increased safety (Elvik, 2008; Elvik & Goel, 2019) • More active modes → more vulnerable road users → decreased safety (Olszewski et al., 2019)

Figure 4 - Overview of the relations between indicators

3. Methodology

Following the research goal a framework needs to be developed for assessing well-being using traffic simulation software. This framework will not only be designed for indicators suitable for simulation, but also for indicators that are not suitable for simulation. However, the focus of the framework is on the group of indicators that can be assessed using traffic micro-simulation software. This group consists of the seven indicators as introduced in Table 1 in section 2.3. The methodology of the process for assessing mobility-related well-being using traffic simulation software is visualized in Figure 5.

In the process as depicted in Figure 5 there are several shapes. The pink squares stand for the different phases of the process. The phase titles are followed by a number, this number is the section number of the explanation of that phase. The intermediate steps are represented by the blue rectangles within the pink areas. These intermediate steps are also in the explanations of the phases. The initial inputs for the process are the green triangles. Each phase in the process leads to a (intermediate) result. These (intermediate) results are shown as the yellow ellipses. Intermediate results are the inputs for a subsequent phase in the process. The result of the entire process is a score for the simulated part of the assessment of well-being.

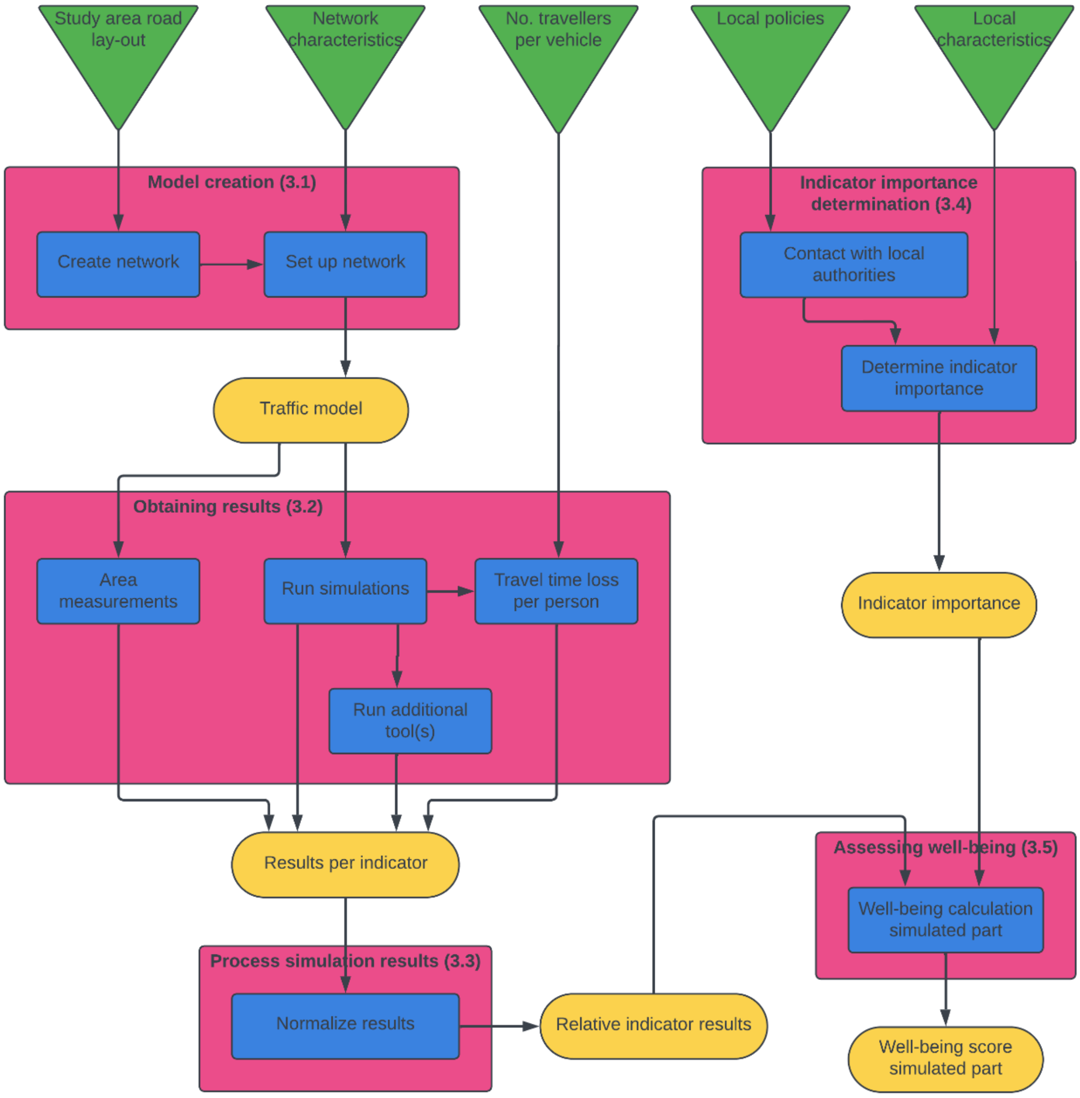


Figure 5 - Overview of the process for the assessment of the simulated part of well-being

The process as shown in Figure 5 is set up for studies in which multiple variants of the same study area are compared to each other. This is necessary since it is impossible to determine the exact well-being of a single variant. However, it is possible to determine the relative performance of different variants for a study area compared to a reference scenario. In most cases, this reference scenario is the current situation, which enables the assessment of the impact of different variants on well-being. Examples of how these variants could differ from the reference scenario are changes in traffic intensities, modal split or in the network layout itself.

The explanations per phase of the process are not specified for certain simulation software. The descriptions are general and therefore there is no explanation of how each step should be taken exactly for a certain software. In chapters 5 and 6 there are more in-depth descriptions of PTV Vissim, which is the micro-simulation software for the case study that is performed. However, before these two chapters, there is first a chapter about the survey that was held. This survey is used to establish whether certain indicators for the simulation part of the framework are considered more important than others.

3.1. Model creation

In this section of the process the traffic model is created and set up according to the local circumstances of a studied area. This is the first step in the framework, and will thus form the basis for every study.

Create network

For the creation of the network in the traffic model, it is necessary to know what the road layout is of the location of the study. This forms the basis for the analysis, as it is done for a specific location. First, a reference network should be created that represents the current road layout. If the study requires that multiple different road network layouts are examined, this is also the step in which the other networks should be created.

Set up network

The second step in model creation is for setting up the model. Here the OD-matrix should be implemented into the model. Also, the vehicle types should be implemented correctly to allow for a representative study. Furthermore, active modes and public transport must be present in the model, as they are directly involved in multiple indicators. If the study requires that multiple different intensities or modal splits are examined, this is the step in which the different variants should be created.

In this step, the measurement systems for gathering the data need to be put in the model. These measurements should be the same for all variants in a study to allow for comparisons between the different variants. Measurement start and end locations should therefore be outside of the area in which changes to the road network are made.

3.2. Obtaining results

When the model is created it is time for the next phase, and thus the next section of the process. This section is for the gathering of results that follow from running the simulations. These results can be obtained directly from the model, by performing some calculations on certain outcomes, or by using outcomes in entirely different tools. This phase is completed when the results for every indicator are obtained.

Area measurements

To know what area is taken up by the paved surface it is necessary to measure this area. With the model set up, it is possible to determine the area of every link in the model. It should not be necessary to run any simulations for this indicator specifically, as a simulation does not change the size of the links and thus has no influence on the paved surface area.

Run simulations

Except for the paved surface area, it is necessary to run simulations to find out what the values are for each indicator. However, a sufficient amount of simulation runs must be performed to ensure that statistically significant results are obtained. The number of runs necessary to obtain significance varies per study and is also dependent on the required significance.

Travel time loss per person

Generally, the outcome of a traffic model is on a vehicle basis. For the indicator of travel time loss per vehicle, it is necessary to know the delay per person. Therefore, the delay per vehicle needs to be multiplied by the number of people that are in each vehicle to obtain results for the delay per person. Rather than investigating every vehicle in the network, the average number of occupants per vehicle should be considered. Different vehicle types should be distinguished, as the average occupancy depends on what type of vehicle it is. Especially for public transport the occupancy number is interesting, because they often transport the most people per vehicle. Ideally, the local transport operator should be contacted to retrieve data on how many passengers there are in a public transport vehicle on average.

Run additional tool(s)

In the case that the traffic simulation software is unable to produce results for each indicator, there may be an option to obtain results with the help of additional software. For this software, the input may be data that is retrieved from the traffic model. This additional software needs to be run or applied to obtain results for the indicator that would otherwise have no results. What type of additional tools are useful depends on the simulation software and the availability of additional software or tools for that specific simulation software.

3.3. Process simulation results

The section 'obtaining results' should result in every indicator having results. These results are the input for this section in which the results are processed. The outcome of this section should be results for each indicator that can be compared to each other. The only step in this phase of the process is the normalization of results.

Normalize results

The input for this process is the outcome of the previous section in the framework. For each indicator, the results are available per variant. The scores for the different indicators all have different units, which makes it impossible to properly compare different indicators with each other. Therefore, for each indicator the results per variant are scored relative to the reference scenario. This results in every indicator having a percentage of the reference scenario for each variant. To have an equal influence of a halving and doubling of a score, all results are normalized. This means that instead of having a percentage a value between 0 and 1 is obtained. To achieve this equation (1) can be used.

For percentages lower than 100%, there can simply be divided by 100 to obtain the normalized value in the desired range. However, if the percentage is higher than 100, meaning the value has increased compared to the reference scenario, dividing by 100 would not lead to a value between 0 and 1. Therefore, instead of dividing by 100, 100 is divided by the percentage score. By inverting the division it is ensured that if an indicator result is 50% (i.e. halved) it counts for an equal amount as when a result is 200% (i.e. doubled).

Percentage scores far away from 100%, both very low and very high scores, have a higher impact than percentages relatively close to 100%. This impact should also be represented in the normalized values. This can be achieved by deducting the normalized values as obtained in the previous two paragraphs from 1. By doing this deduction the more impactful scores receive a higher normalized value, which is more intuitive. The resulting equation for the normalization can be seen below.

$$Normalized\ result = \begin{cases} 1 - \dfrac{Percentage\ score}{100}, & \% \leq 100 \\ 1 - \dfrac{100}{Percentage\ score}, & \% > 100 \end{cases} \tag{1}$$

It is not necessarily true that an increased value for an indicator means an improvement in well-being. It differs per indicator whether an increased or a decreased value is positive for well-being. Therefore, scores also need to have the option to be negative. This means that the range in which a score for an indictor can be should be between -1 and +1. In this case, 0 would mean that it is equal to the reference scenario, -1 the maximum negative influence and +1 the maximum positive influence on well-being. For every indicator should be determined what the effect is of an increase and decrease in well-being, after which the normalized score(s) should be adjusted appropriately.

3.4. Indicator importance determination

In this section, the goal is to establish the relative importance of the indicators. A one per cent change for a certain indicator might be regarded as more impactful than for another indicator for example. Also, the circumstances of a study area are of influence, which is why they should be taken into account for establishing the relative importance of indicators. Besides that, local policies have an influence. These policies should therefore be factored into the establishment of the relative importance.

Contact with local authorities

Generally, a branch of government gives the order for a traffic study. In each study area there are different policies regarding mobility, and these policies might differ per region. The local policies should be taken into account when establishing the relative importance of indicators. Therefore, it is important that there is contact with the local authorities as they know best what type of policies are relevant for a specific study area. For example, if a green party is the ruling authority the emissions might be considered as more important than for a party that is more car-focused.

Determine indicator importance

Not only the local policies should be considered for indicator importance. It is also very much of an influence where the study area is. A rural area and an urban area are very different and require careful consideration of what is important. In rural areas, noise emissions are much less important than for urban areas, since there are hardly any people living nearby who would have nuisance from it. Furthermore, the existence of active modes or public transport in a network is of influence for indicator importance. If in a study area there are no active modes, a highway for example, the indicator for the attractiveness of active modes is not relevant and can be weighted accordingly.

3.5. Assessing well-being

With the normalized results per indicator and the relative importance of indicators available, it is possible to assess the well-being based on results for the indicators derived from the traffic model. The resulting scores allow for a comparison between the different variants that were created in the model creation section.

Well-being calculation simulated part

The scores for the indicators per variant and the relative importance per indicator are the inputs for the score that is given to each of the different variants. Each variant will be scored the same way, according to the following equation:

$$Well-being_{variant} = \sum_{indicators} importance_{indicator} * variantscore_{indicator} \quad (2)$$

Equation (2) shows that for a variant the score for each indicator is multiplied by the relative importance of that indicator. To obtain the overall score based on the indicators used, the values for all indicators are added together. As this is done for all variants, they can be compared to each other. In all cases, the reference scenario should have a score of 0, since its variant scores are all 0. If a variant has a value lower than 0, it would mean that there is a reduction in well-being based on the simulation results. On the other hand, a positive value for well-being for a variant means that well-being would increase based on the indicators used for that study.

4. Survey

In section 3.4 is mentioned that for every study needs to be established which indicators are important, and what the relative importance is of each indicator. Some indicators may always be considered more important than others. When this is the case, this will be of interest for the contact with the local authorities, as this could form the basis for the process of determining the relative importance. In contact with the authorities, it could thus be advised that in general certain indicators should be taken as more important. It should not necessarily lead to the same ranking of importance, but it can help in establishing the final ranking of indicators for a study area.

To find out whether such a subliminal ranking of indicators exists a survey was held. In this survey, the seven indicators as introduced in Table 1 are to be scored on importance. These seven are the indicators suitable for simulation purposes. The target group for the survey are mobility experts since they are knowledgeable about what traffic studies entail. The people in the target group also have some knowledge about well-being, although the topic is still introduced shortly in the introduction of the survey.

The main question in the survey is what the respondents think is the relative importance of the seven indicators used for the traffic simulation. These seven are: emissions – gases, emissions – noise, paved surface, travel time loss per person, attractiveness active modes, attractiveness public transport, and traffic safety. To make answers from different respondents comparable to each other the respondents are asked to divide 100 points between these seven indicators. Respondents are free to score an indicator with any number ranging from 0 to 100, as long as the total score of all indicators is equal to 100. The more important an indicator is considered, the more points should be awarded to it.

Furthermore, since there are multiple aspects to some indicators, the respondents are also asked to rank the aspects of some indicators. Only for emissions – noise and travel time loss per person there is not asked for the different aspects. The same principle as for the main question is used for these aspects, so 100 points need to be divided over the different aspects. The number of aspects differs per indicator, ranging from three to five aspects.

Finally, some background information about the respondents is collected. This background information consists of a respondent's age, profession and preferred mode of transport to work. As the target group for the survey is Dutch, the survey is also completely in Dutch. The entire survey can be found in Appendix A.

4.1. Survey results

In total, 65 people responded to the survey. These respondents were quite well spread in age and by preferred mode of transport to work, as follows from Table 2. It has to be noted that one respondent preferred not to answer the question about age, while two respondents did not want to state their preferred mode of transport to work. However, as there are not many people per subgroup for age or preferred mode of transport, no conclusions can be drawn based on subgroups.

The results of the survey are that there is some difference between indicators, although these differences are not very substantial. The outcome of the survey is shown in Table 3 and is visualised in Figure 6, with an additional overview in Appendix B. If all indicators were scored equally, they would all have a score of approximately 14. This is not the case, but the scores are not far from this hypothetical average.

Table 2 - Overview of respondents' age and preferred mode of transport to work

	Car	Bicycle	Walking	PT	Unknown	Total
<25	0	1	2	6	0	9
26-35	3	8	0	7	1	18
36-45	3	4	0	3	0	10
46-55	5	6	1	2	1	14
56-65	3	5	0	3	0	11
Unknown	0	1	0	0	0	1
Total	14	24	3	21	2	**65**

What stands out in Table 3 is the fact that the standard deviation of the importance per indicator is very high, which means that the results differ a lot between respondents. For the indicator of travel time loss per person, the standard deviation is even higher than the relative importance itself. In Figure 6 is also visible that for every indicator there is at least one major outlier, with the highest single score awarded being 70 out of the possible 100. Since the standard deviation is so high, it is impossible to state with certainty that certain indicators are more important than others.

Table 3 - Relative importance and standard deviation per indicator

	Relative importance	Standard deviation
Emissions - gases	18	13,2
Paved surface	11	9,6
Traffic safety	17	9,9
Attractiveness active modes	20	9,5
Attractiveness Public Transport	14	8,5
Emissions - noise	10	7,4
Travel time loss per person	9	10,0

For the aspects of indicators the standard deviation is comparable to or larger than the standard deviation for the main question. Therefore, it is not possible to make any conclusions about the aspects of indicators either. Nevertheless, the results for the aspects can be found in Appendix C, where each of the five indicators with multiple aspects has a dedicated section.

In the survey, no situation is presented for which the importance of indicators should be scored. The main question is to score the indicators relative to each other, there was no further specification on how they should fill in the survey. Due to the lack of a study area or network being presented this likely resulted in every respondent imagining his or her own situation. The relative scores for the indicators are thus based on those specific situations that the respondents had to come up with. These situations are highly unlikely to be similar across all respondents, which is likely part of the reason the scores vary so much between respondents. Of course, the opinions on which indicators are important differ per person regardless of a (imagined) study area.

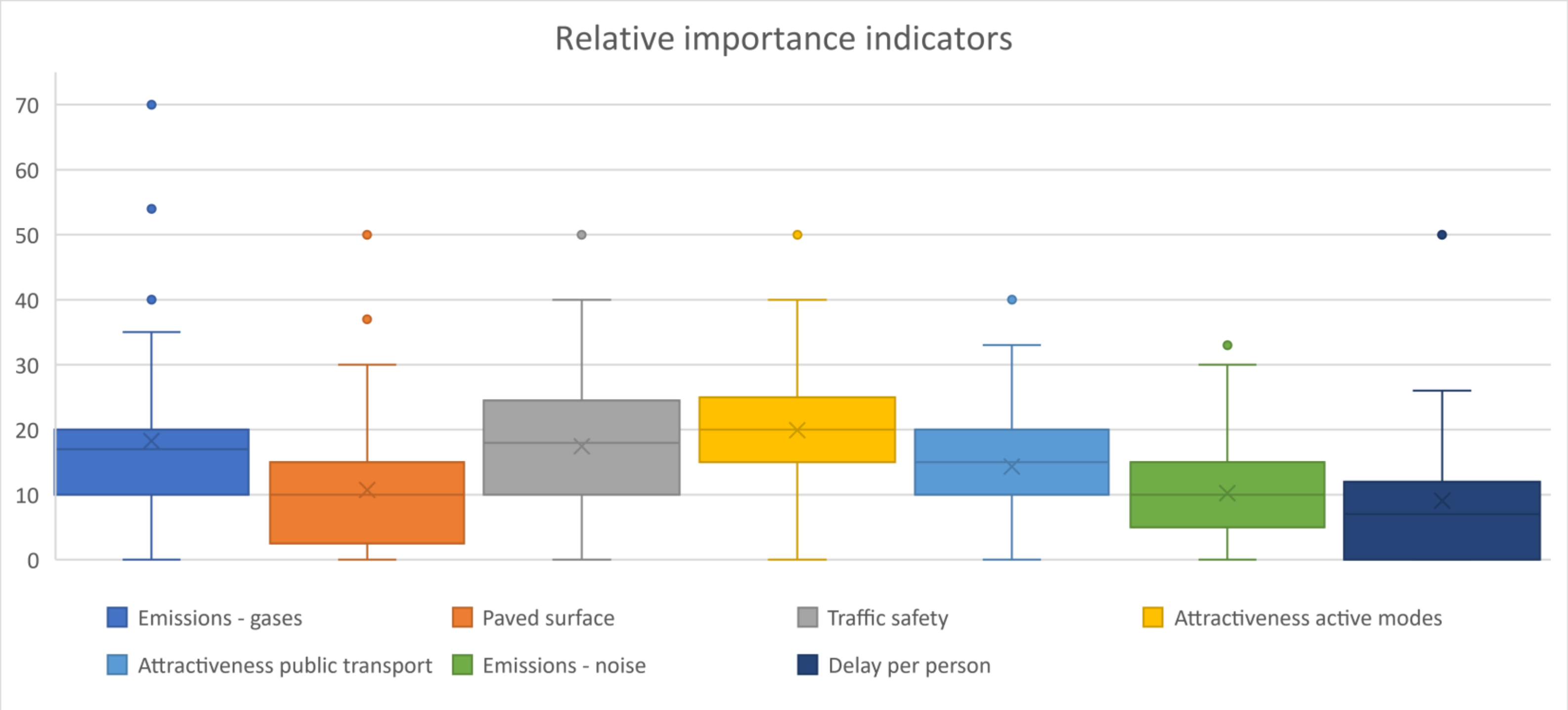


Figure 6 - Overview of the relative importance of indicators resulting from the survey

Due to the high standard deviation and the fact that different situations require different rankings of indicators, it is necessary to establish a dedicated ranking of indicators for every study area. Therefore, the survey does not result in a general ranking of the relative importance of indicators. To get a suitable ranking multiple actors could be involved in the process. One type of actor is an experienced traffic engineer who is already familiar with establishing such rankings. Secondly, contact with local authorities could lead to important insights, as they know what the local circumstances and policies are. These policies might be of influence on the importance of indicators, and should thus be considered for a suitable ranking. Finally, local residents could be surveyed on what they think is important to consider, as it is the well-being of those residents that is affected by a project.

5. Simulation software

To show how the process from section 3 can be applied a case study is performed. The software used for this case study is PTV Vissim. In this section, there is an explanation of how this software can be used to obtain results for all indicators. For each indicator there is a dedicated section with a detailed description of what results are necessary. PTV Vissim is particularly useful for traffic micro studies, so the case study will be a micro traffic analysis. Where Vissim is not able to provide useful results for an indicator, other software will be introduced that can help to obtain these results. The only indicator for which this is the case is traffic safety.

Emissions – Gases

There are two possible options in Vissim to determine the emission of gases from vehicles. The first is to create an equation that determines the total emissions. This would require each emission gas to have a separate equation. For the second option these equations are already created and implemented in Vissim. This option is to make use of the Bosch add-on module in Vissim. This module is specifically developed for a detailed calculation of emissions from vehicles in a simulated network. This module is ideal for this research and will therefore be used.

The add-on Bosch module can easily be switched on in the results menu of Vissim. However, before an analysis can be performed the model needs to be set-up for an emissions calculation. For this, a vehicle emission class needs to be assigned to each vehicle type. Vissim has many different emission classes based on vehicle type, engine type (diesel or petrol), and engine performance. Among the differences between engine performance are the size of the engine and the engine's age. Larger engines generally cause more emissions, while newer engines generally cause fewer emissions. In Vissim there are vehicle emission class presets available for multiple countries, which are based on the vehicle fleet of those countries. Unfortunately, there is no preset available for the Netherlands. Therefore, the emission classes for France are used since these average emissions are very similar to Dutch emissions (ICCT, 2021).

When all vehicles are assigned to an emission class, it is necessary to select the option of emissions calculation using the Bosch module. As there are two options for emissions calculations the Bosch module needs to be selected so that Vissim knows the emissions calculations should be done via this method. When the Bosch module is selected, the vehicle trajectory data is stored. This trajectory data includes vehicle location, speed, and acceleration. The resulting data is then combined with the emission class of a vehicle to determine what the emissions are from each vehicle. This calculation happens on a Bosch server, where the input is automatically uploaded to. The results are also downloaded back automatically after each simulation run.

There exist various emission types in the module, but only the three emission gases introduced in section 2.3.1 are examined. This means that only carbon dioxide (CO_2), nitrogen oxides (NO_x) and particulate matter (PM10) are considered. The impact of each of these gases is explained in section 2.3.1 as well.

Emissions – Noise

The noise resulting from traffic is dependent on many factors. Examples of these are the surface type of the road, the geometry of surrounding buildings and the presence and location of greenery. With Vissim only it is impossible to determine the effect of the road surface type or the surrounding area. However, other factors can be measured that influence the overall noise emissions. These factors and their workings are introduced below.

The exact number of decibels emitted differs per location. If it is measured very close to a road the noise levels are much higher than when it is measured far away from a road. Since the noise level drops the farther it is from a road only the relative values are considered between variants rather than the exact amount of noise in decibels. It is possible to create a noise map, which shows the noise level at different locations of a study area, but this type of noise evaluation is outside of the scope of this research.

The speed at which vehicles travel has a major impact on the noise level. The faster vehicles travel the more noise they cause, as both engine and tyre noise are increased. Therefore, the average speed of vehicles should be monitored, as it is an indication of how fast vehicles travel in the study area. In Vissim the average speed per vehicle is an output that can be produced, also per vehicle type. This distinction in vehicle type should be made as larger vehicles are generally louder than smaller vehicles.

Furthermore, the amount of stops per vehicle should be considered. This is because vehicles make more noise when accelerating since the engines have to work harder to make vehicles accelerate. The number of stops a vehicle makes in the network is an option that Vissim can give as an output. It is also influence what type of vehicle makes a stop, as heavy vehicles generally cause more noise emissions than lighter vehicles.

Finally, the number of vehicles also influences the amount of noise created. If only a single car would pass a certain location per hour this would hardly cause any nuisance, but when a thousand vehicles travel on the same piece of road they can cause a lot of nuisance. Depending on the study type the amount of vehicles should be considered. If different variants for the road layout are analysed, the total amount of traffic remains the same among all variants. This would not lead to a significant change in vehicle numbers, and thus in noise emissions. However, if the input of the number of vehicles is changed, the number of vehicles passing a location will change. This should result in a change in noise emissions. The number of vehicles is a result Vissim can produce, so that outcome should be used for a traffic study in which intensities differ per variant.

Another notable factor for noise emissions is the share of electric vehicles in the vehicle fleet. Electric vehicles cause less noise emissions than vehicles with a combustion engine, as electromotors hardly produce noise. Thus, the only relevant noise factor for electric vehicles is tyre noise. The amount of electric vehicles is ever-increasing and therefore the total amount of noise resulting from vehicles is also likely to reduce. Nevertheless, the process of the vehicle fleet turning electric is very slow and will still take many years. However, it is important to consider electric vehicles in the model. In the future updates are necessary to stay up to date with the relevant share of electric vehicles.

Paved surface

This indicator is not relevant for all types of study. Only if there are changes to the layout of the road network there are changes in the paved surface. In the survey, there is asked for five different aspects of this indicator. However, not all of them can be measured using Vissim, because some aspects are aimed at how policies could be implemented. The only thing that can be measured for this indicator is how much area is taken up by the road surface. Only if this area is smaller in a variant it is possible to use the space that has become available for something else. What to do with the newly available space depends on local policies. In some instances, these policies might be aimed at increasing the amount of green space, but it is also possible that the additional space will be used for more space for active modes. It is outside of the scope of this research to decide what local governments should do with space that has become available due to a reduction in paved surface area.

Therefore, the only measurable aspect of this indicator is the area of the paved surface. It can be assumed that a reduction in paved surface area will lead to a more attractive living environment. There is no direct function in Vissim to calculate the total surface area of a network. However, the length and width of each link are known. Therefore, it is possible to calculate the total surface area of the links by multiplying the length of each link by its width. The connectors between the links are more complicated because their width is not necessarily the same at both ends. This problem can be solved by taking the average of the start width and end width and multiplying this by its length. This is because these connectors can be considered as trapeziums.

For determining the total paved surface area only the roads are considered. The pedestrian areas and cycling paths are left out of the analysis since in traffic models these generally only consist of road crossings. This would mean that if these areas were considered the overlapping areas would be counted twice. This is because both the road that is crossed and the area for active modes on top of it would be counted.

There is an issue with the connectors between links, which in some instances have an overlap with another link or connector. This would mean that these areas are counted twice. However, there exist areas in between different links that in reality are paved. Since these areas do not appear in the model they do not count towards the total paved surface area. Assumed is that these two factors have an equal effect on the total surface, albeit in opposite directions. Therefore, there is no effect on the surface area, meaning that the total paved surface area can still be calculated.

Travel time loss per person

As the model for the case study is a micro simulation model the best method for the assessment of accessibility is travel time loss per person. If the model was on a larger scale it would have been interesting to assess the amount of jobs accessible within a certain amount of time. However, for a micro-simulation model like the one used for the case study, this is not relevant.

Since travel time loss, or delay, is often used in traffic simulation studies there already exists a feature in Vissim that determines the delay for each vehicle. The delay results from the additional time that is spent in a network in an ideal scenario in which a vehicle does not have to stop or wait for anything. It can just continue on its journey without any interruption. This feature is therefore very well suited for determining the travel time loss per person.

However, in order to determine the travel time loss for each traveller a factor needs to be applied that reflects the occupancy of a vehicle. This is necessary as Vissim determines the delay results per vehicle rather than per person. For two types of vehicles such a factor needs to be determined, namely for passenger cars and for public transport vehicles. For cyclists it is clear that only one person is on a bicycle, while each pedestrian is just one person.

The average number of occupants for a passenger car in the Netherlands is approximately 1,4 persons per vehicle (Bleijenberg, 2023). However, during rush hours this number drops to only 1,1 persons (Ministerie van IenW, 2023). As the simulations in the case study are run to represent the situation during peak hours, the factor for passenger car occupation is set to 1,1. For buses the occupancy can change per bus stop and is also very dependent on the time of day. Furthermore, the bus occupancy differs per bus line. Ideally, the local transport authority is contacted with the goal of obtaining the occupancy of public transport vehicles in the study area. These companies are not always willing to share these numbers, which is why the average occupancy of buses in the Netherlands can be used as a back-up. The average occupation of a bus in the Netherlands is 10,3 (Temürhan & Stipdonk, 2016).

Trucks are different from other types of transport in the sense that they do not transport people but goods. Yes, there is a driver in a truck, but the aim of the truck is not to transport the driver to the destination, but rather the load of the truck. Nevertheless, it is assumed that each truck only has the driver in it. Trucks therefore have an occupancy of 1 passenger.

Attractiveness active modes

The attractiveness of active modes is difficult to measure. The goal of increasing the attractiveness is to increase the amount of people that travel by cycling or walking. It is possible to adjust the number of people travelling using an active mode. However, it is unknown what the effects are of measures aimed at increasing the attractiveness of active modes. As an example, it is possible to model a dedicated bicycle lane, but the effects on the number of cyclists of the realization of a bicycle lane are unknown.

The area that is reserved for active modes is an important factor in its attractiveness. A wider cycle path allows for more cyclists, who are also able to overtake each other more easily. The same applies to the pavement with pedestrians. It is, however, not possible to measure the impact of these measures on the modal share of active modes as it is unknown what the effects are on the use of these modes.

For the attractiveness of active modes it is therefore most interesting to consider their travel time losses. In Vissim it is possible to retrieve results on delay per vehicle type. In this case, cyclists and pedestrians are both considered as a type of vehicle. Thus, the delay can be determined for both active modes independently. The delay of active modes is already present in the travel time loss per person, although it is combined with other modes of transport. For this indicator, only the active modes are considered, so there is no influence of other modes on the delay results of active modes.

Attractiveness public transport

As is the case with the attractiveness of active modes, the attractiveness of public transport is hard to determine. An increase in the frequency of a public transport line is expected to increase its attractiveness, but the exact effects on ridership are unknown. The modelling of some additional buses is rather simple, but by doing so it is not possible to determine the effect on the ridership or modal split. It cannot be assumed that a certain decrease in passenger cars will occur because those travellers have shifted to public transport.

The existence of dedicated space for public transport, a bus lane for example, also has an impact on the attractiveness of public transport. However, in order to determine its effect the road layout should be changed. This means that it can be implemented in a variant for the study area, but it is not a metric that can be used for this indicator. In the case study there are variants with and without a bus lane. Thus, the presence of a bus lane is taken into account, although not directly for this indicator.

The best way to measure the attractiveness of public transport is by looking at the delay of public transport vehicles specifically. This can be done in the same manner as active modes since buses and trams can be modelled as separate categories from the other traffic. When investigating the delay for public transport the existence of dedicated lanes is also indirectly considered, as they will have an impact on the performance of public transport. Another factor that is also taken indirectly by analysing the delay is the presence of priority at signalized intersections.

The reliability of public transport is also important for travellers. People need to know when to expect the arrival of a public transport vehicle at a stop. Therefore, the variance in delay should be minimized. There can be a delay in the network, but when this delay is rather constant the time table can be adjusted accordingly. The standard deviation of the delay of public transport vehicles is taken as a metric for its reliability.

Traffic safety

To determine traffic safety the number of accidents should be determined. However, because it is a simulation accidents should not occur. Furthermore, no option in Vissim allows for the measuring of (potential) accidents. Instead, there is an application called SSAM (Surrogate Safety Assessment Model) that can be used. The input for SSAM is a trajectory file which contains the data for location, time, speed and acceleration (or deceleration) per vehicle. There is an option in Vissim that produces these trajectory files. Using the information in these files SSAM determines potential conflicts according to certain parameters.

The two most important parameters in SSAM are the time to collision (TTC) and post encroachment time (PET). The TTC stands for the time it takes a vehicle to run into another vehicle if it keeps going at its current speed. PET stands for the time it takes a vehicle to get to the same place as a previous vehicle that has moved away from that location. It is possible to set these two parameters in SSAM to ensure that a representative analysis can be made. For urban situations, the best values for these two parameters are 1,6 seconds for TTC and 2,5 seconds for PET (Huang et al., 2013). If the values for TTC and PET are lower than these thresholds SSAM considers that there is a conflict. A conflict does not necessarily mean that a collision has occurred, but it does mean that there was an unsafe situation.

Since the trajectory of each vehicle is known SSAM can determine the angle of impact of a conflict. Based on the conflict angle SSAM determines the type of conflict, which can be a rear end, a lane change or a crossing conflict. As shown in Figure 7 the threshold angles that determine what type of conflict has occurred are 30 and 80 degrees. A conflict angle lower than 30 degrees implies a rear-end conflict, while an impact angle of higher than 80 degrees is a crossing conflict. Between 30 and 80 degrees is considered as a lane change conflict.

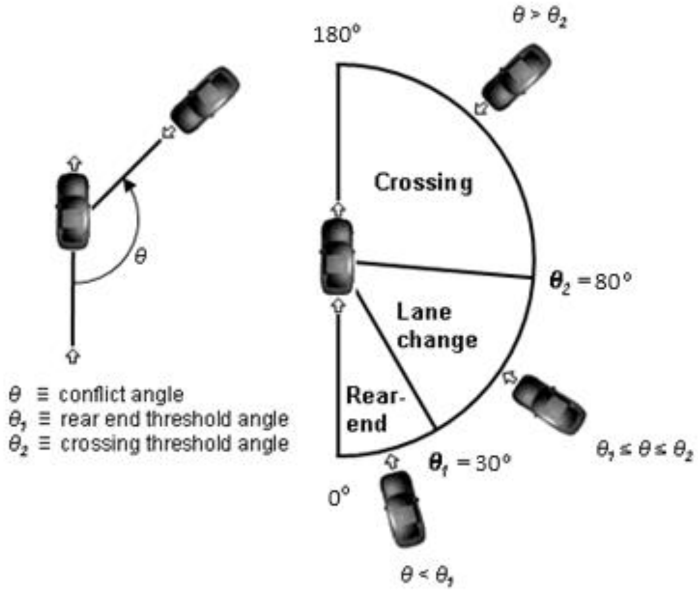


Figure 7 – Screenshot from SSAM with an overview of the types of conflicts based on the angle of impact

Unfortunately, SSAM is not able to distinguish between modes of transport. Nevertheless, the vehicle IDs are known per conflict. For each vehicle ID in a simulation the vehicle type is known. Therefore, the list of conflicts needs to be compared to the list of vehicles to determine what type of vehicles are involved in a conflict. For the analysis of conflicts, a distinction will be made between active modes, cars and trucks. Cyclists and pedestrians are considered the active modes, while all passenger cars are considered as cars. Both trucks and buses are considered trucks due to their heavy weight and thus high impact when they are involved in an accident.

6. Case study

To show how the process presented in chapter 3 can be applied a case study is performed. In this case study it is possible to show the intermediate steps of the process. The intermediate results are shown as well to make the process easier to understand. The outcome of the case study is compared to the results of a traditional analysis to determine what similarities and/or differences exist between a well-being-focused analysis and a more traditional one. The case study follows the process as explained in chapter 3.

6.1. Model creation

There are a few requirements for the network of the case study. First of all, the network should contain not only motorized vehicles but also cyclists and pedestrians. Furthermore, public transport should be included in the network since it influences well-being and is thus considered in one of the indicators as well. Secondly, there should be multiple variants of the network. This is important as this enables comparisons with the original situation. Multiple variants also enable comparisons between the outcomes of the different variants, which allows for a better understanding of the effects in a well-being analysis.

The study area of the case study is a set of intersections on the eastern side of Naaldwijk in the Netherlands. The selected area is depicted in Figure 8. This study area is chosen because it is a good example of a micro simulation model that does fulfil the criteria mentioned in the previous paragraph. The model was originally created for an analysis of how public transport, in this case only buses, could be more efficient in the study area. In the reference scenario, there is not enough space for multiple buses to stop at a bus stop at the same time, which occasionally blocks all other traffic. The results of the case study are compared to the outcomes of the original analysis in section 6.6.

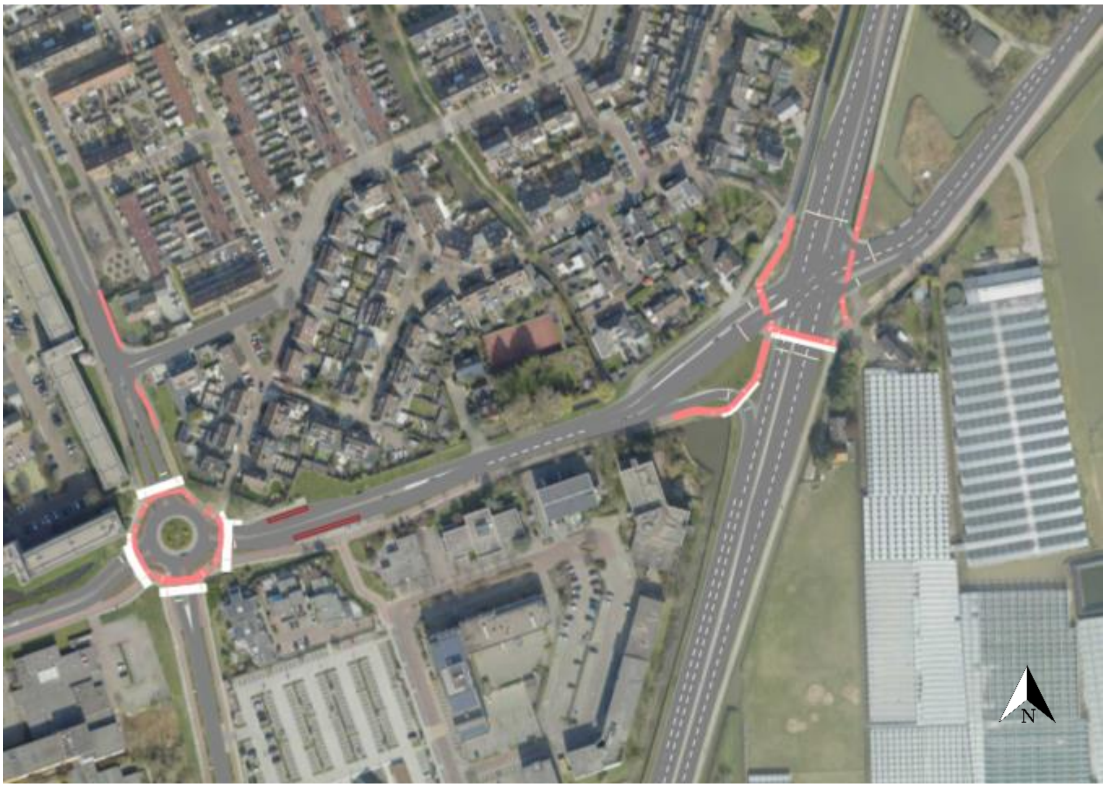


Figure 8 - Satellite image of the case study location including the Vissim network

In the study area there are two main intersections, one of which is a signalized intersection and the other is a roundabout. At the signalized intersection there is absolute priority installed that helps buses pass the intersection more quickly. However, the effectiveness of this priority is restricted by the maximum allowed cycle time of the traffic lights. Moreover, there is a third intersection in the area, although this is a minor priority intersection with a street leading into a residential area. This minor street from the residential area has to yield to the road leading onto the roundabout.

The different colours of the network shown in Figure 8 represent different modes. The grey links are for motorized vehicles, the red links are for cyclists and the white links are for pedestrians. Furthermore, the dark red areas in between the two main intersections are bus stops. Both bus stops serve the same four bus lines, with all four lines travelling in two directions. In peak hours there are up to 12 buses per hour in each direction. This shows that all four modes of transport are included in this network, which fulfils the requirement of having all these modes included in the network.

6.1.1. Variants

The model of the study area was originally designed because the bus stops are too short when multiple buses arrive at the same time. Therefore, all variants contain an elongated bus stop at which multiple buses can stop at the same time without blocking other traffic. In total, there are five variations on the reference scenario with each a different approach to improve on the current situation. In these variants only the lay-out of the road network is changed. There are no changes to the OD-matrix or the modal split of the network.

Bus lane

In this first variant a dedicated bus lane is added. This bus lane is only in the direction going from the signalized intersection to the roundabout. Especially in the evening rush, there is congestion in the direction towards the roundabout. Buses also get stuck in this traffic, which is why the dedicated bus lane is created to prevent this from happening. The longer bus stop is a little less relevant here as the buses do not get stuck in traffic, nor do they hold up other traffic when they are waiting for another bus to depart. This is because they have a separate lane from the other traffic.

Figure 9 - Network variant with a bus lane

Bus lane + bus signal

This variant is very similar to the previous one, as it contains a dedicated bus lane going from the signalized intersection to the roundabout. However, in this variant, a change is made to the traffic lights coming from the east. There are three lanes on this branch. The right lane is for both turning right and for going straight. The middle and left lanes are both for turning left since this is the direction of the largest flow of traffic. For this variant, there is an additional dedicated bus traffic signal on the middle lane that allows for buses to continue straight on rather than turning left like the rest of the traffic. This option for going straight is only for buses, which will have to wait together with all the regular traffic turning left. Once the buses pass the intersection using this dedicated traffic light they arrive on a bus lane, which is the same bus lane as in the previous variant.

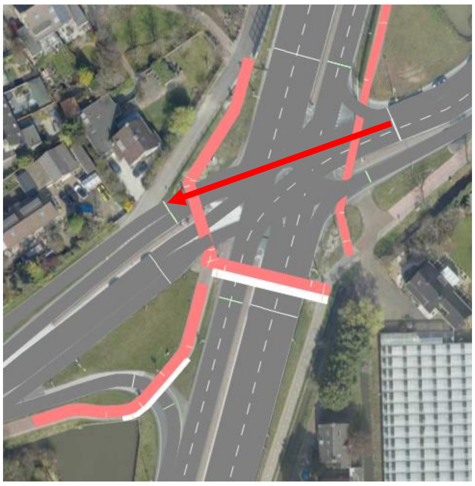


Figure 10 - Network variant with the dedicated bus signal

Roundabout meter

For the third variation on the reference scenario, the attention is shifted towards the roundabout. At the roundabout a metering system is installed. This roundabout meter can best be compared to a ramp metering installation at highway on-ramps. At every branch of the roundabout a light is installed which when turned green allows one vehicle to enter the roundabout. The roundabout meter aims to improve the traffic flow coming from the signalized intersection so that the traffic does not back up onto the signalized intersection. This ensures that the signalized intersection can perform uninterrupted. Nevertheless, ensuring that traffic does not back up onto the other intersection might result in traffic from other branches of the roundabout having to wait longer than they usually would.

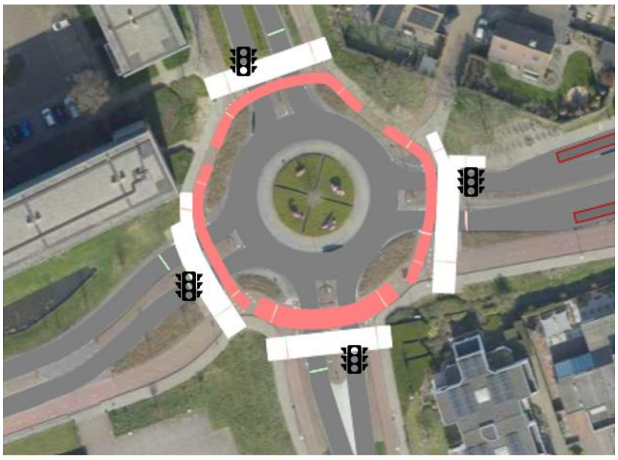


Figure 11 - Network variant with the roundabout meter

Priority square

In the fourth variant, the signalized intersection remains as it is in the reference situation. Only the roundabout is changed, namely to a priority square. A priority square aims to combine the benefits of a roundabout with the benefits of a priority intersection (VerkeersNet, 2016). In Figure 12 an example of a priority square is shown. In this example, it is clear that there is a main road going horizontally which is intersected by a smaller road in the vertical direction. The main road in the study area is the road in the east-west direction, so the orientation of the priority square in the network is the same as is the case in Figure 12. How this is implemented in Vissim can be seen in Figure 13.

Figure 12 - Example of a priority square (VerkeersNet, 2016)

Figure 13 - Network variant with the priority square

Traffic lights

For the final variation again only the roundabout is changed. The roundabout is converted into an intersection containing traffic lights. This means that for this variant the study area has two signalized intersections. In the east and west branches of the converted roundabout, there will be three lanes to line up for the traffic lights, which means that every direction has its dedicated lane. For the north and south branches there will only be two lanes, since the intensity of traffic coming from these branches is much lower. For these branches, the straight and left-turn directions are combined in a single lane while the right-turn lane is dedicated to turning right. Furthermore, to help buses cross the intersection more quickly conditional priority is installed. This means that when buses approach the intersection the lights will adjust to allow buses to cross the intersection smoothly. At this new signalized intersection the conditional priority works better than for the already existing signalized intersection since this intersection is not restricted by maximum waiting times for other vehicles.

Figure 14 - Network variant with the traffic lights

6.2. Obtaining results

The model was originally created for an analysis of how buses can be used more efficiently in this part of Naaldwijk. As it is most interesting to analyse situations in which there is a lot of traffic the model is created for an analysis of a regular weekday. Data regarding traffic intensities have been collected via camera observations with specialized counting software for the roundabout. The traffic data for the signalized intersection is gathered via traffic counts from the loops in the ground present at the signalized intersection.

There are two variants regarding the inputs, namely the morning rush hours and the afternoon rush hours. The morning rush is simulated from 06:45 until 09:15, and the afternoon rush from 15:45 until 18:15. Both simulated rushes have a 15-minute warm-up time. It was found that the afternoon rush is the limiting rush for this particular study area. Therefore, for the analysis of well-being, only the afternoon rush is analysed, as it is expected that both rushes will produce similar results.

To ensure that the results from the simulations are reliable multiple runs are performed. For every variant, a total of 10 runs are executed. To be able to guarantee significance, calculations were made to check whether or not this number of simulation runs would ensure significant results. This resulted in confirmation that 10 runs per variant result in statistically significant outcomes.

6.3. Process simulation results

First, the results per indicator are presented. These results are both in absolute values and in relative values compared to the reference scenario. The relative values are in percentages of the reference scenario, so an increase would lead to a percentage above 100, whereas a decrease would mean a percentage lower than 100. Next, the percentages need to be converted into scores. This section will end with an overview of these scores.

6.3.1. Results per indicator

Emissions – gases

There are big differences in the amount of gases emitted between the three studied gases. As depicted in Table 4 CO_2 clearly is the most common gas emitted in the network, followed by NO_x, while only a small amount of PM10 is emitted. However, the gases are unrelated in their effects, so each gas needs to be analysed independently.

What stands out for the emission of gases is that the reference scenario is the second worst option when only this indicator is regarded. Only the variant in which there is a special signal for buses performs worse. Only adding a bus lane gives very similar results to the reference scenario. The best two scenarios regarding emissions are the priority square and the traffic light, which are closely followed by the variant containing the roundabout meter. The reason that these scenarios have less emissions than the reference scenario is that the traffic flow in these variants is much better and vehicles do not get stuck in traffic as much. Vehicles make fewer stops and spend less time in the network and thus emit less polluting gases, even though their average speed is higher.

Table 4 - Overview of the results for emission for each variant

	Avg CO2 emissions [g]	Relative		Avg NOx emissions [g]	Relative		Avg PM10 emissions [g]	Relative
Reference	7076210	100,0%		11563	100,0%		103,9	100,0%
Bus lane	7091124	100,2%		11477	99,3%		102,5	98,6%
Bus signal	7308939	103,3%		12307	106,4%		108,6	104,5%
Roundabout meter	6770320	95,7%		10368	89,7%		94,2	90,7%
Priority square	6591568	93,2%		10120	87,5%		92,4	88,9%
Traffic lights	6593355	93,2%		10052	86,9%		91,6	88,1%

Emissions – noise

For noise, two results need to be analysed. First is the average speed in the network, the results of which are shown in Table 5. Secondly, the number of stops per vehicle is of influence. This is for two reasons, namely due to braking noise and after having stopped vehicles have to accelerate again, which causes noise. Table 6 shows the results for the number of stops per vehicle. Only motorized vehicles are considered for this indicator, as cyclists and pedestrians do not emit any significant noise.

The variants aimed specifically for buses, namely the bus lane and the bus signal, cause a lower average speed for motorized vehicles overall. These variants succeed in improving the average speed for buses, but only by a relatively small amount. The average speed of the three other variants increases massively compared to the reference scenario, with the buses benefiting the most. However, these higher average speeds result in more noise being emitted as a result of traffic. The increase in average speeds for passenger cars and trucks is limited by the fact that their main flows of traffic are from the eastern branch of the signalized intersection to the southern branch and vice versa. The variants which have changes to the roundabout are therefore less effective, as most vehicles do not use the roundabout intersection.

Table 5 - Overview of the results for average speed for each variant

	Overall avg speed [km/h]	Relative		Cars avg speed [km/h]	Relative		Trucks avg speed [km/h]	Relative		Buses avg speed [km/h]	Relative
Reference	32,50	100,0%		32,87	100,0%		39,01	100,0%		20,17	100,0%
Bus lane	32,07	98,7%		32,37	98,5%		38,52	98,7%		22,99	114,0%
Bus signal	28,96	89,1%		29,02	88,3%		35,40	90,7%		23,05	114,3%
Roundabout meter	38,03	117,0%		38,64	117,5%		45,91	117,7%		30,82	152,8%
Priority square	44,12	135,8%		46,70	142,1%		45,81	117,4%		31,99	158,6%
Traffic lights	42,66	131,3%		45,53	138,5%		46,01	117,9%		33,23	164,8%

The higher average speeds for the last three variants can to some extent be explained by the fact that vehicles make fewer stops. As depicted in Table 6, vehicles only make a fraction of the stops of what they do in the reference scenario. For buses, it is clear that the stop at the bus stop is not counted towards the total number of stops. All buses in the network stop at a bus stop, which would make one the minimum value if this stop would be counted. However, the value lower than one for the traffic lights variant shows that this is not the case.

Trucks and buses make more noise than cars, so a reduction in their number of stops has a greater impact on the total amount of noise created. For trucks, the reduction is relatively small compared to cars and buses, but this can mostly be explained by the fact that they already have few stops in the reference scenario. The reason trucks stop relatively little is that the vast majority of trucks only cross the signalized intersection.

In section 2.3.1 is stated that the number of vehicles also is of influence to the emitted noise. However, all variants have the same vehicle input, which means that there is no difference between the scenarios regarding the number of vehicles. Since there is no difference between the variants the number of vehicles is not taken into account for the analysis.

Table 6 - Overview of the results for number of stops for each variant

	Avg no. stops overall	Relative	Avg no. stops cars	Relative	Avg no. stops Trucks	Relative	Avg no. stops Buses	Relative
Reference	3,89	100,0%	4,3	100,0%	1,7	100,0%	5,0	100,0%
Bus lane	3,96	101,8%	4,4	102,2%	1,7	103,4%	2,6	52,7%
Bus signal	4,44	114,2%	4,9	114,3%	2,0	121,9%	2,8	55,3%
Roundabout meter	3,63	93,3%	4,1	95,8%	1,1	65,9%	1,3	26,5%
Priority square	1,15	29,5%	1,2	27,6%	1,0	58,1%	1,0	20,0%
Traffic lights	1,23	31,5%	1,3	29,9%	1,0	58,1%	0,6	12,5%

Paved surface

For the paved surface, not the entire paved surface area has been taken into account. All links that are the same in every variant are not considered for the total paved surface area. The links that are changed or added for a variant are therefore the only links considered. As is shown in Table 7, the surface areas are still quite large, and for both intersections there are changes. Furthermore, the elongated bus stops are present in all scenarios. The presence of the bus lane adds around 10 per cent of paved surface area compared to the reference scenario. Especially the variant with the traffic light has a high increase in paved surface area, which means that such an intersection takes up more paved space than a roundabout does.

Table 7 - Overview of the results for paved surface area for each variant

	Surface area [m2]	Relative
Reference	8363	100,0%
Bus lane	9193	109,9%
Bus lane + bus signal	9256	110,7%
Roundabout meter	8499	101,6%
Priority square	8433	100,8%
Traffic lights	9532	114,0%

Travel time loss per person

For the travel time loss, the delay function in Vissim is used. First, the delay per vehicle is determined per mode, the results of which are in Appendix D. For each mode the total delay is retrieved by multiplying the average delay per vehicle by the total number of vehicles for that particular mode. To obtain the delay per person the total delay per mode is multiplied by the average occupancy of that mode. The overall results of these total personal delays are shown in Table 8. The total personal delays per mode can be found in Appendix E.

The differences between the variants are significant and not all variants accomplish a reduction in total travel time. Especially the variant with the bus signal has an increase in total travel time, which is mainly because the buses have increased priority at the signalized intersection. Because of this priority, the travel time for buses is reduced, although all other modes have an increased travel time since they have to wait longer before they eventually receive a green light. For the three variants that have a measure at the roundabout the travel time losses are reduced significantly. This reduction is mainly accomplished by the fact that traffic does not back up on the link between the two intersections. Most of the delay is caused by queueing up for the roundabout. The variant with a roundabout meter still has some traffic backing up before the roundabout, but this is better distributed among the different branches. The result of this is that the branch leading from the signalized intersection does not back up all the way onto this intersection preventing traffic there from continuing on their journey. This is also visible in Figure 15 and Figure 16 in the section on traffic safety.

Table 8 - Overview of the results for travel time loss per person

	Total delay overall [s]	Relative
Reference	1320420	100,0%
Bus lane	1330956	100,8%
Bus signal	1582537	119,9%
Roundabout meter	926737	70,2%
Priority square	640164	48,5%
Traffic lights	707219	53,6%

Attractiveness cycling/walking

For the attractiveness of active modes, the average delay of these modes is analysed. For both active modes, this delay is relatively low with only about ten seconds per person in the reference scenario. The reason this is so low is because at the roundabout the active modes have priority, meaning that motorized vehicles have to wait for them. Cyclists and pedestrians can thus continue on their way without having to wait for a gap between two vehicles. At the signalized intersection, however, active modes have to wait until they receive a green light, just like the other traffic. Nevertheless, these waiting times are relatively short because the active modes have dedicated traffic lights. These lights are installed in such a way that the active modes can cross at the same time as motorized vehicles using different branches at that moment. The increased delay for the traffic light option is mainly due to the conversion of the roundabout into a traffic light, which gets the active modes out of priority and lets them wait for green instead. For the priority square, the active modes are out of priority for crossing the busy eastern and western branches but are still in priority for crossing the relatively calmer northern and southern branches.

Table 9 - Overview of the results for the attractiveness of active modes for each variant

	Avg delay Pedestrians [s]	Relative	Avg delay Cyclists [s]	Relative
Reference	8,5	100,0%	12,3	100,0%
Bus lane	8,4	99,2%	12,2	99,7%
Bus signal	8,5	100,0%	12,7	103,2%
Roundabout meter	10,3	121,5%	11,9	96,6%
Priority square	16,2	190,1%	13,2	107,3%
Traffic lights	26,1	307,5%	19,7	160,7%

Attractiveness public transport

The delay for public transport vehicles is set as an indicator of the attractiveness of public transport. Table 10 shows that for every variant the delay per vehicle is reduced compared to the reference scenario. For the bus lane and bus signal the decrease in delay is limited by the traffic that still exists on the link between the two intersections towards the roundabout. In these two variants, buses will get stuck in the same queues as the rest of the vehicles. For the other three variants, there is no queue forming on the link connecting the intersections which allows for the buses to drive on.

The other aspect of the attractiveness of public transport is its reliability. The reliability is measured by the relative standard deviation. The three options in which buses do not get stuck in traffic are also more reliable, as shown by their low standard deviations. The high standard deviations for the variants in which buses get stuck in traffic show that traffic can clear at very different rates.

Table 10 - Overview of the results for the attractiveness of public transport for each variant

	Avg delay Buses [s]	Relative	Standard deviation [s]	Relative standard deviation	Relative
Reference	171,3	100,0%	28,6	16,7%	100,0%
Bus lane	137,3	80,2%	33,4	24,3%	145,5%
Bus signal	136,1	79,5%	29,4	21,6%	129,6%
Roundabout meter	65,2	38,1%	4,4	6,7%	40,0%
Priority square	57,6	33,6%	3,4	5,8%	34,9%
Traffic lights	55,5	32,4%	2,9	5,2%	30,9%

Traffic safety

For traffic safety, the number of conflicts resulting from the SSAM analysis are used. The more conflicts there are for a variant the more likely it is that an accident will occur with the lay-out of that variant. A distinction is made in the type of conflict based on the type of vehicles involved in a conflict. Since three types of vehicles are considered for traffic safety there are six possible conflict types. For all three types with another vehicle of the same type. But also another three conflict types in which different vehicle types have a conflict. However, it is assumed that accidents between active modes do not occur in reality, as due to the low speeds of the active modes any accident will always be solved before it occurs. This type of conflict is therefore left out for further analysis.

Since there are already five conflict types to consider, the conflict angles are not considered towards the score for well-being. Nevertheless, the division of conflict angles per conflict type is shown in Appendix F, as they do explain the number of conflicts to a certain extent.

Table 11 - Overview of the results for conflicts in which only motorized vehicles are involved for each variant

	Car-Car	Relative		Car-Truck	Relative		Truck-Truck	Relative
Reference	39760	100,0%		4460	100,0%		1047	100,0%
Bus lane	30947	77,8%		4685	105,0%		1049	100,2%
Bus signal	41734	105,0%		4595	103,0%		1055	100,8%
Roundabout meter	32077	80,7%		3427	76,8%		933	89,1%
Priority square	11813	29,7%		3275	73,4%		969	92,6%
Traffic lights	14398	36,2%		3174	71,2%		957	91,4%

In Table 11 can be seen that only the variant with the bus signal performs worse than the reference scenario. Especially the priority square and traffic lights have a massive reduction in the number of conflicts compared to the reference scenario. For both the car-truck and truck-truck conflict types there are two groups visible, with the lower three variants performing better than the reference and both bus lane variants. In the model, most trucks only pass the signalized intersection, which could explain the difference in conflict reduction between only trucks and only cars. Most of the reduction consists of a reduction in rear-end conflicts, as can be seen in Appendix F.

Table 12 - Overview of the results for conflicts in which active modes are involved for each variant

	Car-Active	Relative		Active-Truck	Relative
Reference	178	100,0%		74	100,0%
Bus lane	130	73,0%		119	160,8%
Bus signal	175	98,3%		72	97,3%
Roundabout meter	81	45,5%		33	44,6%
Priority square	80	44,9%		26	35,1%
Traffic lights	0	0,0%		21	28,4%

There are much fewer conflicts in which active modes are involved than is the case for motorized-only conflicts, as follows from the numbers in Table 12 being much lower than is the case in Table 11. Most noticeably there are no conflicts at all between active modes and cars in the traffic light variant. The 21 conflicts that exist between active modes and trucks are therefore likely caused by the length of the trucks, as they take longer to clear an intersection.

Even though the conflict angle is not considered for the well-being score, it can be used to explain why there are so many conflicts for the variants in which traffic backs up. For all variants, the majority of conflicts occurring between two motorized vehicles are rear-end conflicts. Especially with long queues it is start-stop traffic, which causes many read-end conflicts to occur. Figure 15 shows that in the reference scenario rear-end conflicts (shown in yellow) occur on the entire link from the signalized intersection to the roundabout, and even lead back onto the signalized intersection itself. There are so many conflicts there that all the individual squares together form a solid line. On the other hand, the link from the roundabout to the signalized intersection has very few rear-end conflicts. In Figure 16 the conflicts for the variant with the priority square are shown. The traffic in this variant does not back up onto the signalized intersection, as is backed up by the lack of yellow squares leading back from the priority square onto the signalized intersection.

What becomes clear from Figure 16 as well is that rear-end conflicts mostly occur in the branches leading towards an intersection. When vehicles have passed an intersection there are hardly any conflicts. In both Figure 15 and Figure 16 the majority of lane change and crossing conflicts occur at the intersections. This makes sense, as those are the places where vehicles can cross paths with each other. Especially the variant with traffic lights causes a reduction in lane change and crossing conflicts, which is likely due to the traffic lights restricting the possibility of different flows of traffic from being at an intersection at the same time.

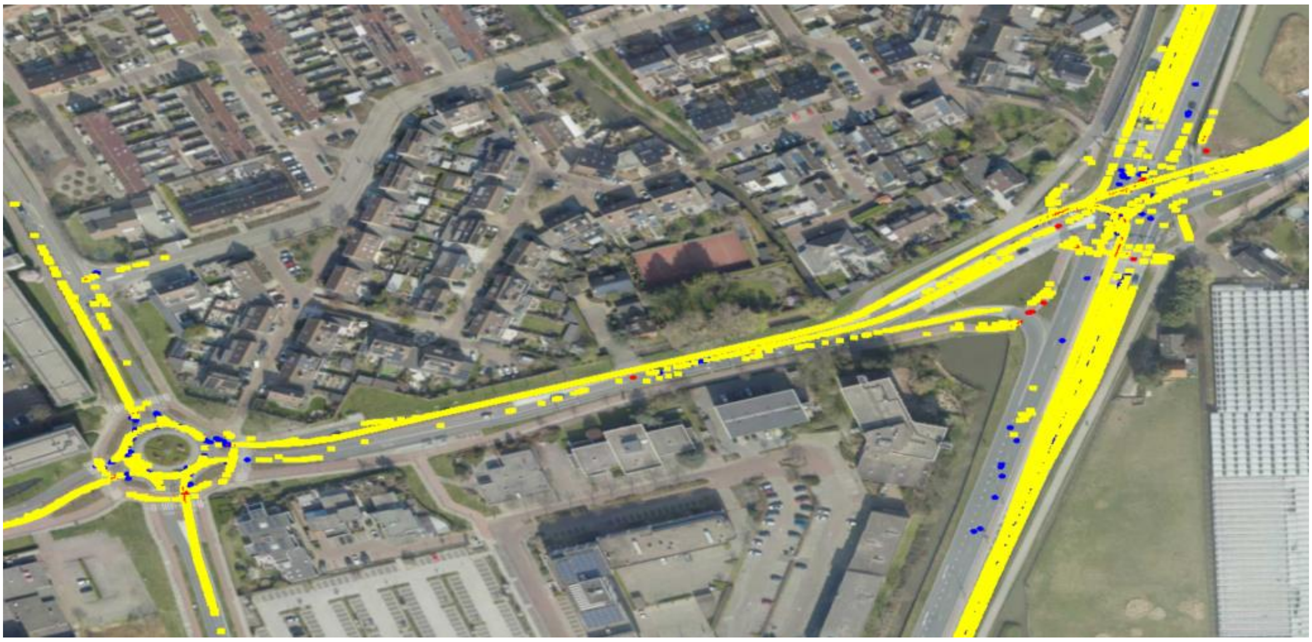


Figure 15 - Overview of the study area with the location of conflicts for the reference scenario sorted by type of conflict (yellow = rear-end, blue = lane change, red = crossing)

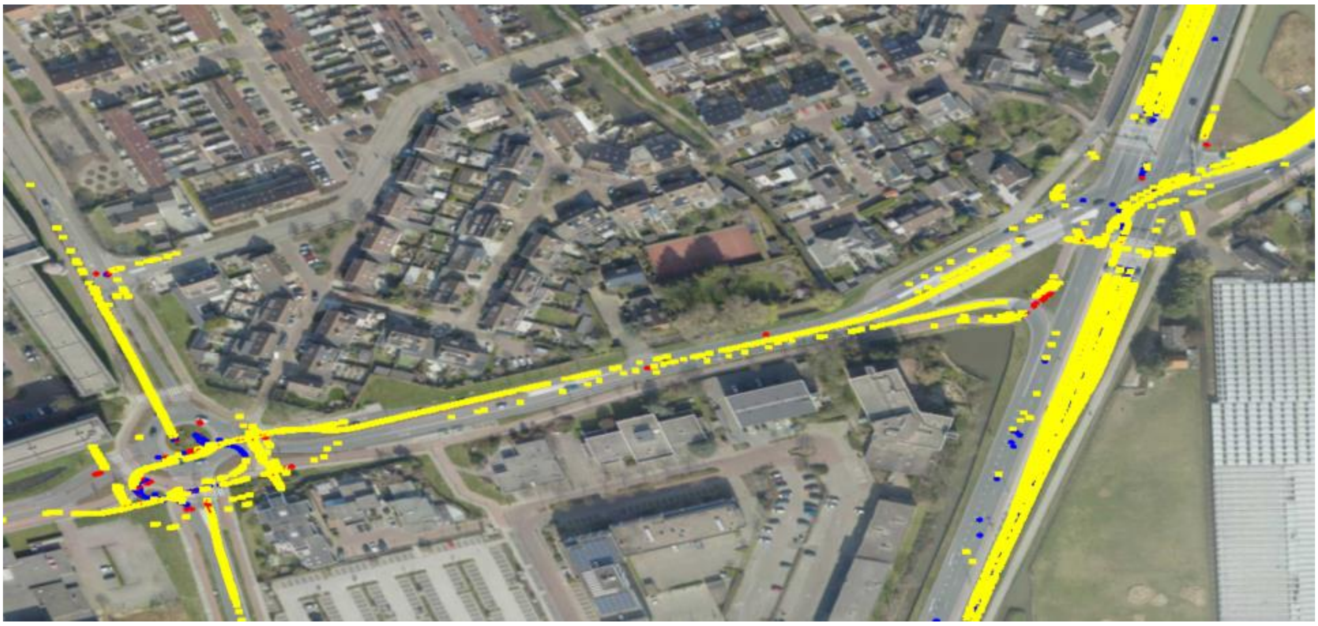


Figure 16 – Overview of the study area with the location of conflicts for the priority square variant sorted by type of conflict (yellow = rear-end, blue = lane change, red = crossing)

6.3.2. Normalize results

With the simulations run and the results available it is possible to give each indicator a score that enables comparisons. In section 3.3 is explained how these scores are obtained. This process is relatively straightforward for the indicators of travel time loss per person and paved surface area. For the other indicators, this is more complicated as there are multiple results to be combined to obtain a score for those indicators. The process for these five indicators is not the same. Therefore, the processes for the scores of these five are explained individually.

Emissions – gases

For the emissions of gases, three different gases that influence well-being are measured. For this indicator, these three aspects need to be combined into a single score. This is achieved by multiplying the scores for each aspect by the relative importance of each gas. For the case study, it is assumed that all gases have an identical influence, so their relative importance is one-third each. The overall score is thus obtained by multiplying the score per aspect by a third and then adding the three resulting values together. The scores per aspect and their contributions to the overall score for emissions – gases are shown in Table 13.

Table 13 - Overview of the scores and contributions towards well-being for emissions - gases

	Score CO2	Contribution CO2 (0,33)	Score NOx	Contribution NOx (0,33)	Score PM10	Contribution PM10 (0,33)	Emissions - gases overall
Reference	0,00	0,00	0,00	0,00	0,00	0,00	**0,00**
Bus lane	0,00	0,00	0,01	0,00	0,01	0,01	**0,01**
Bus signal	-0,03	-0,01	-0,06	-0,02	-0,04	-0,02	**-0,04**
Roundabout meter	0,04	0,01	0,10	0,03	0,09	0,03	**0,08**
Priority square	0,07	0,02	0,12	0,04	0,11	0,04	**0,10**
Traffic lights	0,07	0,02	0,13	0,04	0,12	0,04	**0,11**

Emissions – noise

For noise there are two aspects for which results are available. These results are somewhat related, as the average speed is likely to increase when fewer stops are made. It is thus assumed that both aspects have an equal effect on the overall emission of noise. Therefore, the same principle is used for emissions – gases, except the relative importance of each aspect is not a third but 0,5. The resulting scores and contributions can be found in Table 14.

Table 14 - Overview of the scores and contributions towards well-being for emissions - noise

	Score avg speed	Contribution avg speed (0,5)	Score no. stops	Contribution no. stops (0,5)	Emissions – noise overall
Reference	0,00	0,00	0,00	0,00	**0,00**
Bus lane	0,01	0,01	-0,02	-0,01	**0,00**
Bus signal	0,11	0,05	-0,12	-0,06	**-0,01**
Roundabout meter	-0,15	-0,07	0,07	0,03	**-0,04**
Priority square	-0,26	-0,13	0,70	0,35	**0,22**
Traffic lights	-0,24	-0,12	0,68	0,34	**0,22**

Attractiveness active modes

The attractiveness of active modes is measured by the delay experienced by both pedestrians and cyclists. To ensure that every person is considered equally important the number of people travelling by each mode should be included in the calculation of the contributions per mode. For this case study specifically, the average number of pedestrians is around 300, whereas there are approximately 2900 cyclists per simulation run. Therefore, the resulting factors for pedestrians and cyclists are 0,1 and 0,9, respectively. In Table 15 the resulting scores and contributions are shown.

Table 15 - Overview of the scores and contributions towards well-being for the attractiveness of active modes

	Score pedestrians	Contribution pedestrians (0,1)	Score cyclists	Contribution cyclists (0,9)	Attractiveness active modes overall
Reference	0,00	0,00	0,00	0,00	**0,00**
Bus lane	0,01	0,00	0,01	0,01	**0,00**
Bus signal	0,00	0,00	0,00	0,00	**-0,03**
Roundabout meter	-0,18	-0,02	-0,18	-0,16	**0,01**
Priority square	-0,47	-0,05	-0,47	-0,42	**-0,11**
Traffic lights	-0,67	-0,07	-0,67	-0,61	**-0,41**

Attractiveness public transport

For public transport, there are again two aspects for which results are gathered. For the case study, it is assumed that these two aspects, namely the delay and the variance of the delay, contribute equally to the overall score for the attractiveness of public transport. Therefore, both aspects are multiplied by 0,5. The scores and contributions resulting from this are shown in Table 16.

Table 16 - Overview of the scores and contributions towards well-being for the attractiveness of public transport

	Score delay	Contribution delay (0,5)	Score variance	Contribution variance (0,5)	Attractiveness public transport overall
Reference	0,00	0,00	0,00	0,00	**0,00**
Bus lane	0,20	0,10	-0,31	-0,16	**-0,06**
Bus signal	0,21	0,10	-0,23	-0,11	**-0,01**
Roundabout meter	0,62	0,31	0,60	0,30	**0,61**
Priority square	0,66	0,33	0,65	0,33	**0,66**
Traffic lights	0,68	0,34	0,69	0,35	**0,68**

Traffic safety

The indicator traffic safety consists of the most factors that should be considered. There are five types of conflict which do not all have an equal impact on overall traffic safety. Conflicts involving active modes have a higher risk of serious injury or worse. This is because they are vulnerable road users and are not protected by the vehicle they are driving. Conflicts involving trucks and buses are also more likely to have serious consequences, but with this type of vehicle, the seriousness is due to their size and weight. Therefore, conflicts between cars and both other vehicle types are considered twice as important as conflicts between cars only. For this case study conflicts between trucks are considered equally important as conflicts between cars and other modes. Finally, conflicts between active modes and trucks are considered three times as impactful as conflicts between cars only. The resulting scores and contributions are shown in Table 17, as well as the resulting scores for traffic safety overall.

Table 17 - Overview of the scores and contributions (con) towards well-being for traffic safety

	Score C-C	Con C-C (0,1)	Score C-A	Con C-A (0,2)	Score C-T	Con C-T (0,2)	Score A-T	Con A-T (0,3)	Score T-T	Con T-T (0,2)	Traffic safety overall
Reference	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	**0,00**
Bus lane	0,22	0,02	0,27	0,05	-0,05	-0,01	-0,38	-0,11	0,00	0,00	**-0,05**
Bus signal	-0,05	0,00	0,02	0,00	-0,03	-0,01	0,03	0,01	-0,01	0,00	**0,00**
Roundabout meter	0,19	0,02	0,54	0,11	0,23	0,05	0,55	0,17	0,11	0,02	**0,36**
Priority square	0,70	0,07	0,55	0,11	0,27	0,05	0,65	0,19	0,07	0,01	**0,44**
Traffic lights	0,64	0,06	1,00	0,20	0,29	0,06	0,72	0,21	0,09	0,02	**0,55**

6.3.3. Relative indicator results

Now that the scores for all indicators are normalized it is possible to put them all in one overview, which is Table 18. What stands out from this overview is that generally the lower three rows have higher scores than the top three rows. It is therefore most likely that one of the lower three variants comes out as the variant with the highest score for well-being based on these indicators. However, before the conclusions of the simulations on well-being can be drawn the relative importance of indicators should be included as well.

Table 18 - Overview of the normalized scores of every indicator for each variant

	Emissions – gases	Emissions – noise	Paved surface	Travel time loss per person	Attractiveness active modes	Attractiveness public transport	Traffic safety
Reference	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Bus lane	0,01	0,00	-0,09	-0,01	0,00	-0,06	-0,05
Bus signal	-0,04	-0,01	-0,10	-0,17	-0,03	-0,01	0,00
Roundabout meter	0,08	-0,04	-0,02	0,30	0,01	0,61	0,36
Priority square	0,10	0,22	-0,01	0,52	-0,11	0,66	0,44
Traffic lights	0,11	0,22	-0,12	0,46	-0,41	0,68	0,55

6.4. Indicator importance determination

Normally this step in the process would involve contact with the local authorities. As this is a case study based on an already existing model this contact has not happened. It is therefore not possible to base the relative importance of indicators based on input from the local authorities.

Instead of basing the ranking on the input of the local authorities, a different way of ranking indicators needs to be established. For this case study the ranking of indicators that followed from the survey are used. This ranking is not necessarily the most relevant for this study area. However, since this case study is meant as an example of how the framework can be applied it is more important to have a ranking than for this ranking to be relevant. If this had been an actual study more effort should have been put in establishing the importance of indicators. The ranking as shown in Table 19 is used for the case study.

Table 19 - Relative importance of indicators

	Relative importance
Emissions - gases	18
Paved surface	11
Traffic safety	17
Attractiveness active modes	20
Attractiveness Public Transport	14
Emissions - noise	10
Travel time loss per person	9

6.5. Assessing well-being simulated part

With all the scores per indicator known, as well as having established the relative importance of indicators, it is possible to determine the well-being scores per variant. These well-being scores are based on the seven indicators that are used in the simulation process. The sum of the relative importance of indicators is 100, so the range of the score for well-being is between -100 and +100. A negative score means a decrease in well-being compared to the reference scenario, whereas a positive score implies an increase in well-being. Table 20 shows the results of the multiplication of the scores per indicator from Table 18 and the relative importance from Table 19. The resulting overall score for well-being per variant can be found in the rightmost column. The contribution of each indicator is also presented. The results are also visualized in Figure 17. Here the contribution of each indicator is shown, as well as the resulting overall score for well-being.

Table 20 - Overview of the relative score for well-being and the scores per indicator

Variant	Emissions - gases	Emissions - Noise	Paved surface	Travel time loss per person	Attractiveness active modes	Attractiveness public transport	Traffic safety	Well-being
Reference	0,0	0,0	0,0	0,0	0,0	0,0	0,0	**0,0**
Bus lane	0,1	0,0	-1,0	-0,1	0,1	-0,8	-0,8	**-2,5**
Bus signal	-0,8	-0,1	-1,0	-1,5	-0,5	-0,2	0,0	**-4,2**
Roundabout meter	1,4	-0,4	-0,2	2,7	0,2	8,7	6,3	**18,9**
Priority square	1,8	2,3	-0,1	4,7	-2,2	9,4	7,7	**23,7**
Traffic lights	1,9	2,3	-1,3	4,3	-8,1	9,8	9,6	**18,5**

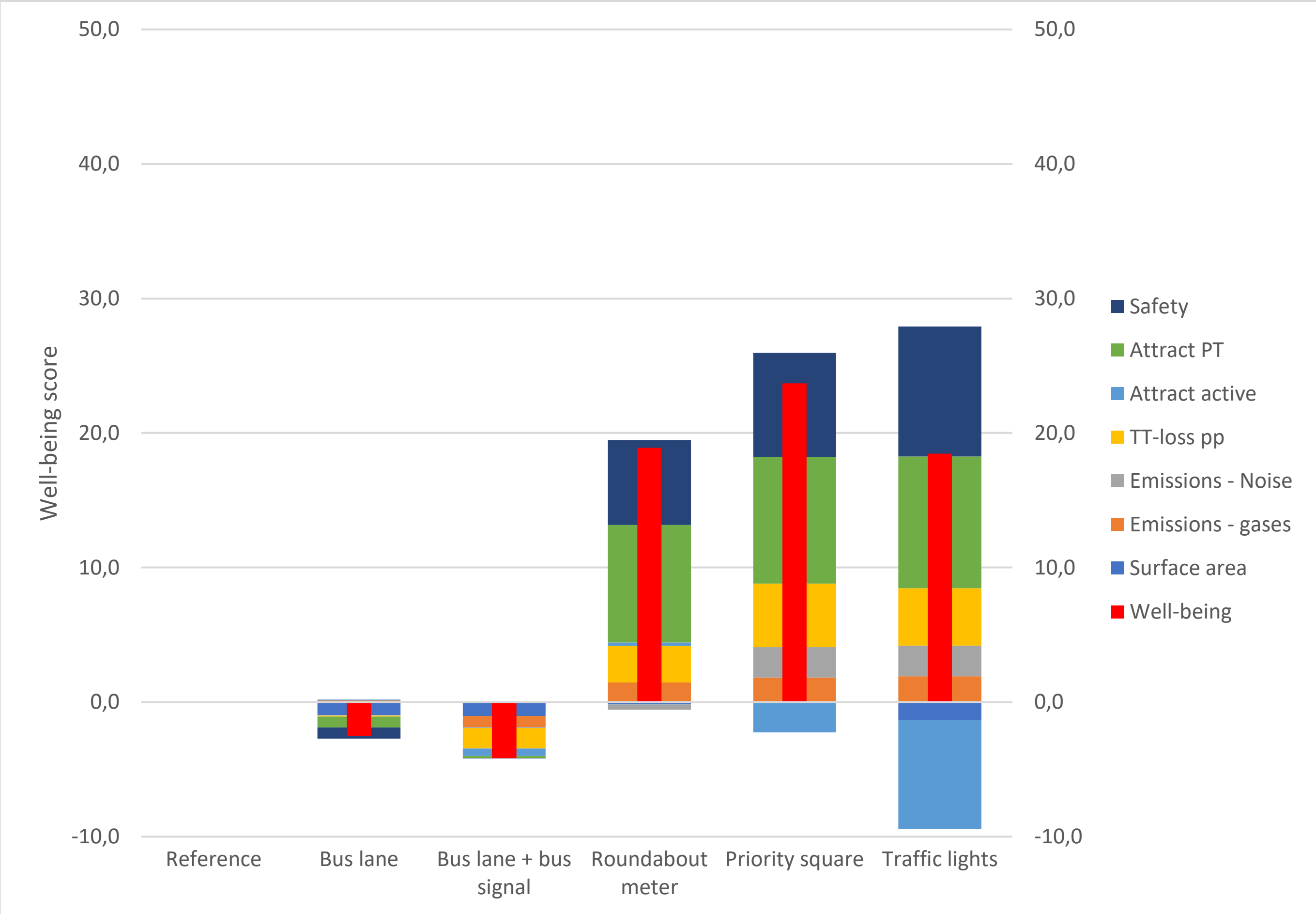


Figure 17 - Visualization of the scores for well-being per variant and the contributions per indicator

In the rightmost column of Table 20, there is a clear distinction between two groups of variants. The group with the reference, bus lane and bus signal performs relatively poorly compared to the other three variants. For the variants with a bus lane and the one with a bus signal, the well-being situation is even slightly worse than for the reference scenario. It is more interesting to examine the well-performing variants, as it is one of these three variants that would likely be implemented based on this analysis. The high scores are due to high scores for the attractiveness of public transport and traffic safety. The scores for personal travel time loss and the attractiveness of active modes are also relatively high. The overall highest score is for the variant with the priority square, although the variant in which a second signalized intersection is added follows closely.

Paved surface area and both emission indicators have a relatively small influence on the overall scores of all variants. For this case study the height of the scores for well-being based on the simulated indicators is mainly influenced by the attractiveness of alternative modes (both active modes and public transport) and traffic safety. The travel time loss per person is the only indicator for which the scores are relatively in the middle between the three low and the three high-scoring indicators.

6.6. Comparison with traditional analysis

The results of the analysis aimed at assessing well-being using traffic simulation software are compared to the results of a more traditional analysis of the same study area. The results of the well-being-focused study are presented in the previous section. The results of the traditional analysis followed from the final report of the analysis. The main findings in this report are presented below. After the results are presented a comparison between the well-being-focused and the traditional analysis follows.

The more traditional analysis is focused mainly on improving travel times and reliability of buses in the study area. For all variants, there are improvements for buses travelling in both directions, although the variants with the most improvement are the roundabout meter and the traffic light. The priority square performs well for the afternoon rush, but considering the morning rush it performs comparable to the reference situation, which means that there is quite some delay for buses. Therefore, the options with the roundabout meter and traffic light are considered further. This further analysis leads to the traffic light being the preferred option, although it is mentioned that this is a relatively expensive solution. The main reason the roundabout meter is not chosen as the final solution is the fact that traffic safety would be impacted too much. As the concept of a roundabout meter is very uncommon it will be a new situation for most people, which could cause uncertainty among travellers. Furthermore, red-light negation is expected to negatively influence traffic safety as well. For both the final variants it is noted that the delay for active modes is increased significantly.

The results of the traditional analysis are relatively similar to those of the well-being-focused analysis. The main similarity is the fact that the three best options for the well-being analysis are also the best three that result from the traditional analysis. However, for the morning rush it turns out that the priority square does not perform as well as the other two. Since the morning rush was not considered for the well-being analysis, this worse performance is not noted in the case study. The priority square would likely experience a decrease in its score when the morning rush is taken into account for the well-being analysis. The main weak point of the roundabout meter that came out of the traditional analysis is the expected lack of traffic safety for that variant. However, the scores for the indicator of traffic safety in the well-being analysis are relatively high for the roundabout meter. The safety score for the traffic light variant is higher than for the roundabout meter, but this does not mean that the roundabout meter scores poorly. The expected lack of traffic safety is not noticeable in the well-being analysis. This might be explained by the fact that red light negation is not taken into account and the novel design of the roundabout meter is also not of influence for the simulated vehicles.

7. Framework

The goal of this research is to set up a framework for the assessment of the mobility aspect of well-being. There is an emphasis on how traffic simulation software can be used for such an assessment, but not all aspects can be assessed using this type of software. Therefore, the non-simulation part of the mobility aspect is included in the framework. The created framework is presented in Figure 18. There are three main areas of the framework, which are all for a different part of an assessment of mobility-related well-being. These three parts are explained more in detail in the sections below.

Indicators for well-being

On the left side of the framework, the indicators for well-being are shown. However, this research focuses on the indicators for the mobility aspect of well-being specifically, which is why there is a further specification on this side. There are two types of indicators of the mobility aspect of well-being: indicators that can be assessed using traffic simulation software and indicators for which no data can be gathered via this type of software.

For the part that can be assessed via simulation software all seven indicators that are set up in section 2.3 are shown in the framework. These indicators are colour-coded per dimension in the same way as is the case in Figure 3. The indicators for the simulation aspect are connected to the simulation process as shown in Figure 5. The first three phases in Figure 5 together form the circle simulation process as shown in Figure 18. For each indicator results come out of the simulation process. The results should be processed so that the outcomes of different indicators can be compared to each other. This process of normalizing the results is explained in section 3.3. An example of how the processed results can look is given in the case study in section 6.3.2.

For the non-simulation indicators, the same colour coding for the dimensions of mobility-related well-being is used. Examples of indicators that are not suitable for assessment via simulation are given for each of the four dimensions. These examples are based on the exploration by (Vonk Noordegraaf et al., 2021). Important here is to note that the shown indicators unsuitable for simulation are not all indicators for this group of the mobility aspect of well-being, but rather a selection. The dotted lines for all dimensions clarify that this is the case.

The non-simulation indicators should be taken into account as well for a complete assessment of the mobility aspect of well-being. Although it is not possible to gather results on them using traffic simulation software, this does not mean that there is no data on these indicators. Different sources can be used to obtain information or results for every indicator. However, as the source of the data for different indicators is likely to be different, it can be difficult to directly compare indicators to each other as is the case for the indicators involved in the simulation. How this should be done exactly is outside the scope of this research.

Importance of indicators

On the right side of the framework, the process to establish the relative importance of each indicator is shown. There are three inputs for this process. The first is the input of a traffic engineer, who has experience with well-being-focused analyses, and thus about what impact the scoring of indicators has on the overall outcome of an analysis. With the experience from other analyses, the traffic engineer can adjust the relative importance in the right direction. The input of the traffic engineer can form the basis for the establishment of the relative importance of indicators.

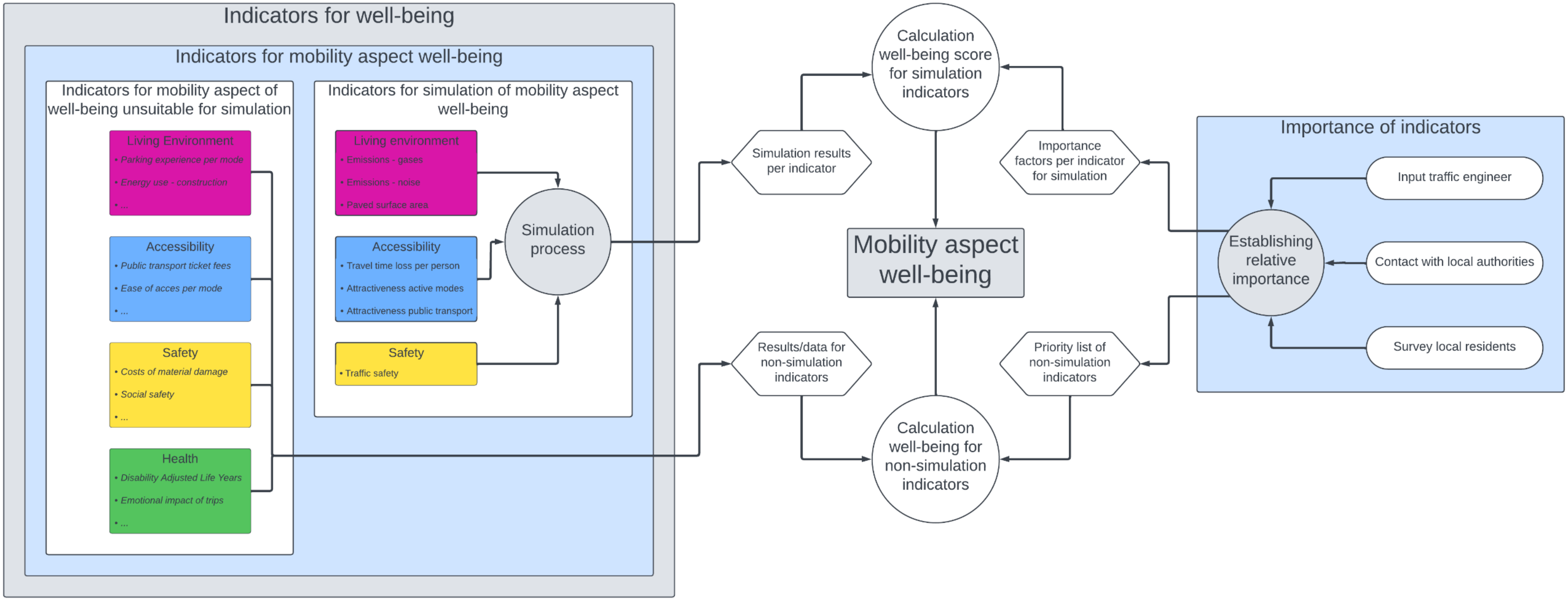


Figure 18 - Framework for the assessment of the mobility aspect of well-being

The traffic engineer should not determine the ranking on his own, bus should have contact with local authorities as well. Local authorities generally know what characteristics of a study area are important for an analysis. These characteristics should be taken into account when establishing the relative importance of indicators, as an analysis at a rural location likely requires a different relative importance of indicators than an urban location for example.

Finally, local residents could be involved in the process. The realization of a construction project generally has an impact on residents, which is why it can be interesting to involve them in the process. When these stakeholders are involved in the process they could have useful input for the decision-making process for the indicator ranking. They might not have the knowledge that the traffic engineer has, but their input could still be useful as the well-being is assessed for their living environment.

There are two outcomes of the establishment of the relative importance of indicators. One is for the simulation part of the assessment, while the other is for the non-simulation part. The outcome for the simulation part is a list of factors for each of the seven indicators. The higher a factor is, the more important that indicator is regarded. Secondly, the non-simulation part should have a priority list for the indicators. As the data for these indicators does not necessarily allow for comparisons between indicators this is a priority list. If the results for this non-simulation part would be comparable the results for this part would also be a list of factors. The priority list should be used to determine which indicators should be investigated first, as they are considered to have the most influence on well-being.

Assessing the mobility aspect of well-being

The third part of the framework is shown in the middle of Figure 18. From both the left and the right side of the framework there are two separate streams. These streams come together in two different score calculations. The top score calculation is for the simulation part of the assessment, whereas the bottom score calculation is for the non-simulation part.

For this research, most attention is towards the simulation part of the assessment of well-being, thus to the top part of the framework. The calculation of the score for well-being using simulation software is already explained in section 3.5. As is shown in the framework the inputs for the calculation of well-being for this part are the processed results of the simulation and the list of factors for the importance of indicators. These two results should be put into equation (2), which is introduced in section 3.5, to determine the well-being score for the simulation part of the assessment. With this equation a score is determined for each indicator and the scores of all seven indicators are then added together to obtain the final score for the mobility aspect of well-being using traffic simulation software. An example of how this formula can be applied is shown in the case study in section 6.5.

The simulation part of the framework is only suitable for use if there are multiple different variants for the same study area. The basis for the assessment using simulation software is that only the relative scores for well-being can be assessed, thus requiring multiple variants to obtain relative results. An absolute value of well-being is impossible to establish as there are too many factors that influence well-being that the seven investigated indicators can never give a full representation of well-being.

The bottom part of the middle of the framework is dedicated to establishing the score for well-being based on the non-simulation indicators. Many indicators belong in this part of the framework. The priority list should be set up in such a way that the most important indicators are thoroughly investigated. Indicators that are deemed less important do not require as thorough of an investigation as the most important indicators, as their impact is also considered much less. How exactly the scores for well-being should be established for this part of the framework is outside of the scope of this research, as that is aimed mostly at the simulation part of the framework.

8. Discussion

In this research, some noteworthy points might influence the outcome of the research. In this section, these points are mentioned and explained why they might influence the results. Furthermore, the effect of the mentioned points will be elaborated on.

Broadness of well-being

The concept of well-being as used in this research is very broad. Although there is a specification towards the mobility aspect of well-being, this aspect is still very broad. This broadness makes it difficult to find all the indicators that influence the well-being experienced by people. In this research, the aim is to find as many indicators as possible that can be derived from traffic simulation software. Although seven indicators are established for the simulation part of the framework, there are still many indicators that are not suitable for retrieving results out of traffic simulation software. The fact that many indicators are not suitable for the simulation part of the framework means that the broadness of well-being is not fully captured. Furthermore, for the health dimension, there is not even a single indicator established, although this dimension is indirectly present in some other indicators.

The lack of broadness for the simulation part is incorporated into the framework where there is a dedicated section for non-simulation indicators. For this research the focus is on the indicators that can be derived from simulation software, so further research is necessary to ensure that also the non-simulation part can be used for assessing well-being. When this assessment of non-simulation indicators can be done as well, an analysis of well-being will be more complete than only looking at the well-being scores resulting from the simulation part.

Survey results significance

The results of the survey show a very large standard deviation. This means that there is little certainty in the scores for each indicator, or aspects of indicators for that matter. There are not that many responses to the survey, but it is unlikely that more responses would have led to a more significant outcome of the survey. This is because the responses already vary massively between each other. The fact that outliers (scores above 40) are present for every indicator except one shows that opinions are very different for different respondents. The fact that no situation was presented for which the relative importance of indicators should be established could have contributed to the high variance. This is because the respondents now have to come up with a situation of their own, which will be different for every respondent. As mentioned, for every situation a different ranking of indicators should be made, which would explain the differences between responses. This also highlights the importance of establishing the weight of the indicators for every situation independently.

Nevertheless, the average scores resulting from the survey have been taken for the case study in this research. Ideally, there should have been contact with local authorities to determine the relative importance of indicators, as this would have led to a suitable ranking of indicators for the case study location. The input of a traffic engineer who has experience with well-being-focused simulations would also have been helpful, but since this is a new framework there is no traffic engineer with this experience yet. Nevertheless, when examining the individual scores per indicator of the case study, it can be assumed that well-performing variants will always score higher than relatively poor-scoring variants.

Bias local authorities

A key part of the establishment of the relative importance of indicators is the contact with local authorities. These local authorities should be involved in the process of assessing well-being as the studies will be performed to gain insight into their areas. Therefore, they are expected to be knowledgeable about what is or what should be important in the study areas. However, when asking a policymaker directly whether they want less pollutant gases resulting from traffic at the cost of a few more traffic casualties they will always state that this is not an acceptable option. For policymakers, it is very hard to agree with a policy that would lead to a direct increase in casualties even though it might be beneficial for the overall population. Therefore, this type of question should be avoided as the answers will have an impact on the relative importance of indicators.

Moreover, the local authorities are generally a government institution like a municipality or a province. These institutions are democratically elected every few years and policies are bound to change when there is a change in the leading parties. The policies set by the ruling party or parties can influence the scoring of indicators. Parties with a high interest in climate are more likely to rate the emissions of gases high, whereas a more car-focused party will rate travel time loss higher, especially for passenger cars. Which party is setting the policies therefore matters for the establishment of indicator importance. Especially when policies change during a project, this could result in a different ranking.

Implications modal split

With the attractiveness of both active modes and public transport, there is clear attention towards different (greener) modes of transport. Generally, well-being is increased with an increase in people taking these greener modes. Ideally, these modes are made so attractive that it will cause people to leave their car at home and take a bike or public transport instead. However, the effect of the attractiveness on the modal split is unknown and can therefore not be simulated, while it could have a big effect on how a study area behaves. A change in which people would switch away from the car would mean fewer cars on the road which means that it is less likely that congestion occurs. On the other hand, more cyclists likely mean more conflicts in which active modes are involved as well, thus reducing the safety in a study area. As a change in modal split will have many different effects, of which the magnitudes are unknown, it is impossible to say what the effect would be on the overall well-being in a study area.

Assumptions for simulation

For the simulation, several assumptions are made that might influence the outcome of the well-being score resulting from the simulation part. Some of the most noteworthy assumptions are discussed in this section.

The case study resulted in the priority square being the most beneficial variant regarding well-being. However, in the comparison with the original, more traditional, analysis it turns out that this option performs very differently between the morning and afternoon rush hours. For the afternoon rush the priority square performs well, but for the morning rush the results are similar to the poorly performing reference situation. As the case study is used purely to show how the framework can be applied, the results of the well-being analysis are still valid. However, it shows that for an actual analysis, it is important to consider both rushes.

The indicator for noise emissions considers the number of stops per vehicle and the average speed in the network. However, the number of stops per vehicle is not a perfect representation of the braking and acceleration of vehicles. Vehicles often slow down but not to a complete standstill. If a vehicle slows down to 5 km/h and then accelerates again this is not counted towards the number of stops since no complete standstill is reached. This shows that not all braking and acceleration are taken into account for the analysis. Nevertheless, as the number of stops is counted in the same way for every variant this should not lead to significant differences. The fact that it is used as a relative value makes that this distinction is not that significant. For a future study it would be interesting to investigate creating soundmaps that show the average sound levels within the study area.

The area measurements as done in the case study also leave some room for improvement. This is because only the links that are changed are considered for the paved surface area determination. Many more links in the network are left out of the analysis when it is done this way. This has an impact on the relative values, as the absolute differences in surface area remain the same while the relative differences become smaller due to the increased surface area. Furthermore, for intersections the used method is not accurate. In the simulated network, only the areas where vehicles drive are counted, whereas in reality there often is paved surface in between those areas. Moreover, the overlapping areas of links are counted more than once while in reality there only is one paved area. It is assumed that these two factors have an equal but opposite effect, although it is unknown whether this is actually the case. For future research these effects should be analysed to determine their effects.

For the travel time loss per person, the occupancy of vehicles needs to be known. Average values can be taken for this, but the average occupancy of a vehicle can differ depending on the time of day or location. Especially for public transport vehicles, there is a lot of variation in occupancy, since people can board and alight at every stop. Moreover, not every public transport line has an equal occupancy. One line has a higher average occupancy than another line. In the case study, an average number for the occupancy is taken, but ideally, the responsible public transport authority should be contacted for the average occupancy of their vehicles in the study area.

Furthermore, for traffic safety the tool that is used, SSAM, needs to be set up correctly. The parameters used for the calculation of whether a conflict occurs or not need to be set up correctly. These parameters have a big influence on the total number of conflicts. However, since the values that are used for this research follow from a study into what values are the best for urban situations, it is assumed that representative values are used for this research.

Finally, upon inspection, it turns out that especially trucks can cause conflicts when going through a turn at the outside of a corner. This is because the trailer takes a more inside line and thus can touch a vehicle at the inside of that corner. However, since the number of vehicles is the same for each variant it can be assumed that the number of conflicts this causes is the same among all variants. In the research, buses are considered as trucks for the traffic safety indicator due to their similar size and weight. Buses transport much more people than trucks, so the number of involved persons in a conflict differs significantly whether a truck or a bus is involved in a conflict. For future research, there could be investigated what the exact impact is of accidents involving buses and trucks. This could lead to adding another category, namely buses, for the assessment of traffic safety.

Heavy traffic

The influence of heavy traffic is not taken into account for all indicators, although their presence can have an impact on the experienced well-being. For the emission of gases their presence is taken into account, as well as for traffic safety. However, especially for emissions - noise, they are not taken into account. Heavy vehicles make more noise when accelerating than passenger vehicles, but also the braking of heavy vehicles causes noise. How much more noise is unknown and this impact on the emission of noise should be considered for future research.

Trucks are different from the rest of the traffic in the sense that they are not designed to transport people. Instead, they are designed to transport goods. This makes it difficult to assess what the travel time loss per person is for a truck, as it does not transport persons. In this research, it is assumed that a truck has an occupancy of one person, but for future research it should be investigated how the load of the truck could be involved in travel time loss per person. It might be that a relation between the (value of the) load of a truck can be compared to a certain number of occupants for example.

When a truck is involved in an accident the impact of that accident is much more likely to be severe than for passenger cars. This is mainly because of their mass and size. However, the exact numbers on how much more severe accidents are when a truck is involved are not implemented. For future research the impact of what type of vehicles are involved in an accident should be included. This does not only account for heavy vehicles like trucks and buses but also for vulnerable road users like cyclists and pedestrians.

9. Conclusion

The goal set for this research, '*create a framework for the assessment of mobility-related well-being that uses indicators that can be derived from a traffic simulation model*,' is accomplished. This accomplishment is achieved via answering the (sub-)research questions.

1. *What is the role of mobility within the overall concept of well-being?*

Well-being is a very broad concept that encompasses everything that has an influence on people's quality of life. Mobility, therefore, is an important aspect of well-being, as it has a major impact on people's lives. Being able to go to any place safely and healthily is important for a high level of well-being. In the previous sentence, the four main dimensions of mobility-related well-being become clear: living environment, accessibility, safety and health.

2. *How can results be obtained for indicators for the mobility aspect of well-being using a micro traffic simulation model?*

The indicators for the mobility aspect of well-being consist of two distinct groups: indicators that can be assessed using traffic simulation software and indicators for which this is not possible. There are seven indicators within the simulation part of the indicators. These seven are: emissions – gases, emissions – noise, paved surface area, travel time loss per person, attractiveness active modes, attractiveness public transport, and traffic safety. For all seven of these indicators results can be obtained using PTV Vissim. However, for the indicator traffic safety the use of another software is required. This software, SSAM, uses output generated by Vissim to obtain results for traffic safety.

3. *How can indicators of the mobility aspect of well-being be applied in a framework for assessing well-being?*

Mobility-related well-being can only be scored on a relative basis, as there are too many outside factors that influence overall well-being. Therefore, for every study area, there should be multiple variants that can be compared to each other to find the relative scores. Only the impact of the seven simulated indicators is assessed. The results of all indicators should be normalized to make them comparable to each other. Furthermore, factors for the relative importance of indicators should be established by input from an experienced traffic engineer, local authorities and local residents. The well-being score resulting from the simulation is obtained by multiplying the normalized results per indicator by the relative importance of each indicator. The total well-being score for a variant is achieved by adding the individual indicator scores together. This entire process is visualized in the top part of the framework, which is depicted in Figure 18 in chapter 7.

How can traffic simulation results be used for an analysis of a study area when assessing people's well-being is the main criterion?

All in all, using traffic simulation software does not lead to a complete assessment of the mobility aspect of well-being. However, it can lead to a very useful insight into what impact certain variants of a study network will have on the well-being of an area. For a complete analysis, it is necessary to also include non-simulation indicators in the assessment of well-being. Therefore, in the final framework, non-simulation indicators are included as well. The process for these non-simulation indicators is the lower part of the framework as shown in Figure 18.

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11. Appendix

A. Appendix A: survey

Sectie A: Enquête indicatoren brede welvaart

A1. **Voor mijn afstudeeronderzoek bekijk ik de mogelijkheden om brede welvaart te betrekken bij het uitvoeren van verkeersmicrosimulaties. Het gaat dan specifiek om het mobiliteitsaspect van brede welvaart, want brede welvaart omvat veel meer dan wat met verkeersmicromodellen vast te stellen is.**

Voor het vaststellen van de brede welvaart heb ik een aantal indicatoren opgesteld, maar mijn aanname is dat niet elk van deze indicatoren een gelijke invloed hebben op brede welvaart. Deze enquête is opgesteld om erachter te komen welke aspecten van brede welvaart als belangrijkst worden ervaren.

Het invullen van de enquête is vrijwillig, volledig anoniem en duurt ongeveer 5 tot 10 minuten. Als je vragen hebt bij het invullen van de enquête, dan kan je contact opnemen via jvink@goudappel.nl

Ik heb bovenstaande gelezen en ik ga akkoord met het invullen van deze enquête ☐

Sectie B: Indicatoren

Hieronder worden een aantal indicatoren geïntroduceerd die elk nog weer onderverdeeld zijn in verschillende factoren. Per indicator is eerst een uitleg gegeven wat ze inhouden, gevolgd door een korte uitleg voor iedere factor van die indicator. Dit deel van de enquête heeft als doel om per indicator te bepalen hoe belangrijk elke factor wordt ervaren.

Per indicator zijn er 100 punten te verdelen over de verschillende factoren. Hoe belangrijker je een factor acht, hoe meer punten je geeft aan deze factor. Er zullen altijd 100 punten verdeeld moeten worden, ongeacht het aantal factoren.

De punten kunnen worden toebedeeld door het verstellen van de schuif. Onder de genoemde opties staan het nog resterende aantal punten dat verdeeld moet worden en het totaal aantal gegeven punten. Als het getal voor resterend negatief is, zijn er te veel punten verdeeld.

B1. Emissies

Hiermee wordt alle uitstoot van gassen bedoeld die komt door voertuigen. Deze gassen hebben invloed op de lokale luchtkwaliteit, het milieu en het klimaat.

CO2: Hierbij gaat het om de impact op het klimaat. CO2 is het belangrijkste broeikasgas, daarom zal er ook worden gekeken naar de totale CO2-equivalent aan uitstoot. Stikstof: Stikstof heeft met name impact op de natuur, en dan vooral de kwaliteit van de natuur. Fijnstof (PM10): Fijnstof heeft een slechte invloed op de gezondheid van mensen. Veel longaandoeningen (o.a. astma en COPD) kunnen het gevolg zijn van fijnstof.

Hoe belangrijk vind je de genoemde factoren als het gaat om uitgestoten emissies?

CO2										
Stikstof										
Fijnstof(PM10)										

B2. **Verhard oppervlak**

Hiermee wordt het totale oppervlak bedoeld dat met name wegen in beslag nemen. Het idee is dat als wegen minder oppervlak nodig hebben om een gelijke afwikkeling te behouden er daardoor meer ruimte en mogelijkheden zijn om de leefomgeving aantrekkelijker en/of klimaatbestendiger te maken.

Meer groen: De vrijgekomen ruimte moet worden gevuld met meer beplanting waardoor de leefomgeving er aantrekkelijker uit komt te zien. Meer ruimte actieve modes: De vrijgekomen ruimte moet worden benut voor actieve modes waardoor het aantrekkelijker zal zijn om er te fietsen of lopen. Ruimte voor waterberging: De vrijgekomen ruimte moet worden benut om het gebied beter bestand te maken tegen (extreme) regenval, wat vaker zal gebeuren door klimaatverandering. Ruimte voor vermindering hittestress: De vrijgekomen ruimte moet worden benut om de hittestress te verminderen. Vermindering constructiemateriaal: Doordat er minder verhard oppervlak is, zal er ook minder materiaal nodig zijn voor de aanleg ervan, wat zowel kosten als het milieu spaart.

Hoe belangrijk vind je de genoemde factoren als het gaat om het reduceren van het verhard oppervlak?

Meer groen										
Meer ruimte actieve modes										
Ruimte voor waterberging										
Ruimte voor vermindering hittestress										
Vermindering constructiemateriaal										

B3. **Verkeersveiligheid**

Hiervoor wordt gekeken naar het aantal conflicten tussen verkeersstromen. Daarnaast wordt er ook gekeken naar het verwachte aantal ongelukken dat in een studiegebied voor zal komen. Ook de maximumsnelheid is van invloed, aangezien de ernst van ongevallen lager is bij een lagere snelheid.

Conflicten gemotoriseerd - gemotoriseerd: Er wordt hiervoor gekeken naar het aantal conflictpunten tussen verschillende stromen gemotoriseerd verkeer. Conflicten gemotoriseerd - actieve modes: Er wordt hiervoor gekeken naar het aantal conflictpunten tussen stromen gemotoriseerd verkeer en fietsers/voetgangers, die extra kwetsbaar zijn in dit type ongeval. Conflicten actieve modes actieve modes: Er wordt hiervoor gekeken naar het aantal conflictpunten tussen stromen verschillende stromen van fietsers/voetgangers. Maximum snelheid: Een lagere toegestane snelheid heeft een positieve invloed op het aantal, maar ook de ernst van ongevallen. Daarnaast verkleint een lagere snelheid ook de snelheidsverschillen tussen modes.

Hoe belangrijk vind je de genoemde factoren als het gaat om de verkeersveiligheid?

Conflicten gemotoriseerd - gemotoriseerd										
Conflicten gemotoriseerd - actieve modes										
Conflicten actieve modes - actieve modes										
Maximumsnelheid										

B4. **Aantrekkelijkheid fietsen/lopen**

Als het aantrekkelijker is om te lopen of fietsen zal men eerder geneigd zijn om zich op een van deze manieren te verplaatsen. Niet alleen krijgen mensen zo meer beweging, maar het zal ook het aandeel motorvoertuigen op de weg verminderen.

Wachttijden bij kruispunten: Fietsen of lopen wordt aantrekkelijker wanneer er minder gewacht hoeft te worden. Dit wachten kan bestaan uit wachten tot groen, maar ook al uit het verlenen van voorrang. Gescheiden stromen: Fietsen of lopen is aantrekkelijker als dit kan op een plaats waar geen ander verkeer komt. Bijvoorbeeld door een fietspad te scheiden van de weg, waardoor er een veiligere omgeving ontstaat. Breedte fietspad: Als er meer ruimte is om te fietsen, maakt dat fietsen aantrekkelijker. De extra breedte zorgt bijvoorbeeld ook voor veiligere inhaalmogelijkheden door e-bikes. Breedte stoep: Als er meer ruimte is vrijgemaakt voor de stoep, maakt dit lopen aantrekkelijker. Het zal het makkelijker maken om elkaar te passeren, maar de extra ruimte kan ook geschikt zijn om fietsen te parkeren.

Hoe belangrijk vind je de genoemde factoren als het gaat om de aantrekkelijkheid om te fietsen of lopen?

Wachttijden bij kruispunten										
Gescheiden stromen										
Breedte fietspad										
Breedte stoep										

B5. **Aantrekkelijkheid ov**

Als het aantrekkelijker is om het openbaar vervoer te nemen, zal men eerder geneigd zijn om zich hiermee te verplaatsen. Als meer mensen het ov nemen, zal dit rendabeler worden terwijl er ook motorvoertuigen van de weg zullen verdwijnen.

Wachttijden bij kruispunten: Het wordt aantrekkelijker om het ov te nemen als dit een snelle, betrouwbare optie is. Als het ov voorrang heeft op kruispunten zal de snelheid toenemen. Frequentie: Als de frequentie van het ov toeneemt zal het aantrekkelijker worden. Doordat er meer ritten zijn is het waarschijnlijker dat er op een geschikt tijdstip een rit vertrekt. Busbaan: Als een bus op een busbaan kan rijden, zal deze niet vast komen te zitten tussen ander verkeer. De bus zal hierdoor sneller door kunnen rijden en dus aantrekkelijker zijn.

Hoe belangrijk vind je de genoemde factoren als het gaat om de aantrekkelijkheid van het OV?

Wachttijden bij kruispunten										
Frequentie										
Busbaan										

Sectie C: Indicatoren brede welvaart

Het is niet alleen van belang om per indicator te weten welke factoren belangrijk zijn, maar ook het belang van de indicatoren zelf is belangrijk om te weten. Daarom is in dit deel de vraag hoe belangrijk je elke indicator vindt. Dit gaat op dezelfde manier als voor de factoren, dus door 100 punten te verdelen. Voor het overzicht staat er per indicator weer een korte uitleg wat ze inhouden.

Let op: er zijn twee indicatoren extra ten opzichte van de vorige sectie, namelijk geluid en reistijdverlies per persoon. Deze staan onderaan bij de uitleg.

C1. Emissies: Hiermee wordt alle uitstoot van gassen bedoeld die komt door voertuigen. Deze gassen hebben invloed op de lokale luchtkwaliteit, het milieu en het klimaat.

Verhard oppervlak: Hiermee wordt het totale oppervlak bedoeld dat met name wegen in beslag nemen. Het idee is dat als wegen minder oppervlak nodig hebben om een gelijke afwikkeling te behouden er daardoor meer ruimte en mogelijkheden zijn om de leefomgeving aantrekkelijker te maken.

Verkeersveiligheid: : Hiervoor wordt gekeken naar het aantal conflicten tussen verkeersstromen. Daarnaast wordt er ook gekeken naar het verwachte aantal ongelukken dat in een studiegebied voor zal komen. Ook de maximumsnelheid is van invloed, aangezien de ernst van ongevallen lager is bij een lagere snelheid.

Aantrekkelijkheid fietsen/lopen: : Als het aantrekkelijker is om te lopen of fietsen zal men eerder geneigd zijn om zich op een van deze manieren te verplaatsen. Niet alleen krijgen mensen zo meer beweging, maar het zal ook het aandeel motorvoertuigen op de weg verminderen.

Aantrekkelijkheid OV: Als het aantrekkelijker is om het openbaar vervoer te nemen, zal men eerder geneigd zijn om zich hiermee te verplaatsen. Als meer mensen het OV nemen, zal dit rendabeler worden terwijl er ook motorvoertuigen van de weg zullen verdwijnen.

Geluid: Met name gemotoriseerd verkeer produceert geluid. Dit komt niet alleen door (verbrandings)motoren, maar ook door het contact tussen weg en banden. Een hoog geluidsniveau is van invloed op zowel fysiek welzijn als mentaal welzijn.

Reistijdverlies per persoon: Hierbij zal worden gekeken naar hoeveel extra reistijd een individu zal hebben binnen het studiegebied. De (gemiddelde) bezetting van voertuigen zal hierbij worden meegenomen, wat vooral van belang is voor het openbaar vervoer.

Hoe belangrijk vind je de genoemde indicatoren voor het bepalen van brede welvaart?

Emissies										
Verhard oppervlak										
Verkeersveiligheid										
Aantrekkelijkheid fietsen/lopen										
Aantrekkelijkheid OV										
Geluid										
Reistijdverlies per persoon										

Sectie D: Achtergrondkenmerken

Ten slotte volgen hieronder nog een aantal achtergrondvragen. Mocht je deze liever niet in willen vullen, dan kun je kiezen voor de optie 'Geen antwoord'.

D1. Wat is je leeftijd?

- < 25 ☐
- 26-35 ☐
- 36-45 ☐
- 46-55 ☐
- 56-65 ☐
- > 65 ☐
- Zeg ik liever niet ☐

D2. Bij wat voor instelling werk je?

- Adviesbureau ☐
- Overheidsinstelling ☐
- Belangengroep ☐
- werkloos/gepensioneerd ☐
- Zeg ik liever niet ☐
- Overige ☐

Overige

D3. Wat is je hoofdvervoermiddel voor woon/werkverkeer?

- Auto ☐
- Fiets ☐
- Lopen ☐
- OV ☐
- Niet van toepassing ☐
- Zeg ik liever niet ☐

Sectie E: Opmerkingen

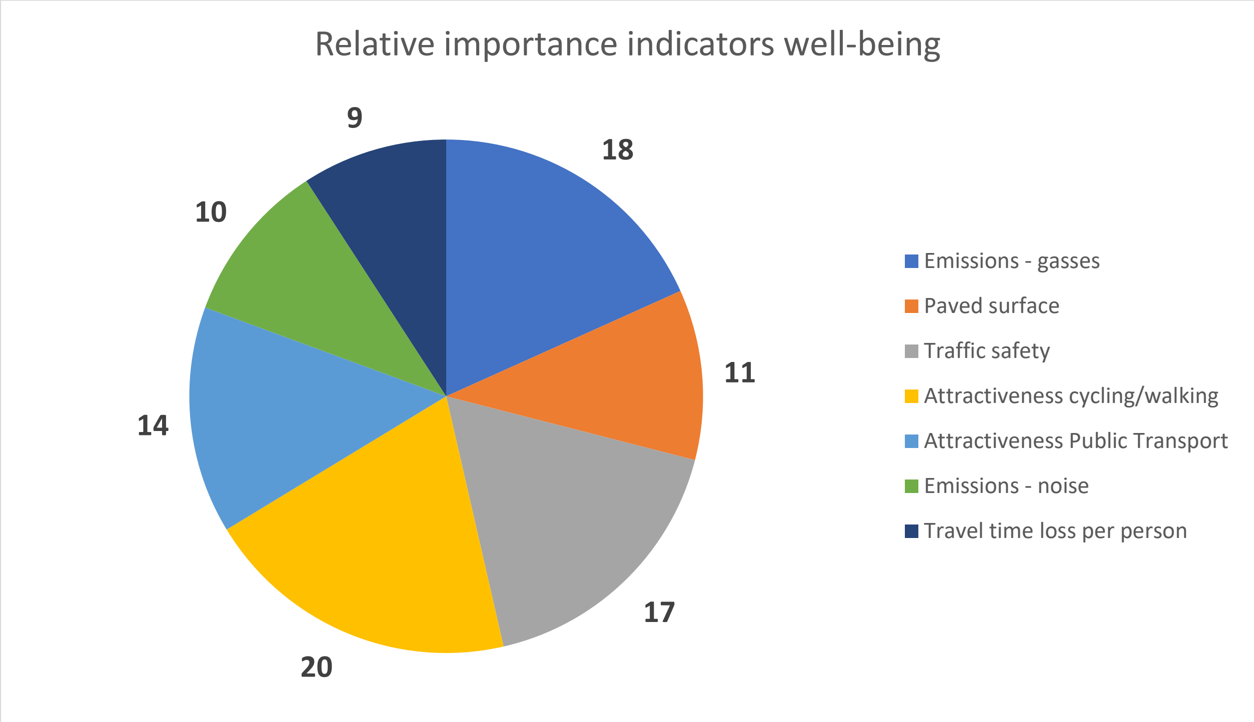
Als je nog op- of aanmerkingen hebt op deze enquête is hieronder ruimte om dat aan te geven.

E1.

Bedankt voor het invullen! Als je nog eventuele vragen of opmerkingen hebt, kan je mij bereiken via jvink@goudappel.nl

Je kunt dit tabblad nu sluiten.

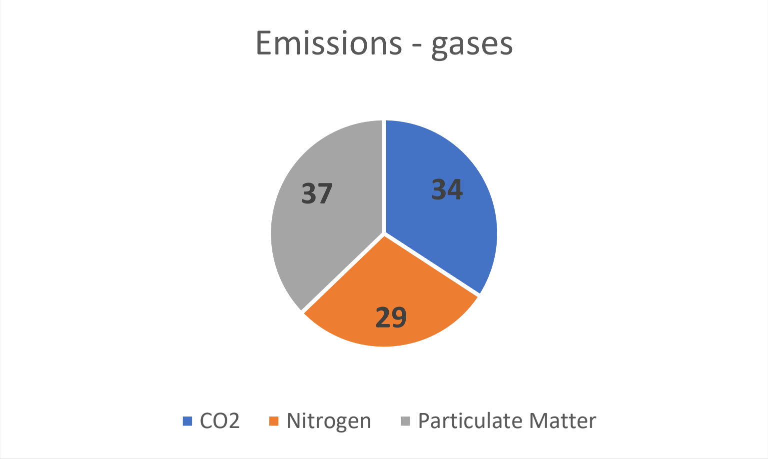
B. Appendix B: Survey results overall

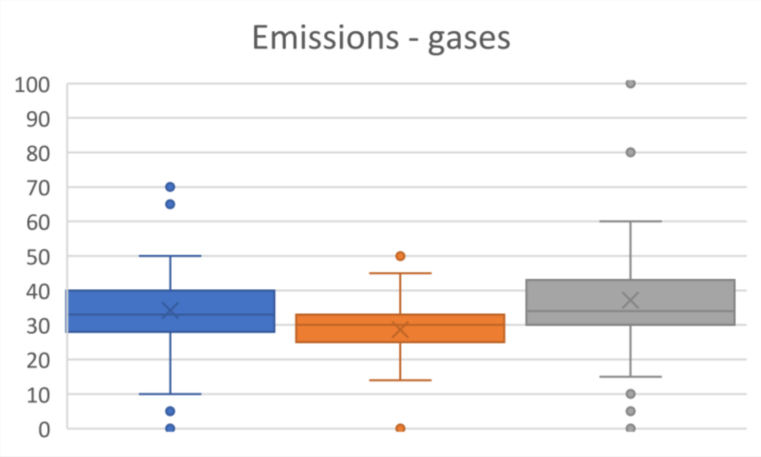


C. Appendix C: Survey results per indicator

C.1. Emissions – gases

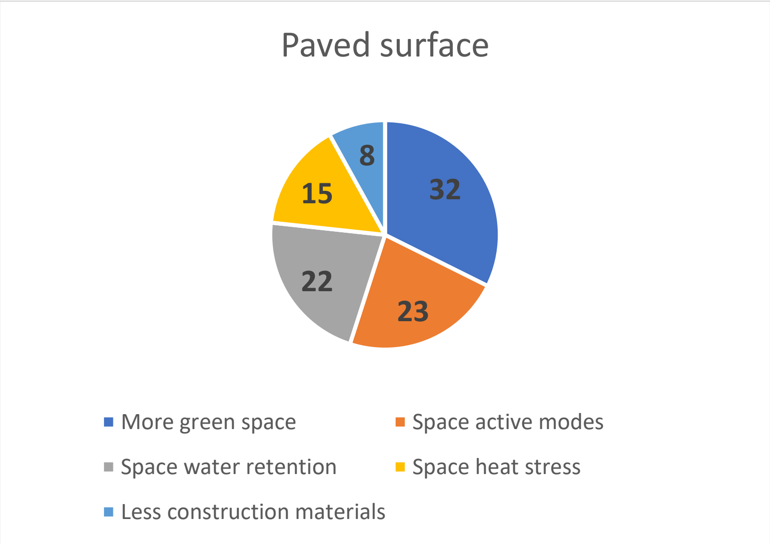
	Relative importance	Standard deviation
CO_2	34	12,2
NOx	29	8,9
PM10	37	15,3

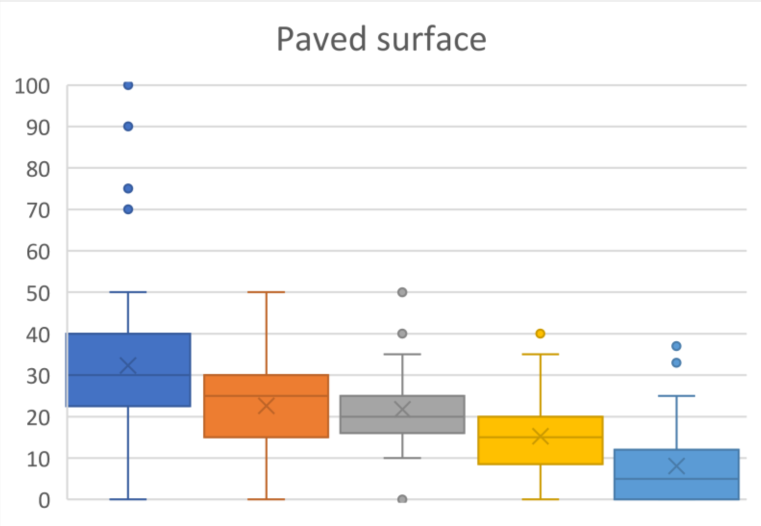




C.2. Paved surface

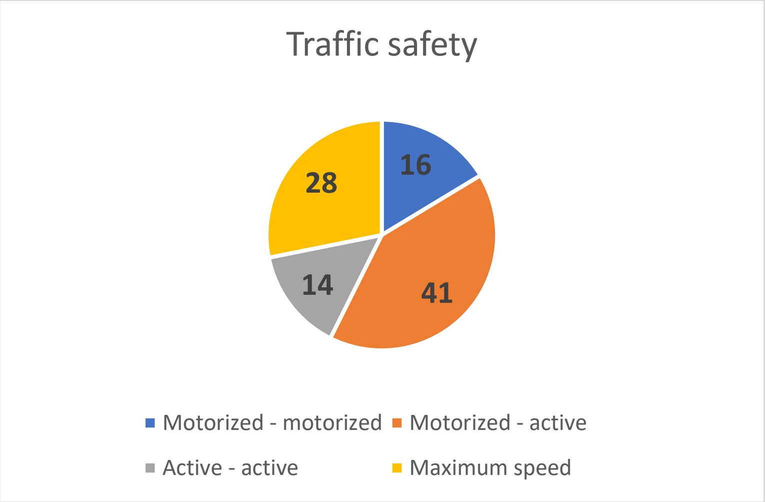
	Relative importance	Standard deviation
More green space	32	16,7
Space for active modes	23	12,2
Space for water retention	22	9,9
Space for heat stress	15	10,1
Less construction materials	8	9,0

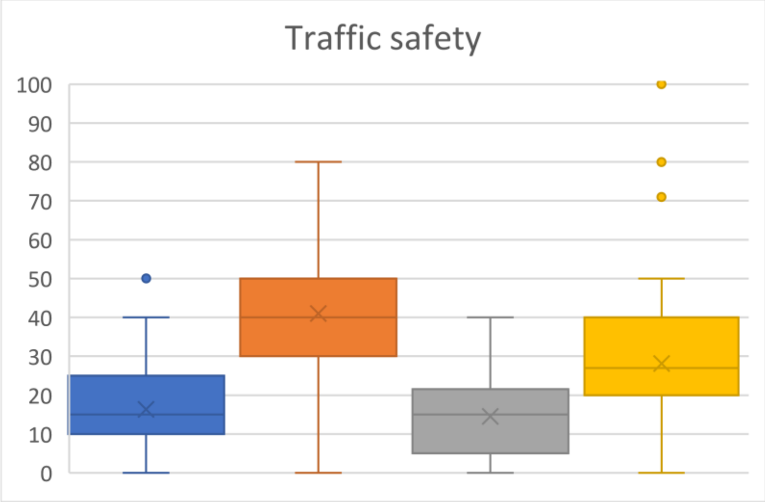




C.3. Traffic safety

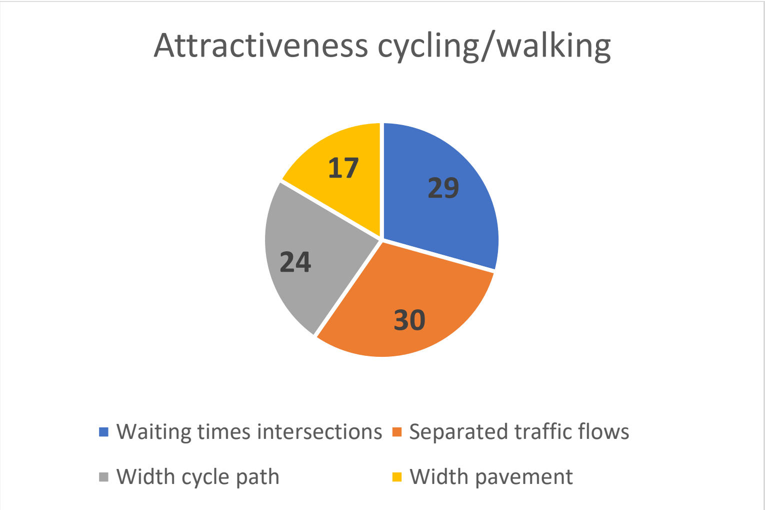
	Relative importance	Standard deviation
Motorized - motorized	16	11,9
Motorized - active	41	15,6
Active - active	14	11,1
Maximum speed	28	19,0

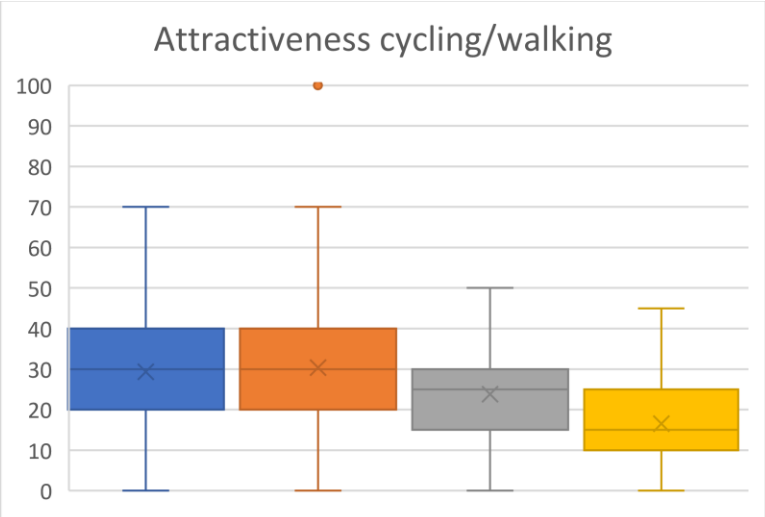




C.4. Attractiveness active modes

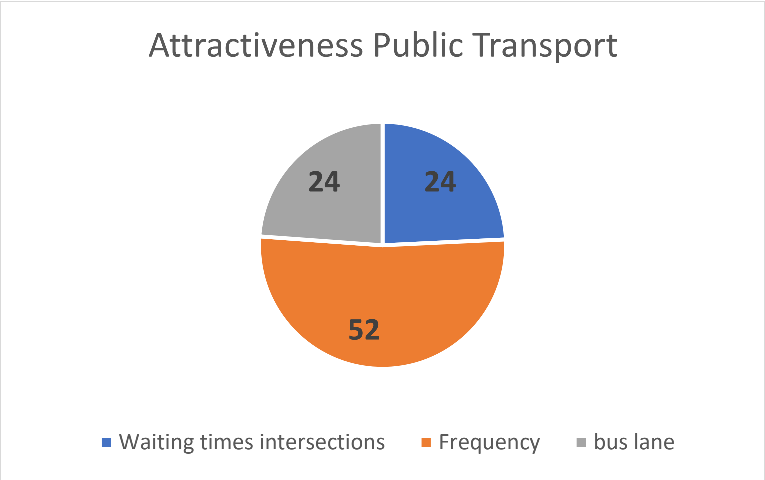
	Relative importance	Standard deviation
Waiting times at intersections	29	13,8
Separated traffic flows	30	17,0
Width cycle path	24	12,7
Width pavement	17	10,4

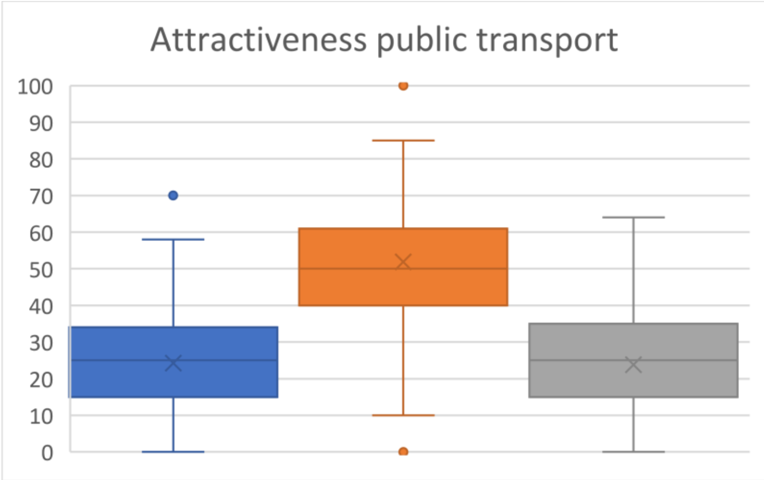




C.5. Attractiveness public transport

	Relative importance	Standard deviation
Waiting times at intersections	24	14,5
Frequency	52	22,1
Dedicated bus lane	24	16,1





D. Appendix D: Average travel time loss per vehicle

Overall

Table 21 - Overall average travel time loss per vehicle

	Avg delay overall [s]	Relative
Reference	96,2	100,0%
Bus lane	98,5	102,5%
Bus signal	118,4	123,1%
Roundabout meter	70,0	72,8%
Priority square	48,2	50,1%
Traffic lights	53,6	55,7%

Motorized modes

Table 22 - Average travel time loss per vehicle for motorized modes

	Avg delay cars [s]	Relative		Avg delay Trucks [s]	Relative		Avg delay Buses [s]	Relative
Reference	133,7	100,0%		94,8	100,0%		171,3	100,0%
Bus lane	137,4	102,8%		97,2	102,6%		137,3	80,2%
Bus signal	166,4	124,5%		116,1	122,5%		136,1	79,5%
Roundabout meter	97,4	72,9%		63,6	67,1%		65,2	38,1%
Priority square	60,8	45,5%		64,1	67,7%		57,6	33,6%
Traffic lights	66,8	50,0%		63,6	67,1%		55,5	32,4%

Active modes

Table 23 - Average travel time loss per vehicle for active modes

	Avg delay Pedestrians [s]	Relative		Avg delay Cyclists [s]	Relative
Reference	8,5	100,0%		12,3	100,0%
Bus lane	8,4	99,2%		12,2	99,7%
Bus signal	8,5	100,0%		12,7	103,2%
Roundabout meter	10,3	121,5%		11,9	96,6%
Priority square	16,2	190,1%		13,2	107,3%
Traffic lights	26,1	307,5%		19,7	160,7%

E. Appendix E: Total personal travel time loss per mode

Motorized modes

Table 24 - Total delay for motorized modes and the fraction of overall delay

	Tot delay cars [s]	Scenario fraction	Tot delay Trucks [s]	Scenario fraction	Tot delay Buses [s]	Scenario fraction
Reference	1051151	79,6%	119803	9,1%	111168	8,4%
Bus lane	1080898	81,2%	122792	9,2%	89118	6,7%
Bus signal	1308148	82,7%	146633	9,3%	88335	5,6%
Roundabout meter	766303	82,7%	80474	8,7%	42308	4,6%
Priority square	478485	74,7%	81178	12,7%	37359	5,8%
Traffic lights	525497	74,3%	80359	11,4%	36000	5,1%

Active modes

Table 25 - Total delay for the active modes and the fraction of overall delay

	Tot delay Pedestrians [s]	Scenario fraction	Tot delay Cyclists [s]	Scenario fraction
Reference	2570	0,2%	35727	2,7%
Bus lane	2548	0,2%	35600	2,7%
Bus signal	2571	0,2%	36849	2,3%
Roundabout meter	3121	0,3%	34531	3,7%
Priority square	4841	0,8%	38302	6,0%
Traffic lights	7880	1,1%	57483	8,1%

F. Appendix F: Conflict angle per conflict type

Table 26 - Conflict angles for conflicts between two cars

	C-C	Relative	C-C rear end	Relative	C-C lane change	Relative	C-C crossing	Relative
Reference	39760	100,0%	37007	100,0%	2724	100,0%	29	100,0%
Bus lane	30947	77,8%	28769	77,7%	2131	78,2%	47	162,1%
Bus signal	41734	105,0%	39010	105,4%	2710	99,5%	14	48,3%
Roundabout meter	32077	80,7%	30279	81,8%	1789	65,7%	9	31,0%
Priority square	11813	29,7%	10386	28,1%	1415	51,9%	12	41,4%
Traffic lights	14398	36,2%	13569	36,7%	826	30,3%	3	10,3%

Table 27 - Conflict angles for conflicts between a car and an active mode

	C-A	Relative	C-A rear end	Relative	C-A lane change	Relative	C-A crossing	Relative
Reference	178	100,0%	0		28	100,0%	150	100,0%
Bus lane	130	73,0%	0		28	100,0%	102	68,0%
Bus signal	175	98,3%	0		40	142,9%	135	90,0%
Dosing lights	81	45,5%	0		5	17,9%	76	50,7%
Priority square	80	44,9%	0		2	7,1%	78	52,0%
Traffic lights	0	0,0%	0		0	0,0%	0	0,0%

Table 28 - Conflict angles for conflicts between a car and a truck

	C-T	Relative	C-T rear end	Relative	C-T lane change	Relative	C-T crossing	Relative
Reference	4460	100,0%	4046	100,0%	395	100,0%	19	100,0%
Bus lane	4685	105,0%	4201	103,8%	451	114,2%	33	173,7%
Bus signal	4595	103,0%	4108	101,5%	460	116,5%	27	142,1%
Dosing lights	3427	76,8%	3121	77,1%	297	75,2%	9	47,4%
Priority square	3275	73,4%	2895	71,6%	334	84,6%	46	242,1%
Traffic lights	3174	71,2%	2922	72,2%	248	62,8%	4	21,1%

Table 29 - Conflict angles for conflicts between an active mode and a truck

	A-T	Relative	A-T rear end	Relative	A-T lane change	Relative	A-T crossing	Relative
Reference	74	100,0%	0	-	52	100,0%	22	100,0%
Bus lane	119	160,8%	0	-	101	194,2%	18	81,8%
Bus signal	72	97,3%	0	-	55	105,8%	17	77,3%
Dosing lights	33	44,6%	0	-	27	51,9%	6	27,3%
Priority square	26	35,1%	0	-	3	5,8%	23	104,5%
Traffic lights	21	28,4%	1	-	8	15,4%	12	54,5%

Table 30 - Conflict angles for conflicts between two trucks

	T-T	Relative	T-T rear end	Relative	T-T lane change	Relative	T-T crossing	Relative
Reference	1047	100,0%	991	100,0%	53	100,0%	3	100,0%
Bus lane	1049	100,2%	1001	101,0%	41	77,4%	7	233,3%
Bus signal	1055	100,8%	990	99,9%	62	117,0%	3	100,0%
Dosing lights	933	89,1%	878	88,6%	51	96,2%	4	133,3%
Priority square	969	92,6%	914	92,2%	45	84,9%	10	333,3%
Traffic lights	957	91,4%	911	91,9%	43	81,1%	3	100,0%