

LUT University

School of Engineering Science

Erasmus Mundus Master's Program in Pervasive Computing & Communications for Sustainable Development (PERCCOM)

Valeria Cedillo

Analyzing sustainability effects of road pavement – Case study: Lappeenranta City

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Supervisors: Professor Jari Porras (LUT University)
Dr. Lachlan Birdsey (University of Oulu)

Examiners: Prof. Eric Rondeau (University of Lorraine)
Prof. Jari Porras (LUT University)
Prof. Karl Andersson (Luleå University of Technology)

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ABSTRACT

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Transport sector plays a key role for the overall sustainability development, sustainability indicators and sustainability evaluation are well-known terms that have acquired substantial importance. The concept of sustainability implies interaction of the three pillars: economic, environmental and social. In order to apply these aspects to transportation is necessarily to create an interactive link of transportation with the concepts mentioned before.

The approach of this study was to assess the current state of the roads pavement in Lappeenranta city based on given dataset and evaluate the influence of the road network towards transportation's sustainability. The raw data extraction and process was made using Python libraries, data storing and filtering in MongoDB and for roads visualization QGIS software was utilized.

According to the data provided, three variables were selected, these variables are related to each sustainability aspect.

The outcome of the calculations is represented in graphics, and each variable is firstly evaluated individually. The results demonstrate that the more kilometres a road has the higher the value of the variables will be, but there is no direct relationship between the mentioned attributes, however we can conclude that a more extended sample data set is required, as well as more methods and tools in order to build a framework that can define and compare sustainable goals against the results obtained.

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1. INTRODUCTION

Certainly, climate change is more tangible than ever, as we are facing the highest temperatures in history, it is very alarming seeing glaciers melting and raising sea levels, hurricanes and typhoons forming with more energy, droughts increasing and in overall, making unpredictable weather more common.

It is well known that transport sector is one of the major contributors of CO₂ gases emissions, it is in charge of about 30% of the EU's total CO₂ emissions, and 72% originates from road transportation. EU has put a lot of efforts to reduce the CO₂ emissions by defining an objective to decrease the transport emissions by 60% by 2050 compared to 1990 levels (Europarl.europa.eu, 2019).

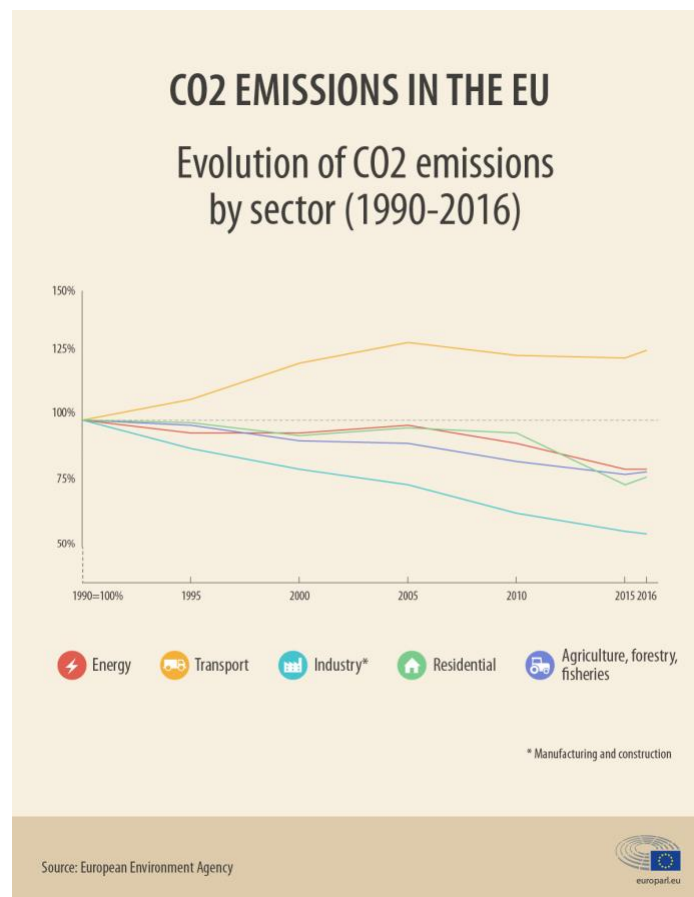


Figure 1. Evolution of CO₂ emissions in the EU by sector (1990-2016) (From Europarl.europa.eu. 2019).

Transport emissions are increasing

Unlike other sectors, transport emissions are decreasing slowly due to the need of mobility is growing, particularly in urban areas, therefore the carbon emissions are rising.

There are many transport modes and the CO₂ vary depending on the type, but for instance, passenger cars have the most impact of pollutants, acquiring the 60.7% of the absolute CO₂ emissions from road transport in Europe, whereas, public transport is the best cleaner alternative such as buses (Europarl.europa.eu, 2019).

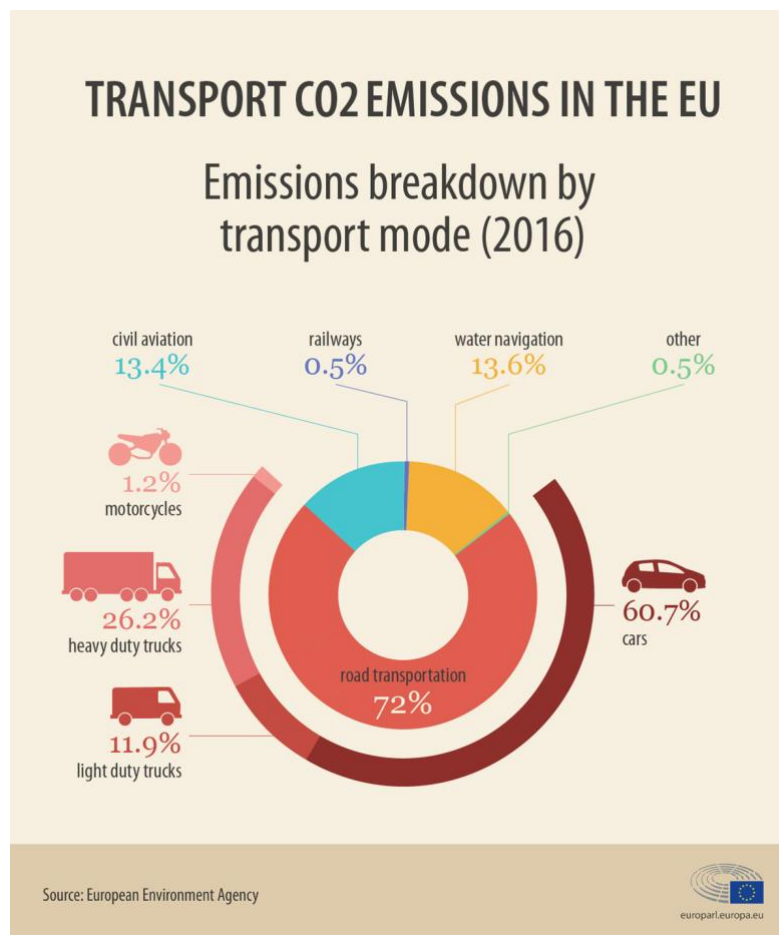


Figure 2. Cars account for 60% of transport CO₂ emissions. (From Europarl.europa.eu. 2019).

Sustainable Transport

Sustainable Transport is a driver of sustainable development, hence is part of the Agenda 2030 for Sustainable Development Goals (SDG) as well as it is part of the Paris Climate Agreement where the targets by 2030 are to ensure safety, affordability, accessibility and sustainable transport systems for all, enhance road safety, in particular by extending public transport, but attending the needs of those groups in sensitive circumstances and minorities such as women, children, individuals with disabilities and elderly people (Sustainabledevelopment.un.org, 2019).

It is equally essential to create and provide quality, reliable, viable and resilient infrastructure, including local / regional and cross-border infrastructure, in order to foster economic development and human well-being (Sustainabledevelopment.un.org, 2019).

As mentioned before, a sustainable system involves the interactivity of the three components: economy, environment and society. If we apply these points to transport system, it is needed an interactive link between them over time. Mobility, economic development, environmental quality and in general the quality of life is dependable of the effects of a good transportation system.

For planners and decision-makers has become crucial the implementation of sustainable urban transportation systems, as the unfavourable effects emerging from the transportation activities are increasing (Haghshenas & Vaziri, 2012). But to develop and apply adequate indicators that are able to measure and cover the entire sustainability concept is a challenging issue in urban transportation.

Currently a large portion of transportation sustainability evaluations are carrying out in the planning stage and are focused on transport infrastructure. And some other traditional indicators are addressed to traffic measurements, such as travel time, but they do not provide a complete analysis of the overall sustainability.

1.1 Background

Finland, one of the most sparsely populated countries of the EU and with most of its populace concentrated in the south, makes the region with a high critical effect regarding transport infrastructure.

The degree of urbanization in Finland is low compared to most other European countries and it's growing mainly in the suburbs and surrounding communities that are further away from jobs and services, causing the journeys getting longer and adopting a car-dependant lifestyle.

The Finnish Transport Agency is in charge of around 78,000 kilometers of highway out of around the 454,000 kilometers in length that comprises the total Finnish road network. It incorporates around 350,000 kilometers of private and forest roads and 26,000 kilometers of municipal streets. Highways and primary roads consist of more than 13,000 kilometers. Approximately 65 % of roads, or some 50,000 kilometers, are paved.

Finland consists of nine regional centres or districts, and under the alignment of the Finnish Transport Infrastructure Agency (FTIA) are responsible for the implementation and development of the road maintenance of its area.

The responsible of the Finnish roads as well as railways and waterways is the Finnish Transport Infrastructure Agency which is also on charge of the development of the transport system, moreover it provides smooth, effective and safe travel and transport (Vayla.fi, 2019).

ELY Centres:

- LAP = Lapland
- NOK = North Ostrobothnia
- SOB = South Ostrobothnia
- CEF = Central Finland
- PIR = Pirkanmaa
- SWF = Southwest Finland
- UUS = Uusimaa
- NSA = North Savo
- SEF = Southeast Finland

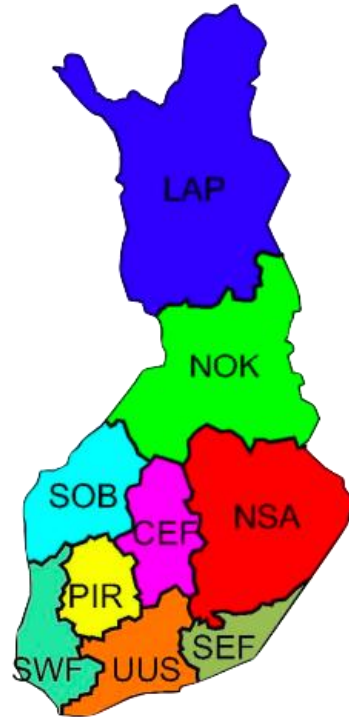


Figure 3. Centres for Economic Development, Transport and the Environment (ELY Centres).

Half of the Finnish road network are low-volume roads, and around 41,000 kilometers of such roads are in the poorest maintenance classification, this represents more than half of the total road network. It is difficult to keep up all the roads in such conditions that when harsh weather conditions come, no issues will happen in anyplace of the road network (Vayla.fi, 2019).

Lappeenranta is a city and municipality located in southeastern Finland, on the shore of the lake Saimaa, approximately 30 kilometers from the Russian border. It is part of the region of South Karelia. Lappeenranta has around 73,000 residents (31 January 2019), which constitute a greater part of the total population of the South Karelia region, making it the 13th largest Finnish city.

For its location, 215 km from both Helsinki and St. Petersburg it is known that Lappeenranta is also a South-East Finnish shopping and the EU and Russia meeting point. Situated on the southern shore of Lake Saimaa makes the city the region's center for tourism. Just after Helsinki, Lappeenranta is the second most visited city by Russian tourists in Finland. Throughout history,

excellent transport links in all directions have been considered to be an essential element for the vitality of the region. Therefore, analyzing the efficiency of road infrastructure is of interest.

The goal is to create a charming, pedestrian-friendly city center where smart public transport and parking solutions, excellent pedestrian and bicycle lanes and green spaces form a harmonious whole. (Lappeenranta.fi, 2019).

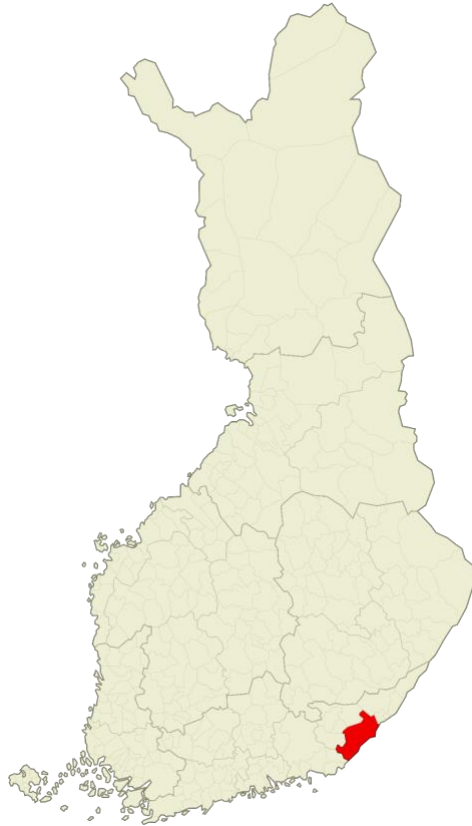


Figure 4. Location of the Finnish municipality of Lappeenranta in 2010.

According with the Finnish National Report published on the United Nations (Sustainabledevelopment.un.org, 2019), the major challenges of road transport in Finland are:

- EU strict policies
- Weather conditions
- The use of intelligent technologies
- Insufficient funds

- Climatic changes

The effects of climate have some implications in raising the costs of road maintenance, and as for now, Finnish Transport Infrastructure Agency has on testing phase some on-going projects involving *intelligent transport*, which its ultimately goal is to achieve a sustainable transport ecosystem.

According with the agency the road network is deteriorating due to the insufficient funding allocated for maintenance. Although the funds granted for reducing the maintenance backlog will be used effectively, it is impossible to repair all important roads in poor condition (Vayla.fi, 2019).

A good resource management not just diminished maintenance costs, it likewise lessens wear and the maintenance costs of vehicles which prompts to reduction in CO₂ emissions by the cars running on a well maintained, smooth and even highways (EUPAVE, EAPA, F., 2016).

However, other approaches to attain a sustainable transport could be explored by leveraging the data collections and statistical publications that are currently available to public. For instance, publications or studies about Finland's transportation system that involve the evaluation and analysis of the three aspects of sustainability during the operational phase were not found, and that is the novelty of this thesis. To include the triple-bottom-line perspective.

1.2 Motivation

While the industry is mostly focused on vehicles and more research has been conducted on this sector, one approach that it is not being taken into account to decrease the CO₂ emissions from road transportation is the impact of the road infrastructure itself has on vehicle emissions. Especially, smooth and well-maintained road pavements will lead to a better performance of vehicles in terms of CO₂ emissions. (EUPAVE, EAPA, F. 2016)

This work is motivated by the need to provide means to assess the impact of the road infrastructure towards the three dimensions of sustainable development based on the data that is currently being collected, to later on serve to transport agencies and experts on the field evaluate and advocate more sustainable choices towards road pavement construction and management when building future and existing projects.

Open data is part of open knowledge, and this research leverages the open content that it's being collected and published by the Finnish Transport Infrastructure Agency, in addition as more data becomes available there is the opportunity to create more data-driven transportation systems (Picozzi et al., 2013) and not only in projects that are focused to improve traffic data analysis or to evaluate congestion, but also models that can demonstrate the impact of road infrastructure during the operation phase and are able to provide users dynamic aggregation levels and use visualization techniques that are suitable for decision-makers.

To this end, the difference from other CO₂ saving strategies, the maintenance of roads cannot be postponed any more, since new technologies are not required, in addition the upgrading of the road network include some other benefits such as better air quality which as a result other than CO₂ emissions will be reduced proportionally, among other positive results are noise reduction, less vehicle maintenance costs and safer roads as well as reduction of total energy use, so savings remain (EUPAVE, EAPA, F. 2016).

1.3 Problem definition

In general, sustainable mobility and urban transportation patterns have been studied extensively, yet research focusing on the operational phase of road infrastructure is minimal. Roads in Finland are vital for its large surface area and economic development. Thus, the recognized knowledge gap regarding the road network and its sustainability performance ought to be addressed.

The Finnish Transport Infrastructure Agency supports transport and mobility in Finland, it collects and produces data related to traffic and transport infrastructure, still, there is a need to assess and estimates sustainable effects based on the data. In this research, to answer the following questions is the goal:

- How road pavements influence the transportation's sustainability? and how sustainable is the road network in Lappeenranta?

Our research objective aims to evaluate the impact of road pavements on economy, environment and society in order to provide decision makers or agency staff an outcome based on a data life cycle analysis that help cities to optimize their practices and improve Sustainable transportation planning.

- To define the indicators to be assessed based on the data given
- To analyze relationships among indicators
- To implement, validate and evaluate the proposed model

1.4 Delimitations

The main focus of this project was to design a way to analyse sustainability effects of the road pavement by selecting a set of indicators covering the economic, social and environmental aspects. The proposed system is limited only in the city of Lappeenranta, some calculations, assumptions, and selections were made as a consideration on the available data, additionally some of the data used is outdated.

Social impact is particularly the most subjective aspect assessed, since the study is focused on a specific place the results cannot be meaningful for other cities where circumstances are different, and criteria needs to be changed depending upon the context of in place.

The project is providing a high-level data analysis of the impact of the current conditions of the roads, since a deeper analysis requires information of the pavement material and it is out of the scope of this research since it belongs to another field of study. A small set of indicators are being analysed; hence it may overlook important impacts.

1.5 Thesis structure

This thesis report comprises the following chapters:

Chapter 1: a brief introduction of the transport sector in Europe, a context of the city where this research was held and limitations encountered during the research process – motivation, research questions and research objective.

Chapter 2: it presents the related works on the existing approaches to measure sustainability of transportation as well as modeling and data visualization of road pavement will be discussed.

Chapter 3: it elaborates the methodology of the study, including technical specifications and calculations.

Chapter 4: results, findings and discussions will be addressed which includes a sustainability analysis of the present work.

Chapter 5: to wrap up the study, conclusion and recommendations for future work will be presented.

2. RELATED WORK

A few studies of sustainable infrastructure assessments and specifically road pavement during the operational phase were found, which denotes that there is a gap on the analysis of existing projects considering the three dimensions of sustainability.

The idea of sustainable development was explicitly intended to assess the monetary, ecological and social effects of human activity. Indeed, over the years, economic, social and ecological effects have generally been assessed but as separate issues. This can be seen by the manner in which criteria have commonly been used to assess these impacts (Yevdokimo, Y., & Mao, H. (2005).

In terms of indicators, the authors (Yevdokimo, Y., & Mao, H. 2005) and (López and Monzón, 2010) agree that the election of a “good” batch of sustainability indicators is a hard task. The amount to sustainability criteria within a dataset can be extremely variable making the data collection process and the interpretation of the outcome very difficult.

In spite of the fact that there are numerous approaches that assess the socioeconomic and environmental viability of infrastructure projects, there is as of now no institutionalized or agreed methodology for solid estimation of sustainability infrastructure when evaluating and assessing transportation ventures (Bueno, Vassallo and Cheung, 2015). This is mainly due to the difficulties that exist to define objectives and indicators to measure the three aspects of sustainability that are accepted in scientific and as policy documents (López and Monzón, 2010).

There is controversy as to whether the sustainability evaluation should be done prior to the construction phase, that is, during planning stage or if it is more important to do it after the implementation. However, no details of this were found during the literature review.

Authors mention that a sustainability appraisal should begin with an assessment and decision-making process, since at this stage is when decision-makers own the capacity to drive the direction on the future of sustainability performance of the project. Saying it in another way, applying sustainability premise can be more efficient at the planning phase rather than based the evaluation

on current conditions. However, validating the sustainability of already implemented projects can be effective to re-utilized best practices and procedures in future projects (Bueno, Vassallo and Cheung, 2015).

For example, in Bueno, Vassallo and Cheung, (2015). Sustainability Assessment of Transport Infrastructure Projects: A Review of Existing Tools and Methods. *Transport Reviews*, 35(5), 622–649. shows a comparison of the sustainability assessment between the two phases of the cycle and describes how the evaluation can be used. It can be seen that in both stages there are different objectives, and it is not possible to take for granted where the evaluation is better, everything will depend on the purpose of the study, however, both practices can be applied to have a more complete evaluation.


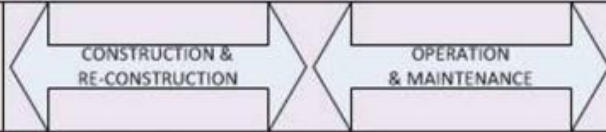
	ex-ante sustainability evaluation	ex-post sustainability evaluation
Corresponding project lifecycle stage		
Sustainability is part of	The appraisal and the decision-making process	The monitoring process, for evaluation purposes
Sustainability aims at	Supporting the selection of the alternative option that maximizes beneficial outcomes on all dimensions of sustainability	Quantifying sustainable practices associated with the construction and maintenance processes. In these stages, sustainability can be used to certify and monitor transport projects
Means by which sustainability can be used: A ROAD PROJECT EXAMPLE	<p>A process where sustainability is used to provide guidance on appraisal and decision-making:</p> <ul style="list-style-type: none"> (i) After identifying project impacts, calculate the global sustainability evaluation of each alternative, for example using a multi-criteria approach (ii) Obtain the ranking order of alternatives and select the alternative with the highest sustainability performance 	<p>Sustainability as a monitoring tool can be used in different processes to:</p> <ul style="list-style-type: none"> (i) Evaluate the project against original objectives that it was designed for (ii) Assess, compare and award the existing road, depending on its performance against relevant sustainability criteria previously defined, for example by a rating system for roads (e.g. Greenroads, GreenLITES) (iii) Improve current practices in roadway construction and do more than the minimum requirements (iv) Suggest best practices and procedures in future road projects, due to the retrospective character it implies
Practical application examples	Gühnemann et al. (2012); Cundrič, Kern, & Rajkovič (2008); Ugwu, Kumaraswamy, Wong, & Ng (2006); Dasgupta & Tam (2005)	Lee, J., Edil, T., Benson, C., & Tinjum, J. (2011); Gambatese & Rajendran, (2005); Anderson & Muench (2013)

Figure 5. Sustainability assessment previous and post implementation (from Bueno, Vassallo and Cheung, 2015).

2.1 Existing approaches to measure sustainability of transportation

Some of the most common tools and methods that include the concept of sustainability for Transport Infrastructure projects can be classified the following way:

- 1) *Appraisal methods for decision-making.* Some of the practices were not meant to be for sustainability assessment, but they are frequently utilized for decision-making processes in transport project evaluation.
 - a. Cost-Benefit Analysis (CBA): The most common method since it empowers the examination among options under the target of augmenting social welfare. Current

technique is mostly applied during the planning phase since it is built upon the opportunity of leverage the user advantages by turn them into monetization such as the cost of investment , as well as reducing the travel time and other unfavourable results such as energy consumption, and CO₂ emissions, resources use (Gühnemann et al. (2012), Hyard (2012), Tudela, Akiki, and Cisternas (2006). On the contrary, CBA may not be able to consider important impacts when they are not monetised such as road accidents. This technique does not consider the three pillars of sustainability in an accurate and specific way since the process of monetization is sketchy for impalpable things that that prompts vulnerability in estimation, anticipating, and assessment. Moreover, it does not take into account the entire life cycle project (Bueno, Vassallo and Cheung, 2015).

- b. Multi-criteria decision analysis (MCDA): With this technique, the various criteria and its values are totally biased opposing to CBA where it is shown to a certain extent some objectivity on the unit prices (Bruhn, M., 2018). This tool is significant when promoting public cooperation and allowing participation of interested parties, nevertheless with the MCDA method, a considerable number of criteria can be taken into consideration at the same time, even those that are difficult to monetize or quantify (Thomopoulos, Grant-Muller, & Tight, 2009). The multi-criteria method may be highly positive due to it fulfills the objective of being multi-disciplinary and can supply the demand to integrate the economic, ecological, and social affects. To summarize, when handling with sustainability of transport projects the multi-criteria scheme it's a good option to provide a proper structure, but it is necessary to be aware that the evaluation process have a tendency to get really subjective (Bueno, Vassallo and Cheung, 2015).

2) *Assessing environmental / social impact.* These techniques evaluate mainly the environmental and social aspect and later on are combined with other methods to have a more integrated sustainability assessment.

- a. Life-cycle assessment (LCA): For decision-making, the adoption of this methodology takes into consideration an environmental performance evaluation of the entire life-cycle from “cradle-to-grave analysis”, from crude material extraction

through materials processing, manufacture, transport, distribution, use, service and maintenance, and disposal or recycling (Stripple and Erlandsson, 2004). A downside of this approach is that not all the sustainability criteria are fully integrated, due to its main objective is focused on the evaluation towards the ecological effects of certain action. LCA method is not the best option if the need is to evaluate the three sustainable dimensions, it can be integrated as a particular step of a whole assessment in order to identify key environmental indicators and with a life-cycle analysis is possible to track the evolution of such indicators of road projects, but do not contemplate LCA as a complete sustainability appraisal tool. (Bueno, Vassallo and Cheung, 2015).

- b. Social assessment (SLCA): The evaluation of social impacts is less developed than the other two aspects of sustainability; environmental and economic. The inclusion of social criteria into LCA has become more popular but it's still under progress, due to social aspects are more critical and broader topic which make them more difficult to define, as social criteria tends to fall into more subjective evaluation and no-quantifiable impacts.
- 3) *Sustainability assessment methodologies*. Involve rating systems and appraisal guidelines that are developed mainly for civil infrastructure in general such as Civil Engineering field.
- a. Rating systems and certification tools: these tools are usually made by governmental or non-governmental organizations with the aim of evaluating, comparing, and awarding a scheduled or current project, based on its performance as opposed to relevant sustainability criteria (International Federation of Consulting Engineers, 2012, p. 17).

During the whole life cycle, rating systems give direction and establish a good basis to integrate sustainability during infrastructure projects, i.e. from planning, operation and maintenance phase. Mostly, sustainable rating systems are based in regional areas, they promote the collaboration of stakeholders which rises awareness and sensitivity to the context of sustainability. In general, the most astounding advantage of rating systems is the inclusion of the economic, social and

environmental aspect and the way to address sustainability through measurable process, but despite of this, these tools are not very reliable due to the lack of transparency thus are not part of the decision making process (Bueno, Vassallo and Cheung, 2015).

The current tools for sustainability evaluation of road pavements are favorable as they serve to experts to find regions where sustainability can be enhanced during the design and construction stages, yet they do not have a scheme for estimating the subsequent effects of the choices made as a major aspect of this procedure (Bryce et al., 2017) coupled with the fact that there is none existing tools that include all the requirements for appraising sustainability of transport projects.

There is extensive literature review on the topic of road pavement assessments. To begin with, the following approaches were the most prevalent:

- Assessment on planning phase
- Life cycle assessments on construction phase
- Traffic optimization during operational phase

The studies in aforementioned approaches, come mostly from areas such as civil engineering where knowledge in building materials is necessary, on the other way traffic engineering focuses on traffic planning, design and operation.

On the contrary, from the ICT sector, the contributions have been done by leveraging IoT resources, installing sensors for data collection, which is later used mainly by the areas mentioned above for the prediction of traffic behaviour and with the use of advance software tools such as GIS.

2.2 Modelling and visualization

When most people hear *models*, they most likely consider individuals and barely they will relate this term with transportation. Fashion models help to anticipate how the clothes will look like when

we put them on. Models, as in transportation variant are helpful to anticipate how the transportation system will work depending on present and future infrastructure asset. Models can give helpful data for planning and foreseeing results, in spite of no model is totally exact; they endeavor to anticipate the future, although future seldom completely participates. (Geoffrey P. Whitfield, and Arthur M. Wendel, 2016

On the other hand, visualization is a relatively new term in the field of computational statistics and data analysis. The way that visualized graphs represent the data and communicates with the user plays an important role in interpretation and exploration of targeted data. This would become a challenge when dealing with large datasets. The term data visualization, as related to the information visualization expresses not only the graphical data to the user but also reflects the structure of data (Vehkalahti, 2008).

Data Visualization in the field of road pavement

Data visualization in the field of road pavement, employ generally Geographical Information System (GIS) tools in order to graphically represent geospatial data as well as basic graphs to visualize quantitative data. Yet, there is the opportunity to develop innovative approaches of interactive data to the field of road pavement and transportation system. (Mazari, et al., 2016).

There has been a notably advance regarding the data collection and storing methods, still the way the data is presented is not familiar and easy to use for decision-makers resulting in a not very significant knowledge compared to the amount of information generated.

Especially in the field of transportation where specialists and researches have interrogate the strategies of data programs when meeting the requirements of users that are dedicated to planning infrastructure, as a result of they still have the arduous challenge of sorting highway data into convenient approaches to help decisions related with the maintenance, enhancement, traffic optimization, monitoring and last but not least, project prioritization. (France-Mensah et al., 2017).

One of the challenges encountered during the present research and that some authors (France-Mensah et al., 2017) also point out, is associated with leveraging data coming from multiple sources and different formats, this draw attention regarding the necessity for a in integrated framework that consolidates and support applications to aid Maintenance and Rehabilitation (M&R) planning.

Furthermore, the leverage on current visualization tools will permit the integration of temporal and spatial information with which the users can interact with, contributing to the need of having an integrated planning process. The less useful information is hiding, the better for the stakeholders to focused on the problem that are trying to understand, for this reason, visualization should be interactive and adaptable to allow users to refine dynamically the view of the dataset.

Pavement management system (PMS) keeps on falling behind the cutting edge in terms of the state of the practice, in spite of the technological innovations and the constant improvement in the development of more refined tools. Although, theoretically there are numerous choices and tools are available, practically speaking the size of the road networks and the unavoidable absence of adequate and good quality data, among other reasons, make most of these alternatives hard to implement. Subsequently, numerous organizations resort to utilizing PMS that use models, methods, and tools that are not the most refined but rather that can be utilized by their faculty, hence they result in a better solutions and decision support than depending on old practices and experience. Last but not least, decision-support area has actually begun to keep pace with the state of the art with the design and architecture of such systems. In fact, the adoption of web-based applications, databases, and analysis tools based on new technologies and programming languages are spearhead in the manner these frameworks are planned and implemented in practice (Zhang and Murphy, 2013).

3. METHODOLOGY

First of all, an extensive desktop literature review was conducted. This newly acquired knowledge allowed for the formulation of different scenarios to be analyzed, and simultaneously it helped to gain complementary insights that allow a better understanding of the current situation.

The method of assessment and analysis of sustainability effect of road pavement is analytic and comprises the following steps: 1) Data Analysis; 2) Scenario building; 3) Selecting sustainability indicators based on the available data; 4) Indicators quantification.

This research was carried out in collaboration with the Finnish Transportation Infrastructure Agency (FTIA), the methodology and its respective stages will be described below, yet, it is important to mention that not all the stages were executed for the present research. For instance, data collection was based on secondary sources, which implies information that has already being gathered by another entity for a different purpose, it consists in both publish and unublish data, the advantage of using secondary sources it is that they are already available and they do not need to be collected again, however sometimes it may not meet specific researcher's need.

Quantitative data of road traffic is being collected by diverse services using an automatic traffic monitoring system (TMS). As of now, it is estimated that there are approximately 500 traffic measuring stations in Finland, and the data collected is shared both in raw form and as generated reports.

Finnish Transport Infrastructure Agency shares open data through different services depending on the content type and technical characteristics of the data. The information used for the purpose of this research is collected and consulted throughout the services listed below:

- *Digiroad* - National Road and Street Network Information System: is an open and free national information database that compiles the geometry of the entire Finnish road and street network as well as the most important road data features. Digiroad supplies a unified digital representation of the traffic network (Vayla.fi, 2019).

- *Digitraffic*: is a service that provides real-time traffic information, it covers roads and rail traffic. The information is distributed through open APIs (Digitraffic.fi, 2019).
- *LIPASTO* – a system for calculating transport emissions and energy consumption in Finnish traffic: it covers the majority of modes of transportation. LIPASTO is a calculation system developed and maintained by VTT Technical Research Centre of Finland Ltd (Lipasto.vtt.fi, 2019).

A data life-cycle methodology was conducted for the present research. The process is described in what follows for its analysis.

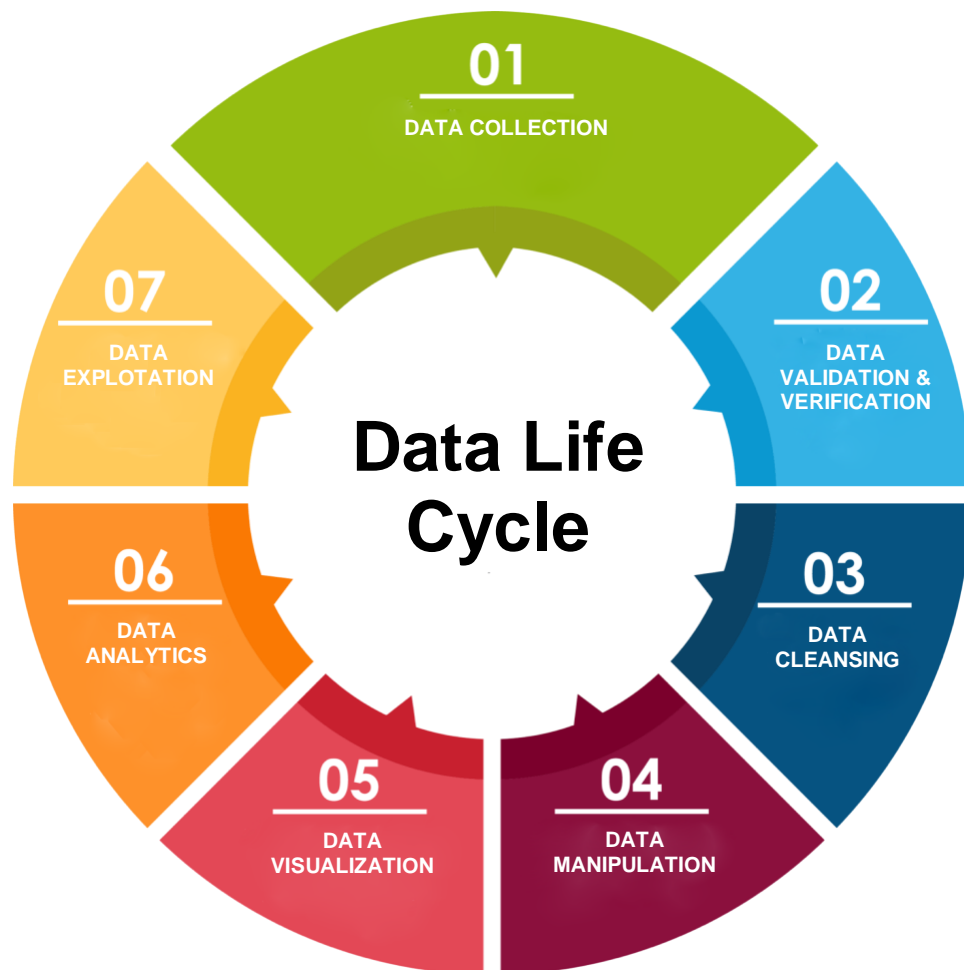


Figure 6. Data life cycle methodology phases.

3.1 Data collection

Is a process of collecting information from all the relevant sources. In this phase, information is gathered from the Finnish Transport Agency (FTA) and The Centers for Economic Development, Transport and the Environment (ELY Centers). The data gathered for this study will be used in the next steps of the methodology and was collected through:

- a. TMS data (Traffic Measurement System): The data is collected from an electrically inductive loop; it is installed in the pavement. It detects the vehicles passing or arriving at a certain point and records information about average speeds and traffic volume. The inductive loop system obtains from the vehicles that are passing the TMS point data such as time, direction, lane, speed, vehicle length, vehicles class and time elapsed between them (Vayla.fi, 2019).
- b. Road weather station data: Currently there are more than 350 weather stations all over the Finnish road network. The devices collect primarily information such as wind, temperature, cloudiness, rain, relative humidity and dew point. (Digitraffic.fi, 2019).
- c. Road weather cameras: These devices provide information on current traffic flow and climate conditions. At present, there are more than 470 road weather cameras (Digitraffic.fi, 2019).

3.2 Data Validation & Verification

Considering that for the aim of this project, just data consumption is being computed, no hands-on were required on the first stages of the data life cycle. Nevertheless, the importance of this step cannot be ignored. Validation and Verification are two ways to ensure the integrity of the input data to the databases.

- a. Data Validation: Checking the input of the data to guarantee its quality, however it does not check the accuracy of data. Data range and data structure are amongst the most common ones.

- b. Data Verification: Is the process of checking the accuracy and inconsistencies of different types of data to find out if it is reasonable. It is performed to ensure that the data matches the original source. A typical data verification is the double entry.

3.3 Data Extraction & Cleansing

Data cleaning refers mostly to identifying and removing (or correcting) inaccurate records from a dataset, caused by mistakes at the entry point, in order for the data to be uniform. In view of this research, data delimitation of the study area was carried out by doing a data selection process.

First of all, having different data sources in different format implied the analysis of the data. On one hand, Digitraffic provides a total of 32 of REST/JSON-APIs and Digiroad a total of 28 shape files. APIs were consulted and analysed with Postman, and on the other hand Digitraffic also provides the CSV reports. Given that not all the information was useful for the purpose of this work, we analysed the relationship of the sources and selected the relevant data, identified dependencies between fields of both sources to finally made a final selection of the key parameters.

Once the source were selected, for the data extraction step, it is important to take into consideration some criteria, such as the reliability of the sources, the time period when the data was collected, outdated data may not be useful and can result in not a very meaningful outcome.

As mention before, it was necessary to combine data from different sources, which in turn have different data formats, therefore a flexible data structure was required for handling the dataset. The method applied was a non-relational database, since it allows us to handle semi-structured data.

For this particular case, the tools used were MongoDB along with Python scripts, using libraries that allow the data transfer from the RESTful APIs in JSON and the TMS raw data that is obtained directly from the TMS points and converted into CSV format. Given

our particular interest in the city of Lappeenranta, a filter was applied during the data extraction, allowing the data mart to keep all relevant rows while avoiding overhead when querying the data later, whereas all attributes were kept for future use.

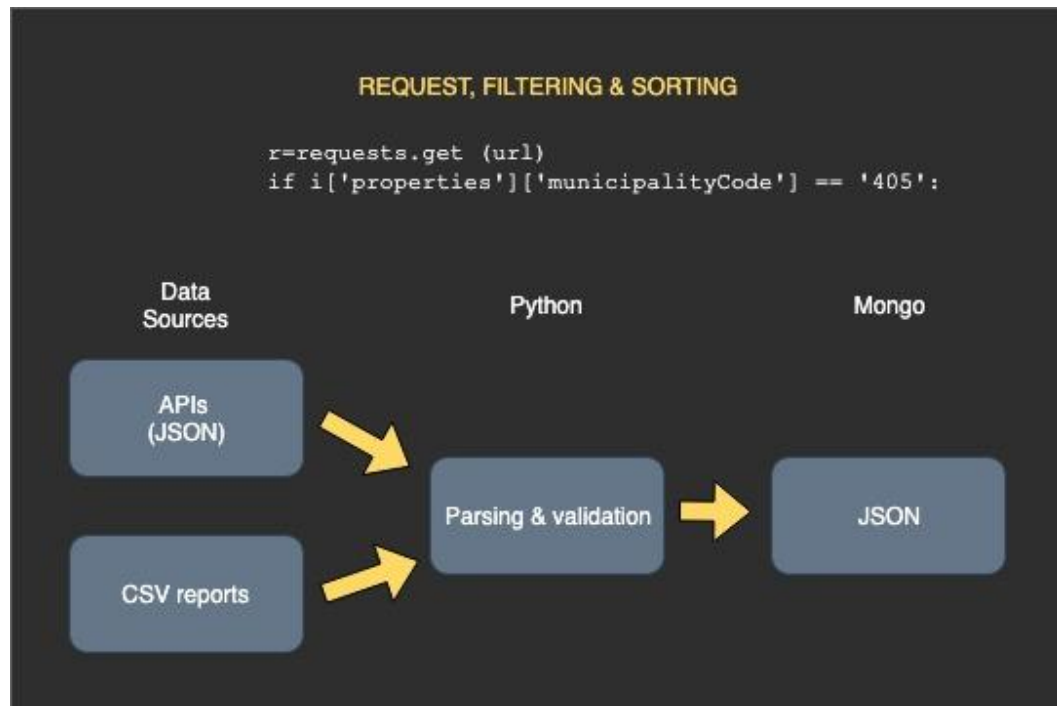


Figure 7. Data extraction model.

For the geographical data, QGIS software was used in order to load the layers which contain the pavement type and traffic volume of the roads, it is delivered in ESRI shape format. A filter in SQL structure was applied in order to highlight the roads of the study area.



Figure 8. Data Extraction process

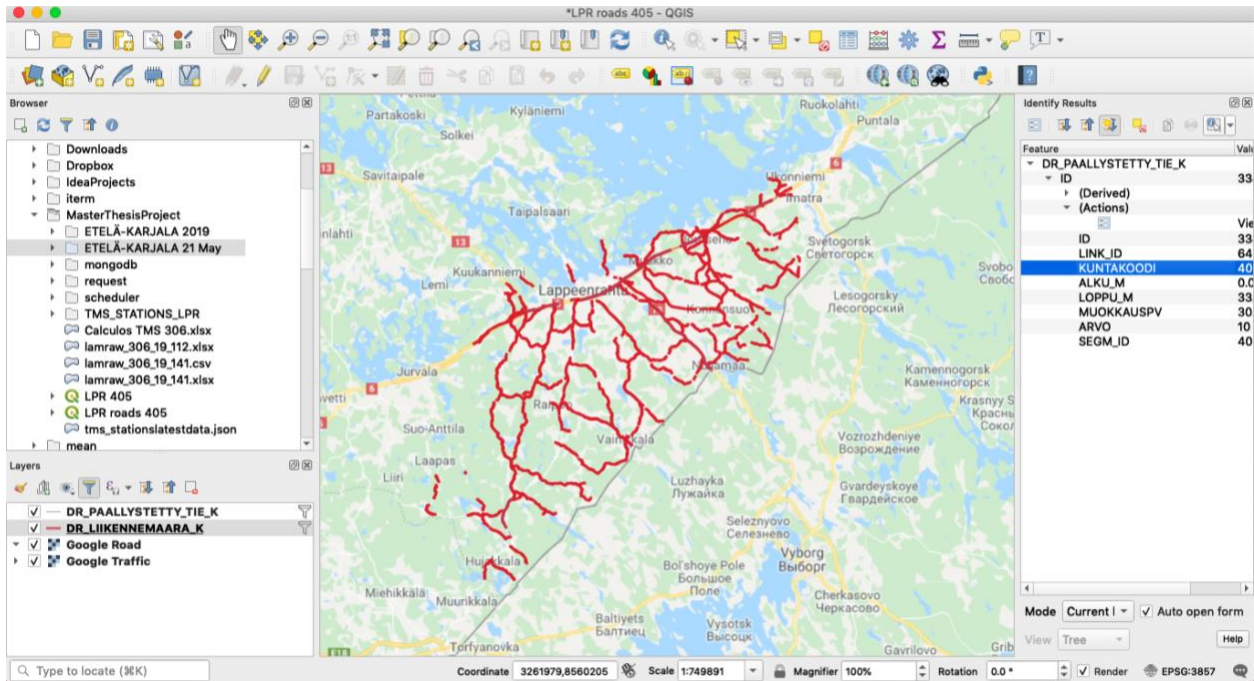


Figure 9. Lappeenranta traffic volume.

3.4 Data Manipulation

In this part of the methodology the data is changed to make it simpler and easier to read and sorted it out (Computerhope.com, 2019). In this phase of the data life cycle, data aggregation, data normalisation, generation of new data is carried out.

For the analysis and calculations of the scenarios, three roads from Lappeenranta were selected based on the available information of the road conditions from the APIs, however, the traffic volume aggregation and the dependencies of this variable were computed with the data of the CSV files since they are loaded every 24 hours and have more recent information which results in more precise information.

Traffic volume:

As mentioned before, the number of vehicles passing per day is registered throughout the TMS points, raw data is added daily and shared to public on the FTIA website.

The files are classified by TMS point id, after having identified the TMS number of every road, the files were loaded, filtered by valid records and aggregate to obtain the traffic volume.

ROAD NUMBER	Length (km)	Traffic Volume (24 hrs)
ROAD 6	50	179494
ROAD 13	17	12368
ROAD 387	6	1320

Table 1. Total traffic volume per road

CO₂ emissions

CO₂ values were taken from LIPASTO unit emissions database. The unit emission database contains emission factors for road and other means of transportation, which reflect passenger and freight traffic in Finland. Unit emissions refer to the amount of emissions emitted during the activity of vehicles, estimated in mass units and assigned per passenger or tonne of freight transported over one kilometer.

Code	Vehicle Class	CO₂ [g/km]
1 ⁽¹⁾	HA-PA (car)	151

2 ⁽²⁾	KAIP (truck, no trailer)	311
3	Buses / coaches	939
4	Semi-trailer truck	619
5	Truck with trailer	784
AVERAGE		560.8

Table 2. CO2 average in Finland (2016)

(1): Share of urban mileage 27%. Car occupancy 1.7 persons

(2): 10 tonne empty delivery truck on the highway, Euro 4 emission class

Calculations have been done for every vehicle class included in the CSV file, it enables to evaluate per vehicle type which one produces more emissions and make a relation with the traffic volume and conditions of a roads. To obtain the CO₂ per road, the average CO₂ value from the vehicle classes was taken and multiplied for the length of the road.

ROAD NUMBER	Length (km)	CO₂ [g/km]
ROAD 6	50	28040
ROAD 13	17	9534
ROAD 387	6	3365

Table 3. Total of CO2 per road

Road conditions and pavement type

All pavement types are classified. There is no pavement segment on the part of road network covered with gravel. Nearly always the pavement information covers the whole link. The data source for all road links is the topographic database of The National Land Survey of Finland (Vayla.fi., 2019).

Code	Description
1	Concrete
2	Stone
10	Asphalt
20	Soft asphalt concrete
30	Gravel surface
40	Gravel wear layer

50	Other coatings
99	Paved, type unknown

Table 4. Paved road classification

Code	Road conditions
4	VERY_POOR
3	POOR_CONDITION
2	SATISFYING
1	GOOD AND VERY_GOOD

Table 5. Road conditions values

To obtain the pavement type of roads, the ESRI shape file was loaded into QGIS, while the road conditions value is fetched from the API's TMS station metadata which contains last winter's pavements condition. Finally, both datasets are combined to visualize the status of the roads, the condition category is displayed with a precision of 100 meters.

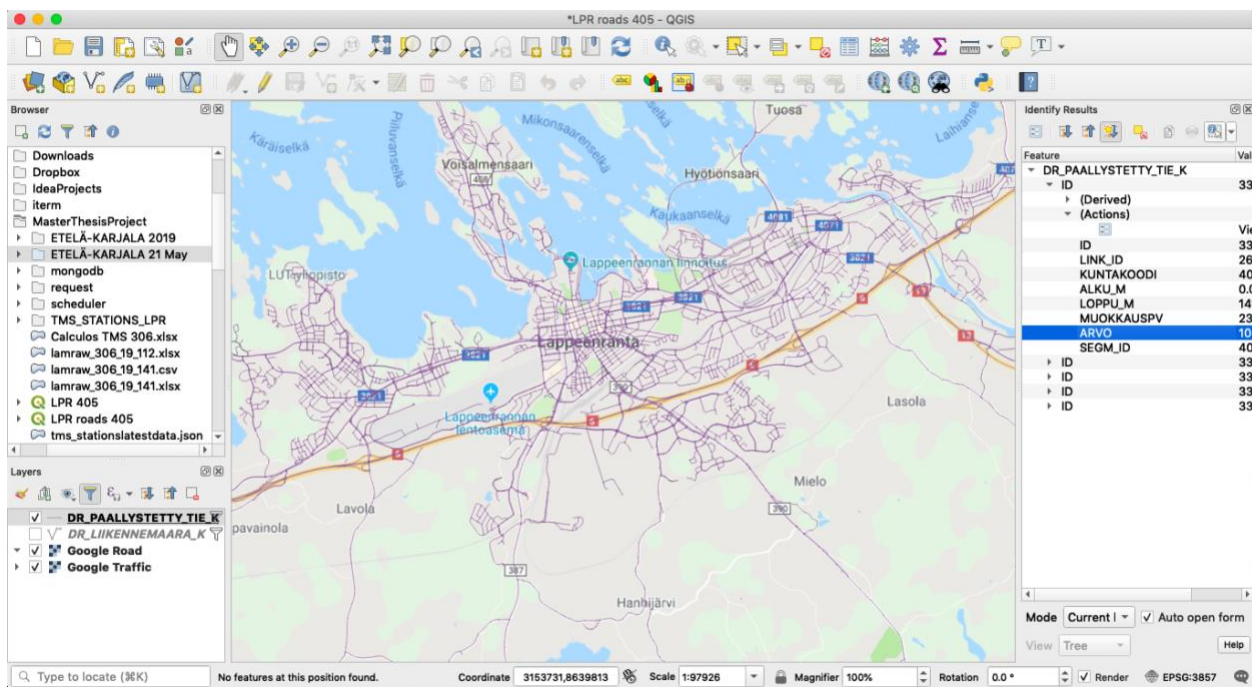


Figure 10. Lappeenranta area pavement type.

ROAD NUMBER	Length (km)	Type of pavement	Road conditions
ROAD 6	50	Asphalt	2
ROAD 13	17	Asphalt & unknown	3
ROAD 387	6	Asphalt	4

Table 6. Pavement type and road conditions of the roads sample

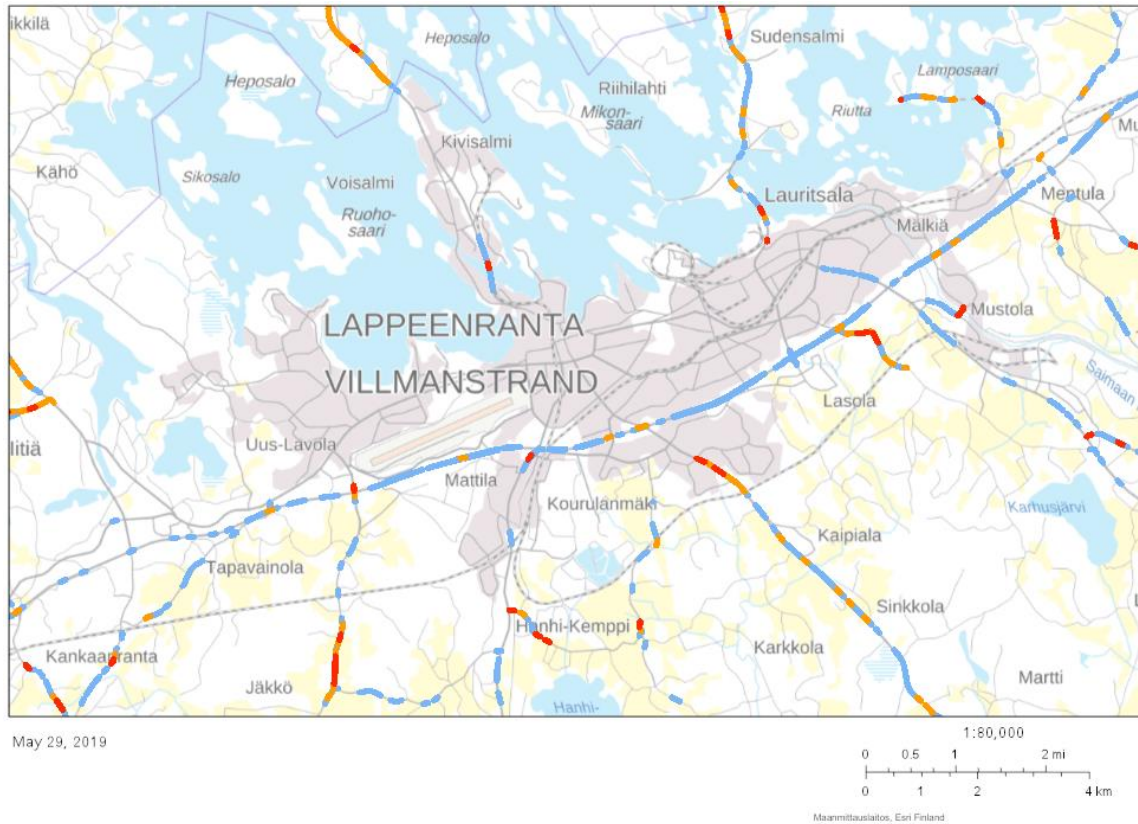


Figure 11. Pavement condition has been broken down to five categories: very poor (red), poor (orange), satisfying (blue), good and very good (green) (Vayla.fi., 2019).

Road maintenance cost

Motorway maintenance and operation cost was determined based on the data published by the FTIA of the backlog maintenance plan 2016-2018, where the estimation cost for the Road 6 was 1,000,000 € (Liikennevirasto.maps.arcgis.com, 2019). The total cost of the road was divided by the length of the road (50 km), which results in 20,000.00 €/km, this figure was used to estimate the rest of the roads.

ROAD NUMBER	Length (km)	Maintenance cost
ROAD 6	50	1,000,000.0 €
ROAD 13	17	340,000.00 €
ROAD 387	6	120,000.00 €

Table 7. Expenditure for maintenance and operation.

Fatality rate

According to Statistics Finland's preliminary data, there were 278 road traffic accidents in April, and based on the report *Traffic Safety Basic Facts on Main Figures* (European Commission, 2017), the fatality rate in 2015 in Finland was 6,8 (per thousand km).

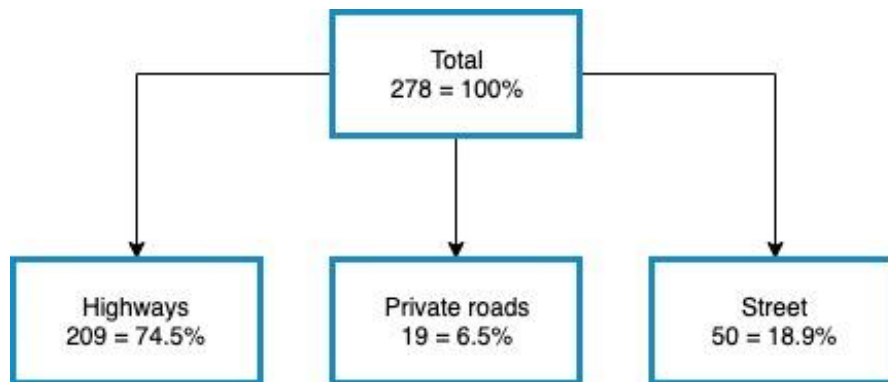


Figure 12. Average of fatal accidents the past 12 months and share (%) by road type (Statistics on road traffic accidents, 2019).

The fatality rate for each road in the sample was calculated from the value mentioned above, and then calculated by the length of each road.

ROAD NUMBER	Length (km)	Fatality rate
ROAD 6	50	0.34
ROAD 13	17	0.12
ROAD 387	6	0.04

Table 8. Fatality rate (per 1000 km).

3.5 Data Visualization

It is called data visualization when the data and information is represented graphically. Some visual elements that can be used are charts, graphs, and maps; these data visualization tools offer a flexible, user-friendly way to show and comprehend trends, outliers, and patterns in the information.

In this phase of the data life cycle we can graphically visualize the results obtained from the calculations of each variable demonstrating its behaviour throughout the period evaluated, at the end of this we aim to correlate the variables and evaluate the impact between them.

Figure 12 demonstrates that the traffic performance is related with the length of the road, being Road 6 the busiest road with the major number of cars registered in 24 hours, whereas for Road 13 and Road 387 the number of cars declines respectively.

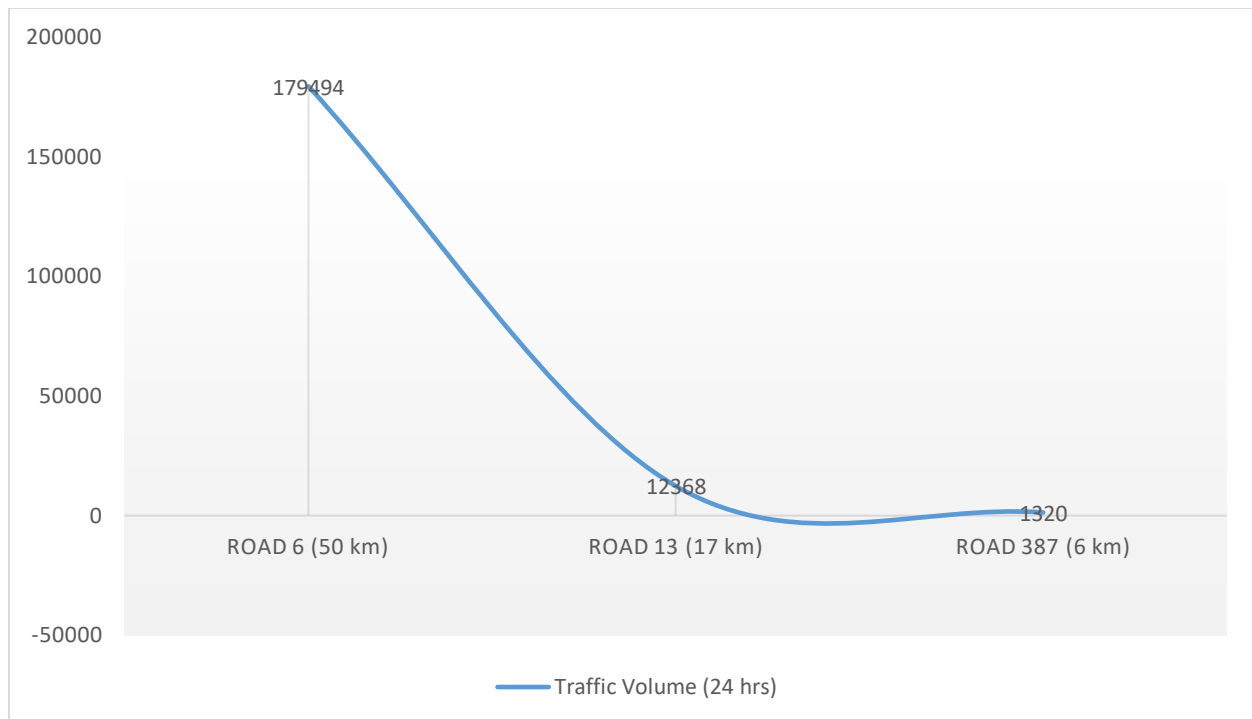


Figure 13. Average traffic volume per road

Traffic performance was broken down by vehicle class, it is evident that passenger cars are the most transited in the 3 roads, following by truck with trailer and semi-trailer truck for road 6, 387 and 13 respectively. Trucks are the third most transited for roads 6 and 13, whereas semi-trailers truck travel more in route 387. Semi-trailer truck and truck with trailer are the median for roads 6 and 13, however on road 387 the same number of trucks

and delivery vans with trailer transited during the time-lapse. Delivery van with trailer is in the 5th position of vehicle class transited on roads 6 and 387, and buses for road 13. Delivery vans with a mobile home are more common for road 6 and 387, even though for the last one the amount of them is minimal. Road 13 has more delivery vans with trailer. Surprisingly, buses are the less frequent for road 6 and 387, while vehicle class 7 is the less frequent for road 13.

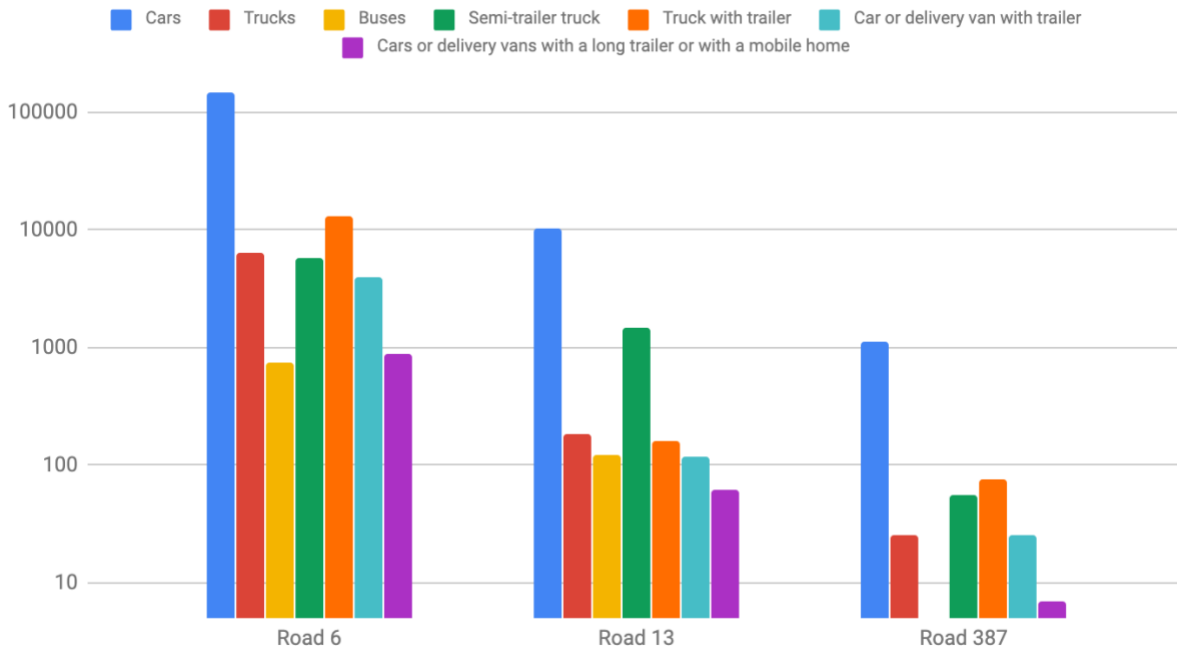


Figure 14. Traffic volume per vehicle class.

The graph below intends to show the CO₂ emissions of every road. Overall, road 6 is the one generating more emissions, the difference in traffic volume and length compared to the other two is significantly visible. However, the difference is just 3 times more between the roads, although the difference in traffic volume is far higher on road 6, therefore, it can be due to the influence of other variables such as speed, the class of vehicles circulating more; specially when heavy vehicles are leading this sections, just after cars. And according to the European Commission, “Heavy-duty vehicles – trucks and buses – are

responsible for about a quarter of CO₂ emissions from road transport in the EU and for some 5% of total EU emissions.” (Climate Action - European Commission, 2019).

Other factors influencing the emissions number, can be the conditions of the roads and even the building materials that were employed and may be reflected in the pavement roughness.

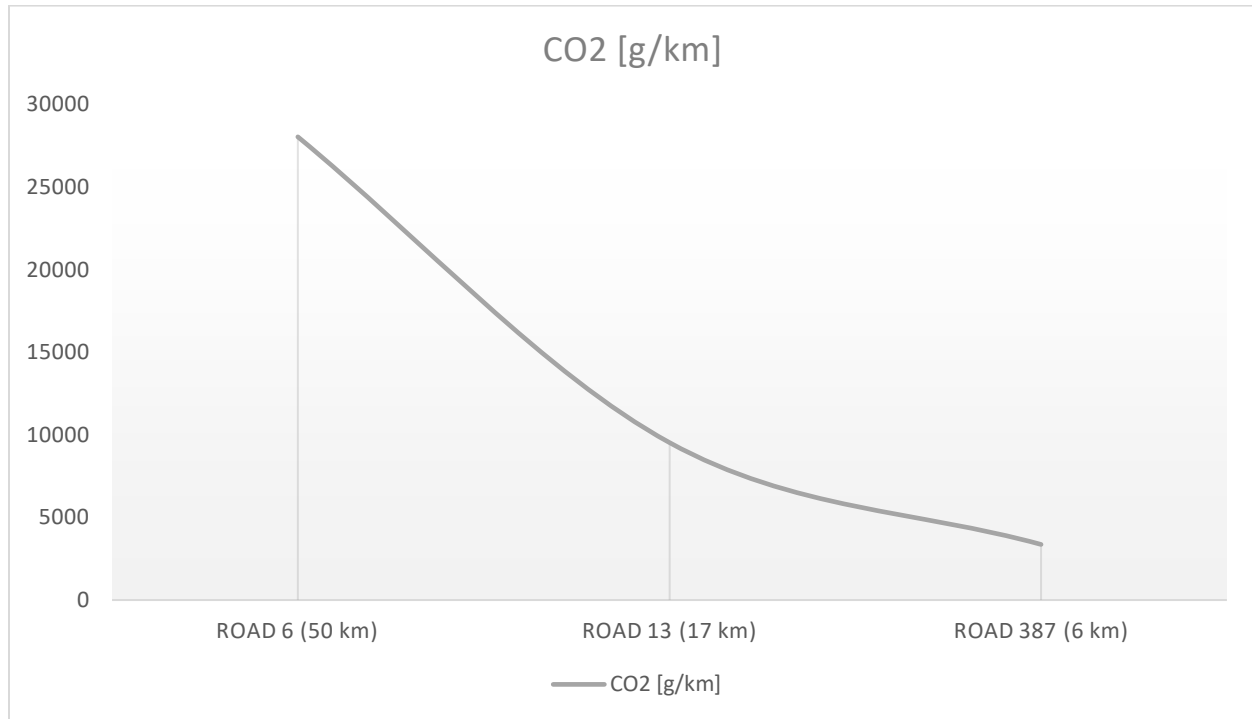


Figure 15. Average CO₂ emissions per road for 24 hours.

According to the FTIA, busy roads around cities are worn, but the main roads are in fairly favorable condition. By contrast, the condition of the lower level road network is poor (Vayla.fi, 2019).

The line graph below clearly depicts what the Finnish transport agency states, it shows the last winter's pavement conditions, and as we can see, although Road 6 has been leading the previous variables, it is in better conditions than the other two roads, whereas the shortest route is more deteriorated.

This is where the participation of policy makers is more notorious, the road network is divided into maintenance classes based on traffic volume, for this reason the response time vary. According to prioritization the local contractors that are in charge of highway maintenance act depending with the service level specified by the Finnish Transport Infrastructure Agency.

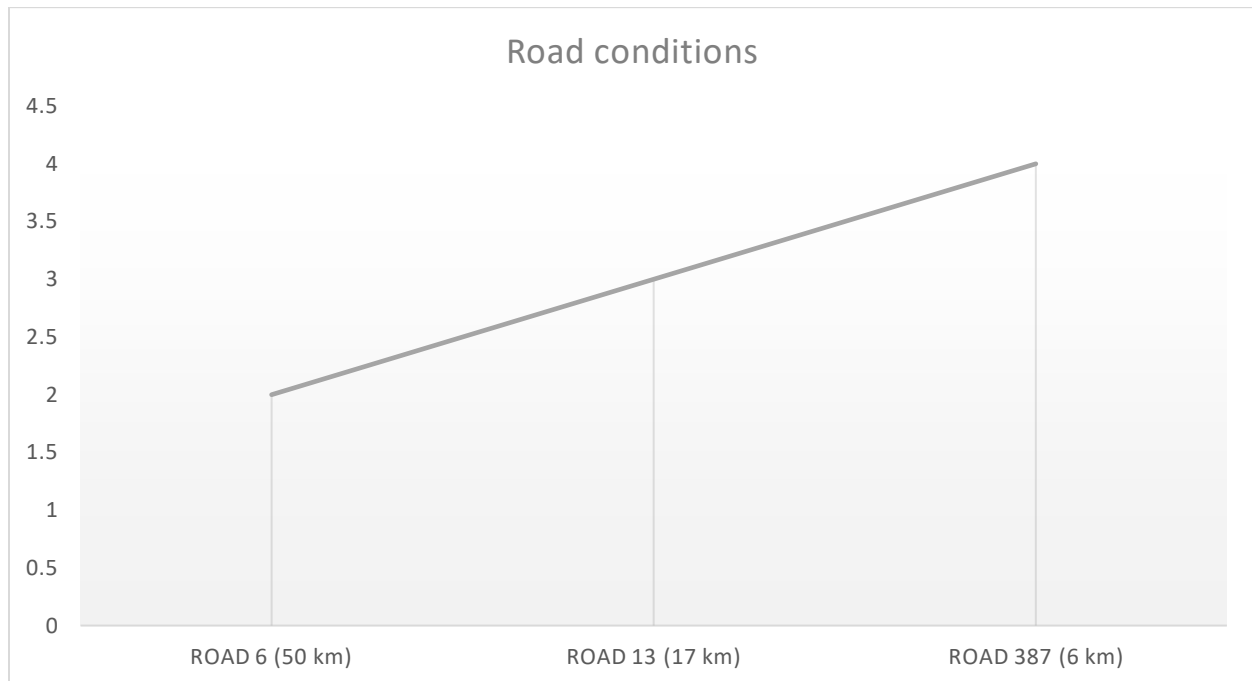


Figure 16. Road conditions 1st semester 2019

In order to provide and guarantee traffic safety, the roads need to be maintained. By repairing and fixing the paving, it ensures keeping street surface in good conditions, which also driving is affected by the condition of the roads, that additionally protects the structural layers underneath the paving.

Figure 16 shows an estimation of the total expenses required for every road, being Road 6 the costliest despite it is in better conditions than the rest.

The Transport Infrastructure Agency says that this summer (2019) it will only be able to maintain the condition of the most heavily-used segments of the road network and most likely smaller roads won't be able to be afforded to repair.

As you can see on the previous graph, road 387 is the most affected and the smaller one, however, based on this summer's roads work projects is not considered to be repaired (Vayla.maps.arcgis.com, 2019).

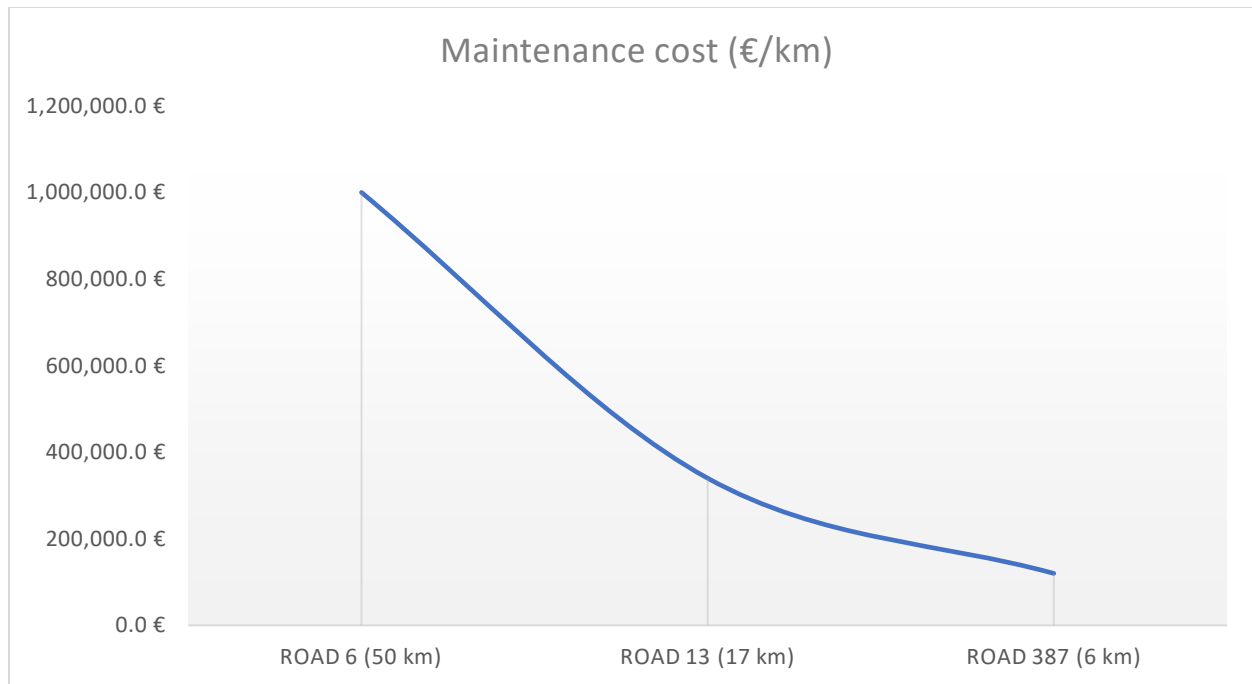


Figure 17. Own estimates based on action plan 206 – 2018 (Liikennevirasto.maps.arcgis.com, 2019).

As the graph below shows the results for fatality rate are linear with the length of the roads, the estimation was obtained based on the national rate given in the *European Commission, Traffic Safety Basic Facts on Main Figures* report. There is not yet an official system for monitoring serious injuries in road traffic in Finland, but statistics based on hospital information are currently being developed.

At a national level, in 2013, 258 people lost their life in road traffic. The number of road deaths varies somewhat year to year; however, the trend is going downwards as compared to 2010 statistics.

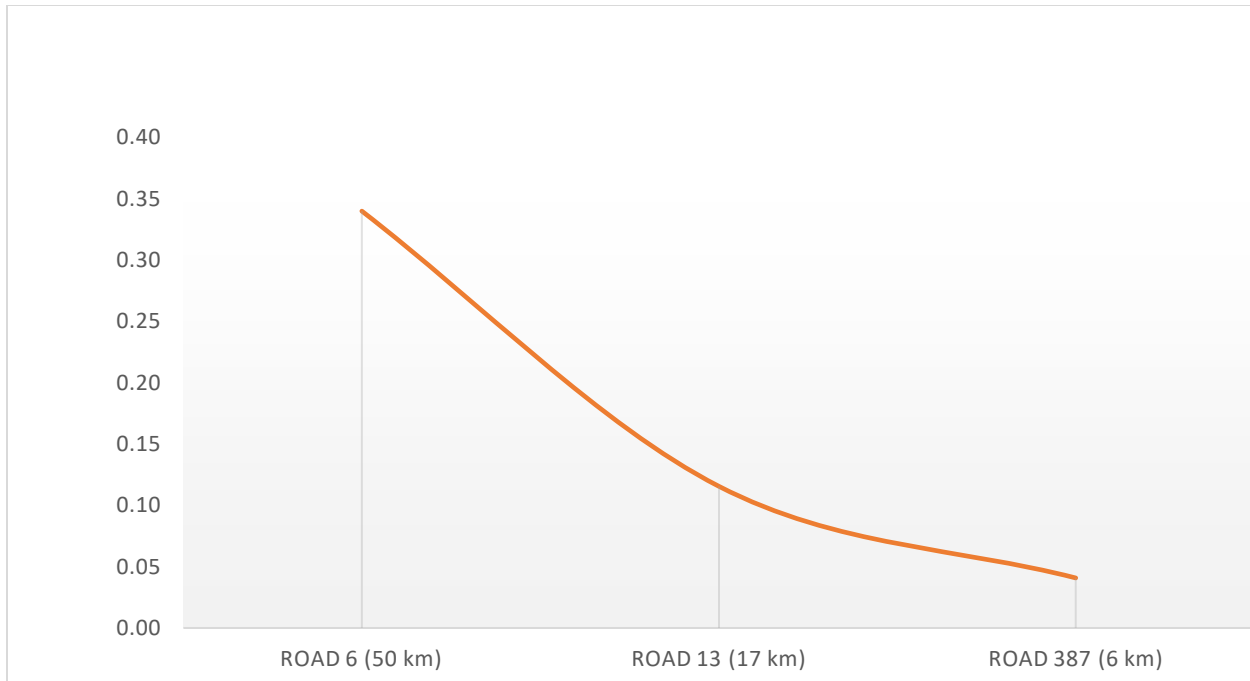


Figure 18. Fatality rate per 1000 km

3.6 Data Analytics

In this phase, we are able to analyse the raw data in order to draw conclusions out of the input dataset and make a comparison of the quantifiable variables. Figures 18 and 19 show a comparison of the variables that represent a proportional relationship, and that the more kilometres the road the greater the results in the variables. Nevertheless, the same behaviour will not necessarily be obtained for all cases.

The cost of maintenance is not directly reflected in the amount of accidents that may occur on the road. It is true that the risk of accidents is greater if the pavement is in bad conditions, but the cost is not related to the fatality rate, to analyse the relationship between repair cost and accident rate, it would be necessary to take into account other criteria such as damage to the pavement after the accident, and it is not within the scope for this research.

On the other hand, despite Figure 19 shows the same behaviour, neither the CO₂ is necessarily related with the length of the road, specially CO₂ that other variables come into

play, such as traffic volume, vehicle classes and pavement conditions that affect directly the rolling resistance and consequently can increase or decrease the emissions factor.

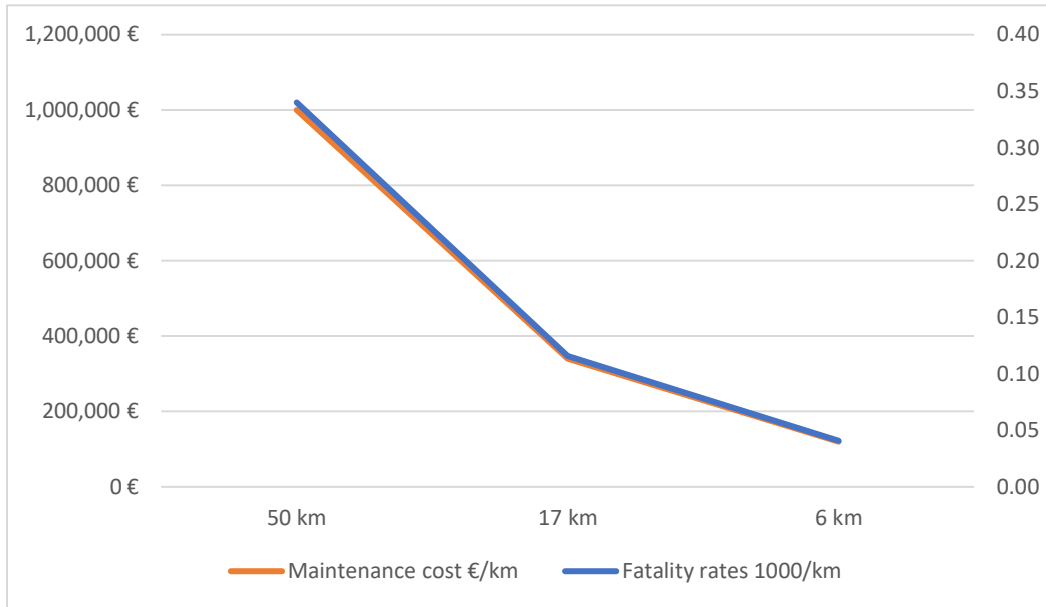


Figure 19. Maintenance and Fatality rate comparison

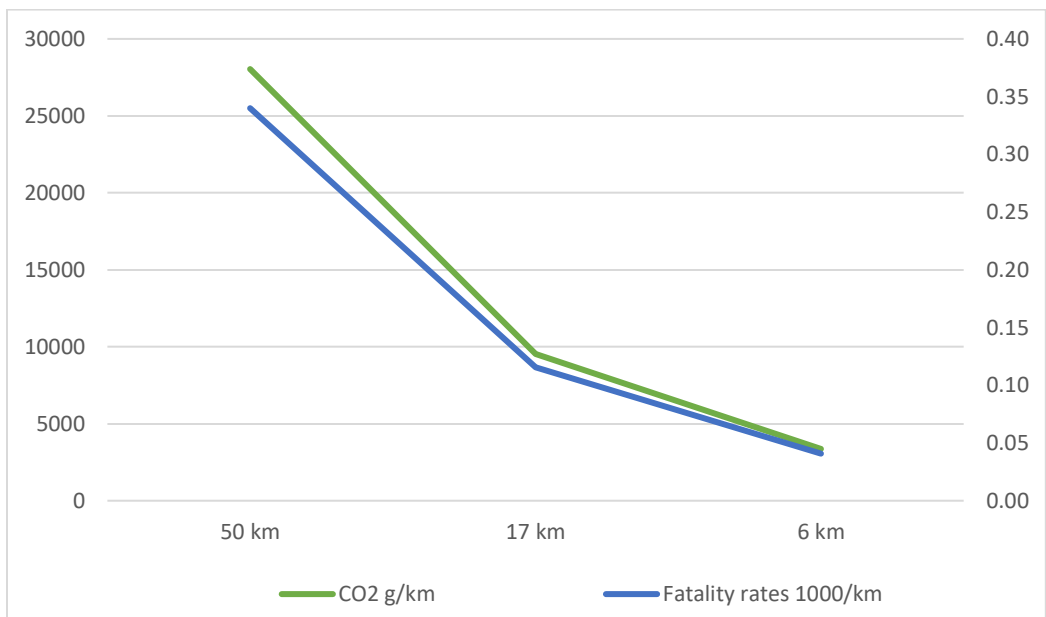


Figure 20. CO2 and Fatality rate comparison

3.7 Data Exploitation

Data is used to support the organization's objectives and operations as users can use it as a tool to analyse current and in the long run historical data that can help to support decision tasks. There are high possibilities to increase access to the data with an automated decision support system when the tasks are performed routinely, moreover it helps managers gain insights into organization processes, activities, and other performance metrics (Power, D. J., 2014).

Based on the outcome, the results and this phase are intended to be addressed to the agency and Maintenance group for them to improve maintenance project planning as they will be aware of the current conditions. Planning is used by the Finnish Transport Infrastructure Agency to promote solutions to reduce traffic, noise and congestions, as well as improving road safety, which are key to sustainable urban development. In addition to safety, reduction of environmental impact and cost-effectiveness, the solutions aim to reduce the need for mobility as well as to improve the conditions for walking, cycling and public transport (Vayla.fi, 2019).

Additionally, information provided can be utilised when, for example, planning driving routes as roads with very poor pavement condition have lower speed limits, moreover it can be useful as well for infrastructure managers when planning road surfacing programmes.

Indicator Selection Criteria

Indicators are used as simple measurements to enhance understanding of what is happening (European Environment Agency, 2016). Sustainable indicators assist in monitoring progress for sustainable transportation and later on can serve on the decision-making process to take the best possible sustainable solution.

The indicators selection criteria were based on the data provided and the literature review, where we identified diverse sustainable attributes that can possible measure road pavements.

- Environmental indicator

Environmental indicator is mostly focused on reduction on CO₂ emissions, air pollution, noise, the use of renewable resources and land consumption.

CO₂: The primary global warming potential of main greenhouse gases. CO₂ has a GWP of 1 despite of the time period used, this is the gas being used as the reference. CO₂ remains in the climate system for a very long time: CO₂ emissions cause increases in atmospheric concentrations of CO₂ that will last thousands of years (US EPA, 2019)

Road pavement conditions have influence on the emissions that vehicles produce, in general smooth and well-maintained roads will have a positive impact on the performance of vehicles with regard CO₂ (EUPAVE, EAPA, F., 2016).

- Social indicator

Social sustainability is described as the most complex and challenging dimension to measure due to its diversity, broad and subjective characteristics (Shen et al., 2011). Social sustainability comprises indicators regarding access, safety, health, information availability, attractiveness, commitment to plans, and coordinated management, thus also including aspects of governance.

In the last ten years the safety on highways in Finland has improved. However, there still a safety target to be achieved, the target set for road traffic for 2010–2020 is to reduce by 50% the number of fatalities as well as to reduce the amount of serious injuries. If the goal is met, no more than 136 fatalities would occur. Additionally, the EU has demanded road safety improvement targets to its Member States (Vayla.fi., 2019)

- Economic indicator

Economic sustainability is characterized through elements dealing with stable funding and subsidies, revenue, economic viability, competitiveness and sufficient capacity, ridership, and cost-efficiency.

Maintenance includes keeping road surfaces in good condition since driving is affected by the condition of the road surface, which also protects the structural layers underneath the paving (Vayla.fi., 2019).

4. RESULTS AND DISCUSSION

The finding of this study clearly shows that selecting a set of predominant indicators is the hardest task, many times it will depend on the dataset and tools you have; however, it is recommended to get more detailed data in order to generate more accurate and useful results.

In the present study case, neither the traffic volume nor the cost of maintenance is directly related to the emissions factor, however the measured variables have a direct relationship with the number of kilometers, yet there are not enough elements to determine that the emissions are related to the length of the road, the fatality rate or maintenance cost, therefore this combination is not sufficient for a conclusion on a determining factor in the reduction of emissions.

With this study, it is not possible to correlate the three variables, hence an holistic evaluation of the three sustainability dimensions cannot be complete, unless a weight or score is given to the indicators based on the qualitative assessments, but still it's unavoidable to not put a subjective weight in especially non-quantitative facts, but indicators are used just to give an understanding of what it's happening in order to monitor the progress towards goals and objectives. The variety of indicators will show different perspective and assumptions.

- Are the emissions related with the conditions of the road?

At a certain extent, the conditions of the road pavement are related with the emissions factor since they have an impact towards the vehicle fuel consumption, and this is due to the rolling losses that is caused by an uneven pavement, potholes, rutting, etc.

The more deteriorated the pavement, the greater will be the rolling losses. It is demonstrated that the fuel consumption and emissions increase with a major pavement roughness regardless the type of vehicle, hence a smooth and adequate texture on the road will decrease CO₂ emissions.

- Are the road conditions related with the pavement type and traffic volume?

The study does not prove a direct relation between traffic volume and the road conditions, many variants are involved in the conditions of the pavement, it is not possible to simply attribute if the road is in poor condition to the traffic volume. For example, there may be a road in poor conditions and with low traffic flow, however the type of vehicles that run on that route are heavy load which can cause greater erosion to the pavement, whereas a road with more flow but with light vehicles transiting at it can be in a better shape.

Some studies state that concrete pavements are distinguished by their durability and low maintenance, but as mentioned before, it depends of many factors, such as the material production and the maintenance strategies

- Is there any relation that the road conditions are affected by vehicle class?

It can be possible, but it's not totally related to the vehicle class, it's difficult to prove the relation between these two factors and a more precise and specific study would require to be done.

On the contrary, studies have proved that the surface texture influences on the fuel consumption of heavy trucks. Finally, it can be assumed that is a bilateral relation and both aspects have consequences on the other.

Sustainability Assessment

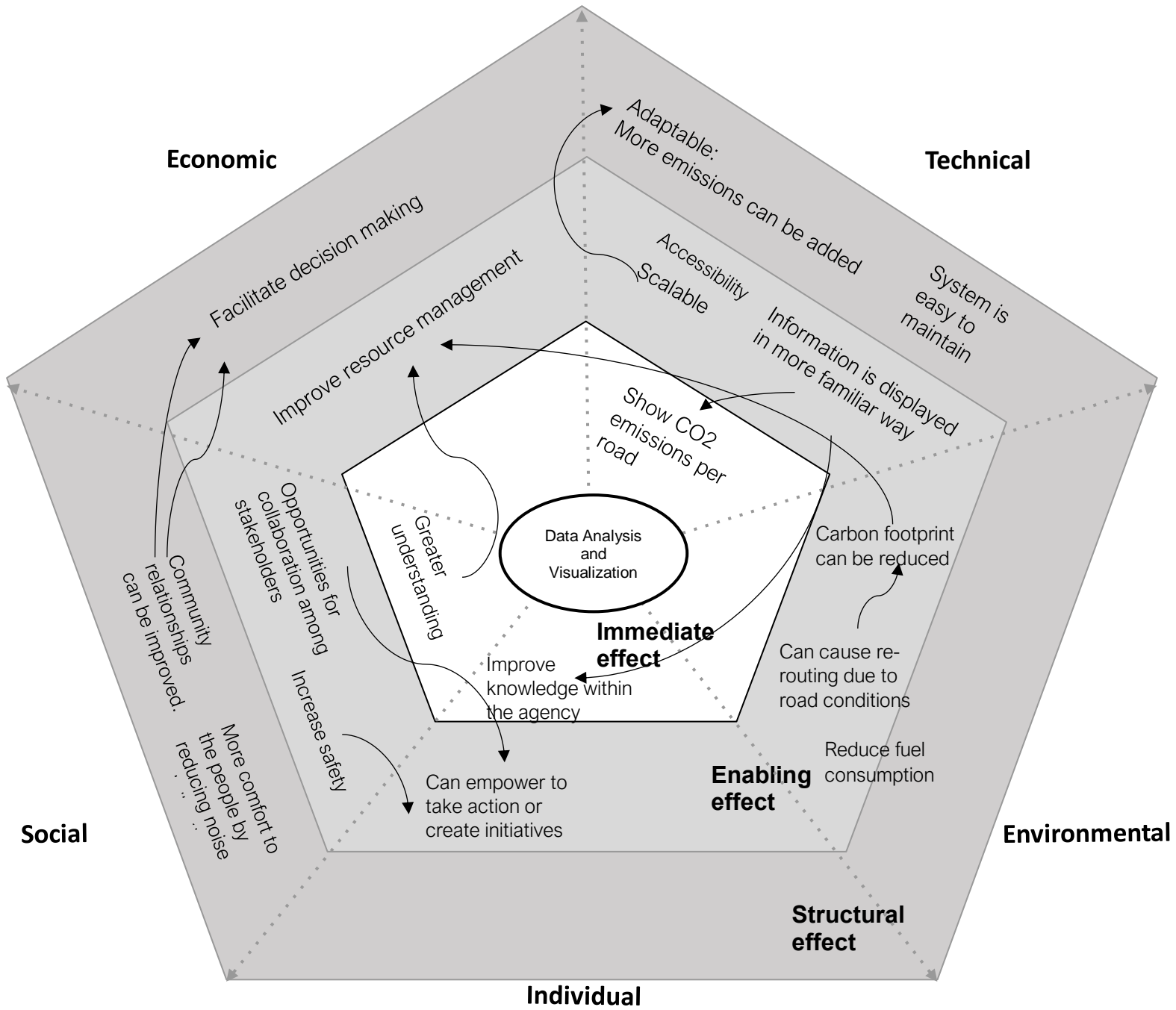


Figure 21. Sustainability aspects (Duboc L. et al., 2019)

Following the SUSAD diagram as a guideline (Duboc L. et al., 2019), Figure 20 shows the sustainability aspects where this work can contribute.

For instance, the orders of effects across time like its immediate technical use effect, the system provides the CO₂ emissions per road which contributes to a knowledge gain at the individual level that furthermore can be extend to more people and can result in a social greater understanding. As a result, this can have a positive effect on the economic aspect by improving the resource management of the maintenance budget as well as to the environment aspect can reduce the carbon footprint and take action by re-routing roads due to road conditions, additionally as enabling effect it can open the collaboration among stakeholder to create initiatives to create a plan taking into consideration the community, as for the technical aspect, the system is scalable if more data is required to be load. Facilitate the decision making and the possibility to add more parameters along with a strengthened community are some structural effects.

Social. Current system is addressed to an organization but not precisely to engage or impact the behavior of specific group of people, however, it influences human decision because the system carries out data, the goals is to improve the resource management by taking better decision that can benefit the economic aspect of the agency.

Individual. The individual impact of current system is the knowledge upon the user that will use the system, and eventually can lead to encourage people to create initiatives or collaborate with other stakeholders to provide an understanding of sustainability. Thus, we can emphasize that individual indicator can and should be equally monitored and compared against one another and over time.

Environmental. This aspect will be reflected by the decisions and actions taken by the agency after consulting the data. It can result on CO₂ reduction, the increase safety by re-routing the roads when they are in bad conditions or under maintenance, which also has an impact towards people's comfort. In this aspect we can identify that the effects might have a positive impact towards the social aspect.

Economic. This work will contribute on the decision-making process, which aim to make a more efficient resource management. The system will show the data that can help to prioritize the maintenance of the roads base on traffic demand, safety or amount of emissions, as well as the conditions of the roads itself.

Technical. On the technical aspect, the system is using open source data, so it is possible to say that it is safe. It's scalable due to the fact that more amount of data can be added, and the adaptability that more indicators can be included such as noise, vibration and so on.

5. CONCLUSIONS AND FUTURE WORK

The final remark of this study is the trade-off that exists among the sustainability aspects and cannot be ignored in assessment methodologies. Although there are several tools to perform a sustainability assessment, there is no standardized method that fully covers each sustainable criterion.

An alternative to cover a greater range of possible impacts could be the combination of tools and methods taking into account the strengths and weakness of each one to reduce the margin of error, however this does not guarantee its effectiveness.

Another important aspect is the context where the assessment is being done, method should be adaptable to the context of the city where the analysis is being done, that's why most of the studies are reduce to case study of the city to be evaluate. For instance, same study cannot be applied to Helsinki, where conditions and necessities are different from Lappeenranta.

This study was limited by the data available, for a deeper and more accurate assessment it is required a larger sample dataset to include more indicators and apply another methods and techniques for a better comparison. Regardless of the amount of data available, it makes it complicated to be analysed when it's coming from different sources and in a variety of formats, an opportunity to centralize the data in a standardize format with internationalisation would allow to explode it easier and faster.

Additionally, citizens and municipality can collaborate and define goals for their community and methods such as survey, questionnaires, interviews can be applied to engage citizens and later on experts on the field could participate identifying significant trade-offs among indicators in a clear and more concise way that help in the decision-making process.

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APPENDIX I. DATA EXTRACTION

```
1 import json
2 import pandas
3 import requests
4
5 from pymongo import MongoClient
6
7 #Connect to db
8 connection = MongoClient("mongodb://localhost:27017")
9 db=connection.dataapis
10
11 try:
12     conn=MongoClient()
13     print ("Connected successfully!!")
14 except:
15     print ("Could not connect to MongoDB")
16
17 # database
18 db = conn.dataapis
19
20 #Query data from API
21 r=requests.get(url='https://tie.digitraffic.fi/api/v1/data/free-flow-speeds?lastUpdated=false')
22 freeflowspeeds = r.json()
23 print ("Current date API: " + freeflowspeeds['dataUpdatedTime'])
24
25 #If collection does not exist, creates it and fill it out for the first time from source API
26 if "freeflowspeeds" not in db.list_collection_names():
27     collection = db['freeflowspeeds']
28 #Filter data just by LPR data
29 counter = 0
30 freeflowspeedsdata = {}
31 print("New collection created")
32 for i in freeflowspeeds['tmsFreeFlowSpeeds']:
33     if i['tmsNumber'] == 306 or i['tmsNumber'] == 533 or i['tmsNumber'] == 534 or i['tmsNumber'] == 547 or i['tmsNumber'] == 556 or i['tmsNumber'] == 557:
34         collection.insert_one({
35             "tmsstationId": i['id'],
36             "timestamp": freeflowspeeds["dataUpdatedTime"],
37             "freeFlowSpeed1": i["freeFlowSpeed1"],
38             "freeFlowSpeed2": i["freeFlowSpeed2"],
39             "tmsNumber": i["tmsNumber"]
40         })
41     print("*****")
42 #If collection exists, get the most recent timestamp from mongodb
```

Line 1, Column 1 Spaces: 4 Python

```
1 import json
2 import pandas
3 import requests
4
5 from pymongo import MongoClient
6
7 #Connect to db
8 connection = MongoClient("mongodb://localhost:27017")
9 db=connection.dataapis
10
11 try:
12     conn=MongoClient()
13     print ("Connected successfully!!")
14 except:
15     print ("Could not connect to MongoDB")
16
17 # database
18 db = conn.dataapis
19
20 #Query data from API
21 r=requests.get(url='https://tie.digitraffic.fi/api/v1/metadata/camera-stations?lastUpdated=false')
22 cameras = r.json()
23 print ("Current date API: " + cameras['dataUpdatedTime'])
24
25 #If collection does not exist, creates it and fill it out for the first time from source API
26 if "camerastationsLPR" not in db.list_collection_names():
27     collection = db['camerastationsLPR']
28 #Filter data just by LPR municipalityCode
29 counter = 0
30 camera_stations = {}
31 print("New collection created")
32 for i in cameras['features']:
33     if i['properties']['municipalityCode'] == '405':
34         collection.insert_one({
35             "camera_stations": i['id'],
36             "timestamp": cameras["dataUpdatedTime"],
37             "roadStationId":i["properties"]
38         })
39 #If collection exists, get the most recent timestamp from mongodb
40 else:
41     lastupdatedb=db.camerastationsLPR.find_one(sort=[("timestamp",-1)])["timestamp"]
42 #Compare timestamp versus source api and adregate data
```

Line 4, Column 1 Spaces: 2 python

```
ffs.py x camera_stations.py x forecast_section_roadNumber.py x tms_stations.py x road_conditions.py x
1 import json
2 import pandas
3 import requests
4
5 from pymongo import MongoClient
6
7 #Connect to db
8 connection = MongoClient("mongodb://localhost:27017")
9 db=connection.dataapis
10
11 try:
12     conn=MongoClient()
13     print ("Connected successfully!!")
14 except:
15     print ("Could not connect to MongoDB")
16
17 # database
18 db = conn.dataapis
19
20 #Query data from API
21 r=requests.get(url='https://tie.digitraffic.fi/api/v2/metadata/forecast-sections?lastUpdated=false')
22 roads = r.json()
23 print ("Current date API: " + roads['dataUpdatedTime'])
24
25
26 #If collection does not exist, creates it and fill it out for the first time from source API
27 if "forecastsections" not in db.list_collection_names():
28     collection = db['forecastsections']
29 #Insert data just from LPR
30
31 roads_lpr = {"roads_lpr":[]}
32 print("New collection created")
33 for i in range(len(roads['features'])):
34     if roads['features'][i]['properties']['roadNumber'] == 387 or roads['features'][i]['properties']['roadNumber'] == 13 or roads['features'][i]['properties']['roadNumber'] == 14:
35         print (roads['features'][i]['properties']['roadNumber'])
36         collection.insert_one(roads['features'][i]['properties'])
37 # collection.insert_one(roads_lpr)
38 # print(roads_lpr)
39
40 print("*****")
41
42
```

```
ffs.py x camera_stations.py x forecast_section_roadNumber.py x tms_stations.py x road_conditions.py x
2 import pandas
3 import requests
4
5 from pymongo import MongoClient
6
7 #Connect to db
8 connection = MongoClient("mongodb://localhost:27017")
9 db=connection.dataapis
10
11 try:
12     conn=MongoClient()
13     print ("Connected successfully!!")
14 except:
15     print ("Could not connect to MongoDB")
16
17 # database
18 db = conn.dataapis
19
20 #Query data from API
21 r=requests.get(url='https://tie.digitraffic.fi/api/v1/metadata/tms-stations?lastUpdated=false&state=active')
22 stations = r.json()
23 print ("Current date API: " + stations['dataUpdatedTime'])
24
25 #If collection does not exist, creates it and fill it out for the first time from source API
26 if "tms_stations" not in db.list_collection_names():
27     collection = db['tms_stations']
28 #Filter data just by LPR municipalityCode
29 counter = 0
30 tms_stations = {}
31 print("New collection created")
32 for i in stations['features']:
33     if i['properties']['municipalityCode'] == '405':
34         collection.insert_one({
35             "roadId": i['id'],
36             "Timestamp": stations["dataUpdatedTime"],
37             "roadStationId": i["properties"]
38         })
39 #If collection exists, get the most recent timestamp from mongodb
40 else:
41     lastupdatedb=db.tms_stations.find_one(sort=[("Timestamp",-1)])["Timestamp"]
42 #Compare timestamp versus source api and aggregate data
43 if stations['dataUpdatedTime'] > lastupdatedb:
```

```
ffs.py x camera_stations.py x forecast_section_roadNumber.py x bms_stations.py x road_conditions.py x
1 import json
2 import pandas
3 import requests
4
5 from pymongo import MongoClient
6
7 #Connect to db
8 connection = MongoClient("mongodb://localhost:27017")
9 db = connection.dataapis
10
11 try:
12     conn = MongoClient()
13     print ("Connected successfully!!")
14 except:
15     print ("Could not connect to MongoDB")
16
17 # database
18 db = conn.dataapis
19
20 #Query data from API
21 r = requests.get(url='https://tie.digitraffic.fi/api/v2/data/road-conditions?lastUpdated=false')
22 roads = r.json()
23 print ("Current date API: " + roads['dataUpdatedTime'])
24
25 #Store only roads and sections from LPR
26 relevant_roads = {'00013', '00006', '00387'}
27 relevant_sections = {"241", "304", "303", "240", "301", "239", "215", "216", "302", "305", "308", "007" }
28
29 #If collection does not exist, creates it and fill it out for the first time from source API
30 if "roadconditions" not in db.list_collection_names():
31     collection = db['roadconditions']
32 #Insert data just from LPR
33 counter = 0
34 road_conditions = {}
35 print("New collection created")
36 for i in roads['weatherData']:
37     road_number = i['id'].split('.')[0]
38     road_section = i['id'].split('.')[1]
39     if road_number in relevant_roads and road_section in relevant_sections:
40         collection.insert_one({
41             "strid": i["id"],
42             "timestamp": roads["dataUpdatedTime"],
```

Line 15, Column 41

Spaces: 4 Python