Swedish Competence Centre in Road Technology

Research agenda

KCV

KOMPETENSCENTRUM VÄGTEKNIK

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Preface

The purpose of this research agenda is to outline a strategic framework for advancing the competence in road technology by addressing the state of the art and key challenges.

The research agenda was developed as a collaborative process between researchers from Chalmers University of Technology, the Royal Institute of Technology (KTH), LTH – Faculty of Engineering at Lund University, Luleå University of Technology and the Swedish National Road and Transport Research Institute (VTI) and has also included experts from The Swedish Transport Administration.

I want to express my gratitude to all individuals and organizations who contributed to the development of this research agenda. Special thanks go to the researchers from the partners of the KCV and the specialists from the Swedish Transport Administration whose insights have been invaluable throughout this process.

I hope that this research agenda will serve as a catalyst for meaningful constructive dialogue and collaboration among researchers, practitioners, decision-makers and other stakeholders in road technology while simultaneously contribute to increased competence and knowledge, allowing the further development of strong research environments in Sweden.

Joacim Lundberg, director KCV

Lund, 2025-02-20

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1 Background to the research agenda

This research agenda was developed from the need rising from the purpose of the competence centre, meaning to increase the competence and knowledge within road technology in Sweden.

The brief background to the KCV, and in extension the research agenda, was that the Swedish Transport Administration identified a need to replace the old BVFF (Bana Väg För Framtiden) research programme with a new direction focusing on competence development and knowledge development. The Swedish Transport Administration invited Chalmers University of Technology, the Royal Institute of Technology (KTH), Luleå University of Technology, LTH – Faculty of Engineering at Lund University, and the Swedish National Road and Transport Research Institute (VTI) to suggest how a competence centre in road technology could be designed given the intention to, within the area and Sweden, to increase competence and knowledge through funding research and thus allow for developing stronger research environments in Sweden.

As part of the submitted proposal, four research areas were established, along with a research council consisting of researchers and specialists from the Swedish Transport Administration to cover the current and emerging competence and research needs from both academia and road authorities.

The full invite and the full suggestion that was submitted and approved by the Swedish Transport Administration 2022 is available in Appendix 1 – Trafikverkets inbjudan and Appendix 2 – Förslag på inrättande av Kompetenscentrum vägteknik. More updated information is also available on the KCV webpage (www.kcvag.se).

2 Purpose and goals with the research agenda

The general purpose of this research agenda for the KCV is to give a direction of the research needs identified by the academia and the Swedish Transport Administration. This research aims to develop new competence and knowledge within road technology in Sweden, as well as deepening existing competence and knowledge through new and increased collaboration in research and education within Sweden. In more detail the purpose with KCV and this research agenda is to:

- Gather the more immediate and the more long-term needs for competence and knowledge within road technology in Sweden, both from the research and educational perspective and the perspectives of the different stake holders such as e.g. road authorities, consultants, contractors, material manufacturers.
- Secure future competence and secure strong research groups at the five organisations that constitute the Swedish Competence Centre in Road Technology.
- Initiate more collaboration within road technology in order to strengthen the research groups cross the different organisations and thus create long-term strong collaborations and research groups across academia, stakeholders and over time the industry.

This is to be achieved by creating new and increasing current competencies and knowledge, thereby ensuring a strong foundation to respond to current and future challenges within road technology. It is also done to ensure competence in education, thereby also securing future competence.

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3 Limitations

This research agenda is limited to the subject areas for the Swedish Competence Centre in Road Technology which is road technology. Road technology is a wide concept requiring multi-, inter-, and intradisciplinary approaches limited to the main focus on road technology and its applications.

Examples on areas that are *not* in the focus for the competence centre are (Swedish Transport Administration, 2022):

- Installations
- Buildings
- Rock engineering
- Geotechnical engineering
- Traffic analyses
- Development of socioeconomic models and methods
- Side areas/landscape
- Geometric design of roads

4 The process to create and develop the research agenda

The development of the research agenda has been performed in a stepwise process using a primarily bottom-up approach with engagement from the research areas, the research council, and the office of the competence centre.

The research areas, and the research council are manned with researchers and practitioners from the Swedish Transport Administrations that are active in their respective area. The groups are balanced between the different participating organisations and have been constructed in order to cover as wide range of subjects and interdisciplinary focus as possible, while also retaining the needs from the stake holder. The competence centre office is structure with researchers within the areas and experienced administrative personnel used to building competence centres, innovation programmes, or that has a deep knowledge in the financial systems required given the Swedish regulations of publicly funded research projects. This combination of competences has been fundamental in developing a true and appropriate research agenda.

The process to develop the first version of the research agenda has followed the following process:

1. The work started with a physical start-up meeting in Stockholm. Here the research areas and the research council met for the first time and got an overview of the work to be done within the different groups. This day continued with work in the separate groups starting to prepare the work to develop drafts of the research agenda and to get to know each other. The day ended in a common discussion between all groups.

   This day was followed up by digital meetings and discussion in each respective group and a second physical meeting in Stockholm to finalise the drafts from the research areas.

2. The draft agendas from the research areas were submitted to the competence centre office who combined the agendas into a coherent document. This document was then submitted to different stake holders in Sweden for review.

3. The review comments from the stake holders are worked into the research agenda by the research council supported by the research areas and the KCV office. Potential comments that seemed out of scope or was not incorporated into the research agenda will be collected in an appendix to the research agenda with comments explaining the reasons why it was not included for transparency.

4. The final draft will be submitted to the KCV board for review and decision to accept or improve the agenda.

5. After the decision was made by the KCV board the final document was translated by the competence centre office to ensure that the research agenda is available both on the native language Swedish and in English to not unnecessarily restrict ideas from researcher not enough proficient in one of the languages.

6. An open seminar will be held to present the finished research agenda.

5 Research needs in the research areas

5.1 Health, environment, and climate effects

5.1.1 Introduction

For a centre specializing in road technology, the fundamental concern lies in defining the scope of road technology itself - a complex issue, especially when regarding road impact on health, the environment, and the effects of climate as well as on safety and accessibility. The choices made in road design, material selection during construction, operation, maintenance, or repaving significantly influence the surrounding environment through emissions via air, soil and water. In some cases, measures to reduce negative impact in one area conflicts with measures in another areas. Hence, these factors necessitate thorough investigation and consideration when making decisions in road construction and management. This research agenda proposes that not only the actual road construction and included materials but also aspects such as road runoff treatment systems are linked to road technology since they arise from the road and traffic.

Therefore, this research area encompasses a range of scientific themes, including climate mitigation and emission reduction in road construction and maintenance. It focuses on climate change adaptation, hydrological impacts, nature-based solutions, and on managing the effects of natural disasters on road infrastructure. Additionally, it addresses air and water quality concerns, the impact of electrification, noise pollution, and the promotion of active transport.

5.1.2 The Swedish Transport Administration needs

The overall aim of the Swedish Transport Administration is to fulfil the national goal to provide ecologically, socially, and economically sustainable transport for the entire country. Several hundred million SEK will be provided for research in support of the overall aim. The national goal is divided into one “functional goal” concerning accessibility through transport, and one “consideration goal” stating that the transport system shall be adapted to avoid fatalities and severe injury and contribute to the fulfilment of the national environmental goals and increased health.

The environmental part of the consideration goal is summarized as a long-term goal for the research in the *Swedish Transport Administration Research and Innovation Plan 2024–2029*: “A future transport system without impact on climate, environment or nature”.

In the corresponding *In-depth presentation of urgent research and innovation for the years 2024–2029* several areas of research are highlighted among which the following are of particular interest for the KCV Research Area *Health, Environment and Climate*:

- Hazardous substances in materials and products used in infrastructure projects and their impact on health and the environment.
- Sustainable and eco-friendly practices in road construction.
- A Non-Toxic Environment, one of the 16 Swedish environmental objectives.
- Water in new and existing infrastructure – flooding, water quality etc.
- Impact of climate change on transportation infrastructure.
- Increased active transport for better health.
- Impact on health due to noise and air pollution from transportation.

All these items need to be addressed when planning for new roads as well as when operating and maintaining existing roads in a changing climate with increasing transport needs and all items thereby relate more, or less, directly to road technology.

5.1.3 State-of-the-art

5.1.3.1 Health

Current research focuses on the intersection of public health and transport including topics such as detrimental effect on health from air pollution and noise, or from different potentially toxic materials as well as positive health aspects related to active transport.

Research on air pollution related to road construction and road surfaces includes Sources, Emissions and Health impacts. Many of the Swedish research groups working in the area of air pollution are considered world leading. Current research includes investigations how the green transition will result in the use of new materials for road construction and how changes in the vehicle fleet that are expected to affect the emissions of pollutants to air and to water. The impact of hazardous materials is part of the general global research efforts into biological responses to all types of substances in order to put regulations on the use of such that negatively affect public health.

Efforts to use certain road surface types to reduce noise emissions are common, focusing on smaller aggregate sizes to reduce surface roughness. A few examples of using porous road surface types to reduce noise generation and radiation can be found and some have been successful in reducing the overall noise emissions. Research into combinations of aggregate size, binder composition, porosity and new materials is currently in its emergent phase. The use of porous road surfaces can also reduce negative health effects by binding particulate matter in the pores and thus avoid resuspension, but the pores will then become clogged which conflicts with the noise reducing effect. Research on the optimised use and maintenance of porous road surfaces for reduced noise and air pollution is in emerging.

The road infrastructure also influences the accessibility, comfort and safety of active road users. There are models to calculate the health benefits of increased cycling and walking. Also, the benefits from a decrease in the number of killed and injured in traffic can be calculated. Effects of infrastructure-related measures on active transport is an expanding research area where some important research activities are found in The Netherlands and Denmark in addition to Sweden.

5.1.3.2 Environment

There is a long history of research on the environmental impact of transport that has resulted in extensive changes such as the ban on leaded fuel, regulated levels of sulphur in diesel and mandatory use of a catalytic converter in the exhaust system. Current research focuses on issues like how road traffic and increased urbanization contribute to the pollution of the air, soil, and surface water through inadequate stormwater management and inadequate control of pollutants such as nanoparticles, microplastics, tyre and road wear particles, metals, and organic pollutants. The current road runoff treatment systems are not designed to effectively remove pollutants. The Swedish Transport Administration has ~200 road runoff ponds connected to the road bodies of which many are incorrectly constructed and poorly maintained. Important to note is that tyre and road wear microplastic particles are the largest emission sources of microplastics in Sweden. Increased use of electric vehicles with heavy batteries and lightweight polymeric and composite chassis and body materials will increase the emissions of microplastics and new types of pollutants even more. These new pollutants, together with already existing types, are emitted to both the air, to the road runoff and to the roadside soil and ditches. The pollutants may be further resuspended to the air and deposited in the surrounding environment and transported to the groundwater and through untreated road runoff to receiving water. New research focuses on roads that can effectively remove the surface road runoff and retain the pollutants within the road body for new road constructions or in the nearby road ditches for existing roads. This research includes development of innovative treatment methods to degrade or wash out pollutants and recover metals and plastics from contaminated road and roadside materials ensuring the reuse of road materials. Sustainable urban drainage solutions such as permeable pavement, bioswales, bioretention filters and stormwater ponds, which efficiently manage both high flows of water and decrease runoff-related environmental impacts are of high importance. Further, existing treatment facilities for runoff quality treatment (e.g. the Swedish Transport Administration's ~200 stormwater ponds) need to be maintained to facilitate function over time and remove accumulated sediment/pollution from the facilities. This involves large costs, questions concerning sediment quality/disposal, and maintenance methods. Today, maintenance is often lacking or insufficient. Here, needs for further research are identified. Research into nature-based solutions for road runoff pollution treatment also has an impact on biodiversity which is a prioritized area of research within the EU. It is well known within the research community that biodiversity is crucial for the survival of pollinating insects and in extension for the ability to maintain agricultural productivity.

5.1.3.3 Climate

Research into climate-related issues related to road technology comprises both climate mitigation, i.e. reducing greenhouse gases, and increasingly also climate change adaptation, i.e. adapting to new circumstances due to a changed climate.

To effectively address climate mitigation in the road sector, a comprehensive approach has been implemented over the past years. For instance, by integrating sustainable materials like recycled asphalt and bio-based binders, reducing reliance on fossil fuels. Further, employing advanced construction techniques, such as warm mix asphalt, to lower energy consumption and emissions during production. In addition, implementing stringent pavement design standards that prioritize durability and longevity, reduces the need for frequent repairs and associated emissions. Establish rigorous monitoring systems for road emissions and environmental performance, enabling data-driven decision-making. However, these actions require a step forward in a unified way to accomplish the mission of climate mitigation.

Compared to physical planning in general, road technology is currently lagging regarding climate change adaptation. Roads are subject to the effects of climate change and extreme weather events which entails large societal costs and environmental damages when they get damaged. Impacts of climate change include rising average temperature and sea level, more extensive rainfall, flooding, erosion, drought, as well as changes in humidity, groundwater levels and frost conditions. Existing roads and transport infrastructure are designed for yesterday's climate and since infrastructure investments are long-term, they risk being maladapted to the effects of a changing climate over time. There are some studies on climate change adaptation of transport infrastructure, such as on vulnerability assessments, road design, and planning documents, and a few on climate change impact on road construction. However, there is a need to better understand the effects and consequences of climate change and extreme weather events on the durability, robustness, resilience and environmental impacts of road construction, and to explore solutions to address these effects and consequences. Climate adaptation of road infrastructure is needed to ensure safe and reliable transportation of people and goods. If done properly, climate adaptation can offer a window of opportunity to simultaneously reduce the contribution to climate change and environmental impact.

Hazards can stem from natural, anthropogenic, or socio-natural sources. Furthermore, they can manifest as standalone events or cascade into multiple hazards. When a hazard disrupts the functioning of a community or society at any level, it transforms into a disaster. While natural disasters may originate outside of road embankments, they frequently impact road infrastructure. Thus, roads must be designed, constructed, and maintained with consideration for potential disasters like floods, landslides, erosion, storm surges, storms, forest fires, heat waves, and sudden icing. Given the exacerbating effect of climate change on the likelihood of natural hazards and disasters, it's crucial to integrate resilience measures into road infrastructure planning and construction. Recent events in Sweden highlight the inadequacy of current roads in mitigating such risks.

Consequently, planning documents as well as technical guidance may require updating and revising to tackle evolving climate conditions and their impacts more effectively.

Other fields intertwined with climate change adaptation encompass risk and crisis management, alongside spatial planning and societal development. This implies the possibility of synergistic benefits.

5.1.4 Research agenda

5.1.4.1 Health

5.1.4.1.1 Air pollution

Even though air quality in many regions has improved, airborne particles (PM) pose a significant health risk in urban regions, leading to premature deaths. Furthermore, it adversely impacts quality of life by causing a range of pollution-related diseases. Thus, there is still an urgent need to further lower the levels of PM in areas where people are exposed to high concentrations. Particulate matter in air has many different origins, including both natural sources (e.g. sea spray, weathering, and secondary organic particles from forests) and anthropogenic sources (e.g. emissions from industrial processes and traffic). Emissions related to traffic are typically divided into exhaust particles and non-exhaust particles (e.g. wear particles from tires, brakes, road surfaces, and road dust suspension). While emissions related to traffic exhaust are decreasing, other sources of PM and problematic areas are emerging where more knowledge is needed. Examples of such areas, and of research questions to investigate:

- Non-exhaust particles are already today dominating road traffic PM emissions and will increase further with increasing traffic and with the ongoing electrification of the vehicle park as electric vehicles (with high torques and weights, wear more on tyres and road surface).
- Tunnels and other underground environments are becoming increasingly common, where acceptable air quality needs to be met.
- The use of recycled materials is increasing in road constructions, the properties of the emitted particles from construction and use might be altered.
- Exposure and health assessments of road-related PM
- Strategies to mitigate PM levels and quantified effects on air quality resulting in health benefits of mitigating road traffic emissions

Projects of relevance for air pollution could encompass a broad spectrum of studies, including PM emissions stemming from the tyre-road surface interaction, emissions from materials during construction or maintenance, or the influence of road surface properties on emissions.

5.1.4.1.2 Noise

Noise from road traffic is an increasing health hazard, and roughly as many individuals die prematurely from noise-related health issues as from being involved in traffic accidents each year in Sweden. The main source of road traffic noise is the interaction of vehicle tyres and the road surface. Several mechanisms are involved in the generation of tyre-road noise, and these are related to different aspects of pavement design. The Transport Administration maintain a database of a large number of properties describing the condition of road surfaces in the different regions of Sweden. There is a need for research into road surface properties that affect noise levels as well as into tools for predicting how future traffic and climate scenarios affect noise. Topics of future research include:

- How will increased precipitation due to climate change affect the yearly average noise levels due to road surface moisture?
- Relating road surface properties to the different noise-generating mechanisms, taking into account trends in vehicle and tyre development.
- Secondary effects such as the need for large aggregate size to limit wear from studded tyres and increased amounts of water in the contact between tyres and road due to rutting from studded tyres and increased precipitation due to climate change.
- Developing models for predicting noise generation in new road surface types using new materials and other innovative aspects.

5.1.4.1.3 Active transport

In general, research on the effects of infrastructure-related measures on active transport needs to be expanded. This includes for example effects on comfort, safety, travel time and increased cycling and walking, as well as cyclists' and pedestrians' exposure to noise and air pollution. Topics for future research include:

- Define appropriate requirements for design, construction, maintenance, and operation of road infrastructure assets to meet the targets of increased active transport and a reduced number of injured cyclists and pedestrians
- Structural design principles and maintenance management systems that meet the specific challenges of infrastructure for active transport
- Winter maintenance methods and strategies
- How to promote increased walking and cycling with higher levels of safety
- Methods and indicators to assess the quality of specific infrastructure for active transport

5.1.4.2 Environment

5.1.4.2.1 Water and soil pollution

Roads and vehicular traffic are major sources of a cocktail of pollutants which are spread via road runoff and are possibly the largest sources of pollution in urban areas. Both asphalt and vehicles contain many chemical substances that can be harmful to humans and the environment. They are released by exhaust emissions, vehicle wear and corrosion, by wear and tear of tyres, road surfaces and brake pads, and by leakage of various fluids from vehicles. In addition, (winter) road maintenance contributes with particles (sand and grit) and salt from anti-skidding and de-icing, which can be considered pollutants in themselves, but also affect how other chemical substances are immobilised or dispersed further into the environment. Large amounts of pollutants and particles from roads are transported to the air, soil and, with road runoff, to receiving waters. However, only a few percent of the stormwater generated in the urban environment is treated, and the road runoff treatment systems that exist along rural roads are not designed to effectively remove pollutants. In addition, large amounts of the pollutants from traffic environments are emitted to the roadside swales and ditches with high risks of being further transported to the groundwater. When roads are to be rebuilt, the deposition of roadside soil containing high concentrations of pollutants will be expensive, and there will be a demand for innovative treatment methods to degrade and wash out pollutants and recover metals and plastics from the contaminated road and roadside materials. More knowledge is needed, and important research questions are:

- How can changes in the vehicle fleet, road maintenance (snow plogging, salting, gravelling, street sweeping), and climate impact (drought vs intense rainfall) affect the release of emerging pollutants and particles?
- To which extent and what are controlling the processes for pollutants and particles to occur, accumulate, be distributed and/or immobilise in new road constructions, permeable asphalt surfaces, ditches, bioswales and other sustainable urban drainage solutions?
- How can the dewatering system and the road runoff drainage systems be developed to take care of larger amounts of water and at the same time treat the pollutants more effectively in existing roads?
- How could the roadside ditches be developed to become more efficient in the removal, retention, and recovery of pollutants by adding, for example, sorption materials such as biochar and plants?
- How can new types of roads be designed that effectively dewater the surface road runoff during intense rains and effectively remove and retain the pollutants within the road body or nearby road ditches?
- How are existing and new road runoff treatment facilities (e.g. bioswales, sedimentation ponds, bioretention filters, wetlands) to be maintained?

5.1.4.2.2 Biodiversity

As more ecosystem services are being developed for the road zone the choice of plants from a functional perspective, such as their ability to retain water in order to delay or distribute the road runoff flow, the effect on biodiversity needs to be considered within that context. Also, there are already invasive species of plants that are favoured by the prevailing conditions in ditches and by the maintenance such as repeated mowing, and there may be a conflict of interests between biodiversity and the construction and the maintenance of the roadside area.

5.1.4.3 Climate

5.1.4.3.1 Climate mitigation

Addressing climate mitigation in the road sector necessitates a holistic and collaborative approach. Research plays a pivotal role in providing the evidence base for sustainable practices, influencing policy decisions, and driving innovation. The outlined actions and corresponding research contributions aim to not only mitigate the environmental impact of roads but also create a resilient, efficient, and sustainable road infrastructure for the future. Research on climate mitigation is closely linked to the research area Sustainable and resource effective roads, for example research on circular economy principles to encourage the reuse and recycling of road construction materials.

The climate mitigation research area includes for example:

- Improve knowledge and material innovation to reduce carbon footprints, enhance durability, and improve performance, as well as well as to develop materials that can be more effectively recycled.
- Development of advanced construction techniques to reduce energy consumption, broaden adoption and improve efficiency.
- Integration of permeable material to enhance water management, reduce runoff, and mitigate environmental impacts and study the effectiveness of diverse climates and soil conditions for optimal design recommendations.
- Improve knowledge and integration of green infrastructure elements, such as roadside vegetation and noise barriers, to enhance environmental benefits. Explore the ecological impact of green infrastructure on biodiversity, air and water quality, and local ecosystems.

5.1.4.3.2 Climate change adaptation

Today’s roads are not planned, designed or maintained for the changed climate we are experiencing, and technical guidance documents are developed for a climate that no longer applies. Research on future impact factors is needed for a resilient road design and maintenance that can cope with the effects of ongoing climate change and exacerbating extreme weather situations. Since not many new roads will be built compared to the number of existing roads, there is a need for knowledge, methodology and technological improvement on maintaining the existing road network. New policy documents are needed as part of a practical implementation strategy to upgrade and refine the maintenance of existing infrastructure to cope with climate change and meet environmental targets such as the national environmental objectives and the global goals for sustainable development.

Hence, the climate adaptation research area focuses on understanding the impact of climate change and extreme weather events on road construction. It aims to increase knowledge about how climate change and extreme weather events affect for example road durability, subsidence, wear and tear, pollution dispersion, and not the least safety. The research area seeks solutions to manage the effects of climate change with the overall aim of achieving resilient roads.

The research area includes for example:

- Improved knowledge of how the increase in mean temperature affects road construction and road infrastructure in the country. As the mean temperature gradually rises, it means that the climate zones shift to which road technology needs to be adapted.
- Improved knowledge of how climate change and extreme weather events affect roads, bridges, bike lanes etc. in rural, peri-urban and urban areas. Ongoing climate change may affect the frequency, intensity, and duration of extreme weather events and natural hazards for which current and planned roads are not designed.
- Improved knowledge on climate change on water, air, noise and soil pollution dispersion from roads, including measures.
- Novel methods in digitalization and using AI and machine learning as support for more dynamic vulnerability identification and susceptibility forecasting as a basis for measures.
- Development of resilient climate change adaptation solutions and adaptation pathways. Solutions may include nature-based solutions as well as technology, material and design improvements preferably keeping climate mitigation in mind, but also strategic adaptation solutions. Adaptation pathways may offer flexibility over time as a way e.g., to manage uncertainties.
- Improved methodologies to assess costs and benefits with emphasis on sustainability and future generations. Holistic perspectives are sought.
- Development of effective, smart and flexible preparedness solutions to manage extreme situations and be prepared for the accountable.

5.2 Assessment of road condition and prediction of its evolution

5.2.1 Introduction

Ensuring that assessment of present road condition and prediction of road condition evolution are accurate is vital for development of sustainable, efficient and safe road infrastructure. Amidst increasing transportation demands, limited budgets, and escalating costs, there is a clear need for innovative solutions, exploring new approaches to improve structural and material designs, construction techniques, and maintenance strategies. Moreover, optimizing resource utilization demands the development of innovative materials and construction methods, emphasizing improved durability, energy efficiency, as well as recycling and re-use practices.

A critical precursor to implementing new technical solutions is the availability of tools for quantitatively understanding how innovations impact the functional and technical lifespans of roads. This necessitates mechanics-based modelling tools for simulating the *evolution of road condition* from both technical and functional standpoints. Additionally, to ensure the availability of data for these models, objective and reliable methods for *measuring road condition* must be established. Accordingly, this research area is divided into two sub-areas: *measurement and assessment of road condition* and simulating the evolution of *road condition*.

Sub-area measurement and assessment of road condition focuses on developing and implementing new techniques to quantify the state of roads in terms of both their functional and technical characteristics. There is a particular emphasis on the necessity to establish methods for objectively, non-destructively, economically, and promptly monitoring and assessing condition of the roads.

Sub-area *prediction of the evolution of road condition* deals with creating and implementing tools for quantitatively predicting the structural and functional evolution of roads in the field. The primary focus is on developing science-based approaches to understand and capture long-term degradation processes at both material and structural levels, considering the combined effects of climatic (e.g. water and frost cycles, air, solar radiation and chemical agents exposure, etc.) and traffic loads. Additionally, new tools addressing the mechanical reliability and facilitating probabilistic descriptions of degradation processes are needed.

The overarching goal of this research area is to enhance understanding of the main mechanisms driving road degradation and to contribute to identifying optimal mitigation measures. Furthermore, the intention is to provide improved comprehension and engineering decision support for adapting road infrastructure to changing traffic characteristics and climatic conditions.

5.2.2 The Swedish Transport Administrations needs

In a recent report by the Swedish Transport Administration, several areas requiring new knowledge and further expertise development have been identified to ensure the safe and efficient advancement of road infrastructure. The development areas within the Transport Administration, linked to the "*Assessment of road condition and prediction of its evolution"* research domain, can be broadly categorized into three areas as follows.

1. *Enhancing the understanding of the degradation of road materials.* There is a pressing need for models and experimental tools to measure, assess and predict the evolution of damage in road materials and coupling it with the technical and functional condition of roads. Ensuring the adaptability of these tools to novel materials is particularly crucial. Numerous new road material concepts are emerging to extend road service life, reduce environmental impact, and enhance road functionality beyond transportation. Examples include alternative binder types (such as bio-binders, polymer and rubber modified binders, recycled binder, etc.), and alternative asphalt mixture types (e.g., noise-reducing asphalt, reclaimed asphalt, self-healing asphalt, fibre reinforced and hybrid materials, etc.). Emphasis in experimental research lies in measuring fundamental material properties controlling damage accumulation and their functional properties, with a focus on non-destructive measurement techniques.

2. *Measurement and modelling of structural condition of roads*. Accurate quantitative description of the structural condition of roads is essential for predicting remaining service life and understanding the factors driving the degradation of roads. This is particularly crucial as a significant portion of ongoing and future road construction projects in Sweden will involve reinforcement and capacity upgrading, rather than building new roads. Methods for measuring the structural condition of existing roads should enable objective and rational measurements capturing parameters controlling deterioration of roads. Moreover, objective methods for assessing the condition of gravel roads are currently lacking and need development.

3. *Understanding the effects of changing traffic and environmental loads*. The emergence of various vehicle technologies aimed at reducing economic and environmental costs are altering traffic loads on pavements and the effects of those changes are not fully understood. High-capacity transport, electric vehicles, semi- and fully autonomous driving, as well as new tire designs with decreased rolling and increased wear resistances, as well as planned increases in the axle loads are just few examples in this context. The impact of the climate change on roads can be categorized into two main aspects: (1) long-term effects from shifting weather patterns, which influence service temperatures and water levels in roads; (2) short-term effects from extreme weather events, such as floods, hurricanes, heatwaves, etc. Condition evolution models capable of taking into account the effects of changing climatic conditions are needed to accurately assess infrastructure vulnerabilities and to effectively allocate the resources.

5.2.3 State of the art

The current state of road engineering heavily relies on empirical and semi-empirical characterization methods and prediction tools, hindering quantitative estimation of the improvements in material properties and their effect on the material and structural service life. Recent advancements in the modelling and experimental characterization of materials aim to establish links between the fundamental hydro-mechanical, physical, and chemical properties of the materials and their performance in real-world conditions. Another active area of research involves understanding and quantifying the impact of the volumetric composition of the materials and the effect of the properties of the material components on the overall performance.

Recent developments in computational and experimental mechanics, encompassing multi-physical and multi-scale modelling approaches along with multi-scale and non-destructive test methods serve as important enablers in this context. Despite significant progress, several critical questions remain unanswered. Amongst them, evaluating and predicting the long-term degradation processes in the field under the combined action of traffic and environmental loads presents particularly challenging issues.

The vehicle-road interaction has received considerable attention in recent modelling, experimental, and field investigations. The interest in this topic stems from two primary reasons: firstly, understanding the dynamics of vehicle-road interaction is crucial for assessing dynamic traffic loads applied to pavements, and secondly, it enables the quantification of functional pavement properties such as friction, noise, and rolling resistance. Specifically, the mechanisms governing tire-road friction are not fully understood, and measuring or estimating friction at traffic speeds remains an open question. This topic gains significance in light of new vehicle types introduced onto road networks, including electrified and semi-autonomous transports.

The active research area of employing sensors and advanced structural health monitoring systems aims to gain insights into the structural and functional conditions of roads, as well as to enable proactive maintenance strategies. To achieve this, there is a pressing need for optimal data management, processing, and interpretation procedures, alongside the development of condition evolution models capable of utilizing data obtained from pavement monitoring systems.

5.2.4 Research agenda

Research in this thematic area is categorized into several key topics:

1. **Mechanics of road materials.** This area emphasizes the development and experimental validation of modelling approaches to understand the mechanical behaviour and degradation of road materials across different length scales. There is a critical need for robust computational tools capable of capturing the long-term effects of cyclic mechanical and environmental loads on material degradation. The main challenges which need to be addressed in this area is the need to improve the quantitative understanding of the mechanical degradation of road materials under combined action of cyclic mechanical and environmental loads. In this context both low and high-cycle fatigue is important, in order to quantify the material degradation processes under both standard service and extreme loads. Furthermore, reducing the degree of empiricism in the material experimental characterization and in their degradation modelling is crucial to be able to facilitate of implementation of new materials into road construction. To expedite the development of new materials aimed at reducing environmental impact of road construction and extending the service life and functionality of roads, the integration of new mechanics-based tools for material design is crucial. New experimental and modelling tools enabling quantitative understanding of the material degradation processes across various length scales and their relationship with the fundamental material properties are needed.

2. **Short-term effect of water, temperature and load characteristics on road structures and road condition**. Research in this domain focuses on advancing experimental and numerical tools to evaluate the structural response of roads, especially concerning new load cases due to a changing climate and evolving vehicle types. Additionally, there is a demand for new non-

destructive methods for monitoring road conditions and utilizing data available in pavement management systems for the prediction of road maintenance needs. A key challenge in this domain is enhancing the understanding of coupled thermo-hydro-mechanical processes within road structures and their impact on road deterioration. There is a pressing need for improved models and experimental methods to quantify the environmental effects on asphalt layer deterioration, thereby enhancing the quantitative understanding of thermal cracking, aging, and moisture damage processes, and their repercussions on the structural and functional properties of roads. Furthermore, there is a need for enhanced quantitative understanding of pavement response to heavy traffic loads, especially concerning emerging vehicle types and low-volume road networks. Better experimental tools and models for assessing the roads bearing capacity based on the field measurements are also essential for predicting the effect of new traffic and climate load cases on the road network. The understanding of the influence of water and temperature on the road's unbound layers and subgrade needs to be improved. This entails experimental characterization and modelling of moisture content effects, freezing and thawing impacts on road bearing capacity, and degradation. Additionally, there is a necessity for improved models to address frost heave phenomena and to quantify its effect on roads.

3. **Long-term evolution of road condition**. This topic focuses on advancing the development, validation, and implementation of models for the evolution of road condition throughout its service life. Road condition encompasses both the structural aspects, such as bearing capacity, fatigue accumulation, rutting, and surface distress, as well as the functional aspects, including roughness and friction. Further research is necessary to establish models capable of predicting road condition evolution based on road's measured structural and functional conditions. An important challenge in this area is effectively utilizing the wealth of data available in pavement management systems to calibrate and validate new pavement design and performance prediction procedures as well as to enable data-driven decision support for pavement maintenance and reinforcement. Another important challenge is evaluating the effectiveness of various methods for restoring pavement surface functionality, especially considering the safety implications associated with road conditions. In order to optimize further road construction and maintenance, it is essential to develop and validate condition evolution models that incorporate a probabilistic description of degradation processes and address reliability concerns. This research topic also involves scaling up recent developments in understanding degradation processes at both the material and structural levels, enabling the prediction of road condition evolution over longer time scales.

4. **Vehicle-road interaction.** The objective of this topic is to assess the impact of current and future vehicle and component designs on roads, as well as to explore how road properties, especially road surface characteristics, influence safety, comfort, vehicle and road wear, and energy consumption. Key challenges in this area include advancing methods for road surface monitoring using instrumented vehicle measurements. These methods should enable efficient and cost-effective network-level measurement of objective parameters controlling vehicle-road interaction. Additionally, there is a need to develop models that accurately capture dynamic load cases, including dynamic axle loads as well as vertical and tangential contact tractions at the tire-pavement interface, which arise during vehicle-road interaction. While considerable progress has been made in this field, vehicle-road interaction models that encompass vehicle three-dimensional dynamic characteristics and the impact of tire parameters and driving scenarios are still lacking. Another crucial challenge in this area is to develop tools that quantify the influence of road surface parameters on the functional properties of roads, including adequate tire-pavement friction, rolling resistance, and ride comfort, while also predicting the evolution of these parameters throughout the road's service life.

5.3 Sustainable and resource effective roads

5.3.1 Introduction

Road constructions require large volumes of construction materials that often consist of virgin materials such as crushed rock. Simultaneously these types of constructions can generate large volumes of excavation masses. The assessment of the materials used in the construction is done using testing methods developed for natural aggregates and is based on material properties and not the actual functional requirements the road require.

The research area *Sustainable and resource effective roads* has been divided into five subareas with the overarching goal to create the conditions that excavated masses from road constructions, other projects, and other waste material streams shall, after potential upgrade, fulfil the given functional requirements and also be usable in road constructions. To identify resources and assess the masses suitability for usage is the first step. Furthermore, effective treatment and production methods to produce suitable materials, and tools for assessing the environmental load that the material has compared to the traditional virgin material is required. Tools to assess the environmental benefits, sustainability, and circularity is required to be able to assess circular masses in a broader perspective. Finally, a base for possibilities to change current regulations to create incitements for increased use of circular materials which also could make actors ready to treat and keep stock of material in sufficient volumes.

The five identified subareas are:

- Materials: Inventory and characterisation of material resources for road construction. Methods for mapping and characterisation of resources and quality assurance of the materials technical performance to create the conditions for a future circular material handling.
- Technology and production: Energy effective and climate-smart technology and production. Treatment and production methods to enable a sustainable mass handling.
- Resource efficiency: Evaluation of circularity and sustainability for road construction purposes. Tools to ensure the environmental benefit and sustainability of the circular masses.
- Governance: Governance for increased recycling, circularity, and resource and energy efficiency. Identification of governance that facilitates for storage and use of upgraded masses.

5.3.2 The Swedish Transport Administrations needs

This research area has the following overarching knowledge needs at the Swedish Transport Administration:

- Increased knowledge and abilities for a resource effective and effective production as well as developed processes that increase the proportion of circular materials and better use of local materials and conditions (road body).
- Increased knowledge and abilities for a resource effective and effective production as well as developed processes that increase the proportion of circular materials and reduce the climate emissions down to zero (pavements, road body).
- Evaluation of current present material in the construction and its properties as road construction material for recycling in the reconstructed/remodelled construction (road body)
- Information/evidence to develop requirements and regulations for planning and technical design with recycled and industrially produced materials and thereby enable improved resource usage. Local materials or materials in existing roads can, for example, be used during reconstruction/remodelling (road body, gravel roads)
- Increased ability to optimise maintenance from a life cycle perspective.

5.3.3 State of the art

The current handling of earth and excavation masses are in large extent linear which leads to increasingly longer transports, increased withdrawal of natural resources, and constant need to develop new areas for deposition resulting in large and increasing emissions of carbon dioxide. During 2020 the European commission released the action plan for a circular economy which is a central component in the “EU Green Deal”. The action plan aims to reduce the European markets dependence of source materials by keeping the values of material, products, and resources for as long as possible and to minimise the volumes of waste generated. Construction and constructions are lifted as an important sector against the background of the sectors total resource needs, the emissions of greenhouse gasses from material extraction and manufacturing of construction produces, and the waste generation of the sector.

The EU Soil Strategy for 2030 was launched in 2021 and has been followed by a proposal for a new directive for soil during 2023. The main focus is on healthy soil, but it also links to a circular economy and handling of excavated masses. Specifically, the strategy outlines that the EU commissions intends to: 1) investigate the flows of excavated soil that are generated, processed, and reuse within EU and to establish guideline values for the market situation in the member states by the latest 2023 in order to gain a complete picture of the situation within the EU; and 2) assess the need of and potential of legally binding regulations regarding a “passport for excavated soil” and provide guidance, based on the member states experiences, for the implementation of such a system. The passport should reflect the excavated soils quantity and quality to ensure that it is transported, treated, or are reused in a safe way elsewhere.

However, excavation masses are seldom used as construction material due to uncertain technical properties. While aggregates that are produced are controlled and CE-marked using standards, excavation masses are described from a material type perspective (Anläggnings-AMA[1]) and if the masses are polluted or not. Excavation masses and other material flows can be treated and refined to generate a high qualitative fraction in sufficient enough volumes for, for example, a road construction. A sustainable circular handling of excavated masses therefore requires an effective material logistic where the materials are transported to and from a fixed facility for processing/refinement. Obstacles for the use of recycled products, soil, and excavated masses remains since these are considered of lower quality and that the industries prefer to use materials which standards are well known and harmonised. Therefore, quality assurance of the masses together with an effective handling are essential for a sustainable handling of the masses.

The excavated masses generated by the construction/building sector (for example soils, organic soils, clays) are classified as waste in the EU-directive 2008/98/CE and represents still about half of the volume waste generated in Europe. Linear economy “extract, manufacture, and deposit” generates waste while the natural resources decline, which describes the current handling of masses from infrastructure and construction projects all over Europe. Around 1.3 billion tonnes aggregates are extracted yearly to be used as unbound material for constriction of infrastructure with a carbon footprint for aggregate materials estimated to about 8 kg CO_2 per tonne. Even though methods exist for valorisation of alternative materials, most of these are not used today and they still represent 50% of the total volumes of waste generated in Europe, in total over 1 billion tonnes. In many OECD countries is this type of waste the by far largest waste flow.

[1] AMA is the Swedish general material and work descriptions. For more information see AMA för bygg- och anläggningsprojekt | Svensk Byggtjänst (byggtjanst.se)

The total amount of accumulated material (bound and unbound) in the current global transport infrastructure are estimated to 314 [218 – 403] giga tonne for 2021 which corresponds to about 1/3 of the global economy material layers in all constructions, infrastructure and machines. The study has modelled the global material flow for expansion and maintenance to about 8.4 [4.2 – 15.6] giga tonnes per year which amounts to about 10% of the global material resource extraction. The built environment, including transport infrastructure, thereby represents a large reservoir of secondary raw materials and a deepened knowledge is required regarding volumes, quality, location, and time availability of these material layers to be able to support and effective resource recycling.

Based on the current praxis related to reuse of excavated masses in construction projects in France, Norway, Portugal, Slovenia, and Sweden, as well as the most important obstructions to effectively reuse the masses, a number of development areas have been proposed: (1) regulations (harmonisation of management systems, clear and simple guidelines, and a deposition tax); (2) organisational (early planning, determination of the volume soil to be used for reuse, and design of contracts to promote reuse); (3) logistical (digital systems and establishment of market); and (4) quality (ensuring that the soil is compatible with a new application). In the area of pollutant soils there are tangible potential socioeconomic benefits with increased recycling, where a number of possible measures of varying character includes: (i) better adaptation of the requirements on the soil masses environmental quality towards what the usage in the area require; (ii) lowered administration required to be allowed to recycle masses; (iii) increase the allowed storage time before deposition; (iv) increase the requirements for treatment of masses before deposition; (v) introduce tax on masses that are possible to pretreat before deposition; (vi) introduce deposition tax and increase the deposition fee for inert soil masses; (vii) increased treatment at location (in-situ and ex-situ); (viii) introduce more innovative procurement and choices between contracts related to Design-Bid-Build (in Swedish: utförandeentreprenad) and Design-Build (in Swedish: totalentreprenad); (ix) calculate key figures or recycling of polluted soil masses; and (x) develop a standardised and more well founded classification of different masses environmental and technical potential for recycling. The literature also asks for clearer incitements, indicators, and key figures, and accounting tools and guiding materials that masses shall be recycled in as high degree as theoretical possible and as high up in the chain of values as possible.

Current validation methods are specifically for some types of material, from a given region and context, and do not give much space for new materials. As noted by the positional document of the European Construction Technology Platform, a reliable assessment of the long-term performance is required in the construction phase when the knowledge on the long-term function is, in many cases, limited. New knowledge is therefore important to obtain a sustainable built environment in accordance with the EUs New Circular Economy Action Plan for 2030.

5.3.4 Research agenda

5.3.4.1 Material

5.3.4.1.1 Characterisation of alternative and local recycled materials

Increased use of alternative and local materials in, for example roads, reduce the use of virgin materials and gives the conditions for a circular economy and better resource utilisation. Alternative materials include: excavated earth masses, cement concrete, asphalt concrete, MSWI-bottom ash (Municipal Solid Waste Incinerator), rock from tunnel construction, and other recycled materials that can be used on road construction. Local material can for example be masses occurring locally during reconstruction or material that is produced during blasting or excavation during construction of roads.

In order to use these materials safely, quality and material properties must be assessed. The function needs to be ensured since these materials sometimes has difficulties to fulfil the requirements in AMA[2] and by the Swedish Transport Administration. Therefore, it is of importance to find new methods and ways to secure that the materials functions in an appropriate manner. This can be regarding:

- Sampling and assessment of material technical properties, their environmental properties, and assessment and handling of uncertainties.
- Treatment methods to improve for example alternative materials, remove unwanted fractions, pollutants, increased strength, and handle invasive species.
- Quality assurance so that materials can be handled as a product.
- Transition from requirements on material often disqualifying alternative materials to functional requirements on the complete road construction.
- The connection between geotechnics and road technology – does alternative materials give other conditions/prerequisites for the geotechnical assessments?

It is important for alternative and locally recycled materials to be easily used and that they then be assess with relevant laboratory testing adapted to the materials ensuring that their functional and long-time properties can be determined. This should be possible to link to technical design models, sustainability, climate impact, and area of usage (traffic loading). The function can be measured on finished constructions. Examples on such functional properties are: rutting development over time, resistance against ground frost, stiffness, and long-time properties. Environmental properties mist also be possible to assess, for example leeching of substances (including pollutants of emerging concern), substance transport with water and accumulation of substances from runoff within the road area (for instance slopes), wear particles and particle bound pollutants.

The content in this chapter is clearly linked to the research areas *Assessment of road condition and prediction of its evolution* and *Health, environment, and climate effects*. Furthermore, it is also linked to the Swedish Transport Administrations knowledge fields *Road construction and road body*, *Pavement, Gravel roads* and *Road equipment*.

5.3.4.1.2 Inventory of material resources

Achieving resource effective roads in all stages of the production and maintenance of roads is built upon handling material resources as sustainable and effective as possible and with a circular perspective. In a circular economy shall the flow of materials ending up in deposition be reduced and preferably stopped altogether and instead steer the flow so that the materials are kept within the circular system. Alternative materials from different sectors within society, as a part of this, can from an early stage be considered as material resources, which also extends to the current material within the road network and road constructions today. To secure that alternative material in society and material in the current road network is seen as a resource that can be used when they are freed during renovations or reconstruction, a unified resource database is needed, in essence a system into which different types of resources can be reported and classified. To construct such a system, it is required to create inventories of alternative materials within different societal sectors and in the present roads. Fo further increases the possibilities to understand current roads as a future material resource, development may be required to be linked to how roads should be designed and documented to facilitate future recycling of the material resource, for instance through the development of digital twins. Systems for quality assurance of information in the resource database may also be required to develop. Material used for winter

[2] AMA is the Swedish general material and work descriptions. For more information see [AMA för bygg- och anläggningsprojekt | Svensk Byggtjänst (byggtjanst.se)]

operation and maintenance such as traction sand require systems to be able to recycle after finished winter season, though for instance purification from pollutants and by sorting.

The content in this chapter is clearly linked to the research areas *Digitalisation, automation, electrification for a modern road infrastructure, Assessment of road condition and prediction of its evolution* and *Health, environment, and climate effects*. Furthermore, it is also linked to the Swedish Transport Administrations knowledge fields *Road construction and road body*, *Pavement, Gravel roads* and *Road equipment*.

5.3.4.2 Technology and production

5.3.4.2.1 Energy efficient and climate-smart technology and production

The creation sustainable and resource effective roads require integrated strategies for energy effective and climate-smart technology and production. To secure that recycling and the recycling process for roads is energy effective and has a low climate and environmental impact, it is important to implement strategies and solutions that reduce the energy consumption, increase the energy effectiveness, and promotes a sustainable energy transition. This includes:

- Solutions that reduce the energy consumption, for instance by using new methods for recycling, and recycling that require less energy compared to current methods.
- Solutions that increase the energy effectivity, for instance by using energy effective technologies and processes during crushing, sorting, and processing of recycled materials.
- A sustainable energy transition for increased recycling, for instance by using recycled sustainable energy sources during recycling and the recycling process and by promote the use of electrical or fuel-efficient vehicles work machines.

5.3.4.2.2 Production of construction materials

Development and effectivization of methods for producing road construction materials from relevant material flows such as excavation masses or waste. Examples on methods and processes that may be used for upgrading of masses are sorting through sieving and soil washing, as well as material processing through crushing and stabilisation.

5.3.4.2.3 Material logistics

A circular masse handling is in many cases a more complicated transport chain of materials that needs to be upgraded and products that need to be kept on storage and delivered to a certain project at a certain time. A sustainable masse handling therefore requires a good material logistic for transportation to decrease fuel consumption and emissions of greenhouse gasses. Important components in the logistical chain are to identify/value resources compared to intended usage and a reliable information handling. Strategical aspects are for example localisation of relocation and intermediate storage sites, locations for treatment facilities, and selections between stationary and mobile solutions.

5.3.4.2.4 Quality insurance of circular materials

Different raw materials, material types, and origins leads to products with different properties which needs to be quality assured in order to reach the market. Methods and standards for sampling and control of granular materials in piles, and identification/evaluation of resources compared to intended use requires development.

The content in this chapter is clearly linked to the research areas *Digitalisation, automation, electrification for a modern road infrastructure,* and *Health, environment, and climate effects*. Furthermore, it is also linked to the Swedish Transport Administrations knowledge fields *Road construction and road body*, *Pavement, Gravel roads, Winter maintenance,* and *Road equipment*.

5.3.4.3 Resource effectiveness

5.3.4.3.1 Evaluation of circularity, sustainability, energy effectiveness, and climate effects

To be able to assess the effects of transitioning towards increased recycling of excavated masses, to use more alternative materials, proceed from new functional requirements, and achieved less transport, less new production of raw materials, and less deposition, different methods and tools which can be used for evaluations need to be developed, tested, and evaluated. Assessment and evaluations of theoretical concepts and terminologies such as circularity, sustainability, socio-economic, energy efficiency, and climate effects can be done in several different ways depending on which starting point is selected. Therefore, it is required to develop and test methods directed towards different types of evaluations, as well as in different stages of a production chain or work process where different amount of information is available in different stages. It may also be of interest to, in detail, evaluate a certain part of chain to better understand what in a process that may be most effective to improve to reach better circularity or sustainability. This subarea deals therefore with the development of methods and tools to evaluate circularity and sustainability of road materials, handling of masses in projects related to maintenance and new construction, road construction and production technical solutions, and to develop end verify climate calculations and quality on data. The basic idea of a circular process is that as little new material as possible should be used at, for example, supporting roads. This can be described as loops where the shortest loop is to maintain current road infrastructure so that the need for new or reconstructed roads are minimised. Where new production or reconstruction still is needed, it is instead of interest to use as much reused or recycled materials as possible. To develop key figures and indicators to measure the degree of sustainability, circularity, and/or resource effectiveness, and investigating during which conditions projects can reach goal values linked to these are also an important knowledge field.

Common methods that are used to assess environmental performance, sustainability, socio-economic aspects, and other aspects, are for instance life cycle assessment (LCA), life cycle cost assessment (LCCA), life cycle profit (LCP), cost benefit analysis (CBA), multi criteria analysis (MCA), climate calculations, and development of different indicators and key figures. During all assessments it is important to clearly define what is intended to be assessed, which theoretical conditions apply, and which system limitations that should be used. To make assessment that also can be used in practice (operational), adaptations of general methods and development of practical tools that can support the evaluations in real projects or project portfolios may be required.

The content in this chapter is clearly linked to the research areas *Digitalisation, automation, electrification for a modern road infrastructure,* and *Health, environment, and climate effects*. Furthermore, it is also linked to the Swedish Transport Administrations knowledge fields *Road construction and road body*, *Pavement, Gravel roads* and *Road equipment*.

5.3.4.4 Governance

5.3.4.4.1 Governance for increased recycling/circularity, increased resource and energy efficiency

In the field of governance, the development areas are on designing regulations and procurement so that these, within the framework of existing legislation, can provide opportunities and incentives to increase recycling, usage of circular materials and circular material management, and resource and energy efficiency.

How can procurement and regulations (e.g. AMA[3] and documents from The Swedish Transport Administration) be adapted to allow higher levels of reuse, alternative materials and local materials. For example, it is stated in the AMA that material of crushed concrete must meet requirements according to

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[3] AMA is the Swedish general material and work descriptions. For more information: AMA för bygg- och anläggningsprojekt | Svensk Byggtjänst (byggtjanst.se)

TDOK 2013:0532 and material of slag from blast furnace must meet requirements according to TDOK 2013:0532. How do the documents contribute to, or hinder, an increased amount of recycled and reused material in road construction. Research in this area can focus on how governing documents and guidelines should be designed so that they contribute to an increased degree of circularity.

Another area of development could be the EU waste directive and how it could be implemented in the maintenance of roads, i.e. in what ways could a higher level in the waste hierarchy be achieved by initially preventing waste, then recycling and reusing and finally avoid landfill as much as possible. Furthermore, in procurement, requirements can be set through technical specifications to achieve an increased degree of sustainability and circularity, for example the sustainability criteria from The National Agency for Public Procurement can be a starting point.

Within the Swedish Public Procurement Act, there are both possibilities and limitations regarding how recycled material can be procured. Knowledge is needed about how technical functional requirements, performance requirements and examination of tenderers can be done within the framework of the principles of equal treatment, non-discrimination, proportionality, transparency and mutual recognition. Furthermore, it needs to be clarified how it is ensured that reused and recycled material meets the functional requirements that apply to investment and maintenance of roads.

The content in this chapter is clearly linked to all the other research areas. Furthermore, it is also linked to the Swedish Transport Administrations knowledge fields *Road construction and road body*, *Pavement, Gravel roads* and *Road equipment*.

5.3.5 Matrix of the research area and the connection to the knowledge fields of the Swedish Transport Administration

	MATERIALS		TECHNOLOGY AND PRODUCTION	RESOURCE EFFICIENCY	GOVERNANCE
	Characterization of alternative and local materials	**Mapping of material resource**	**Energy efficient and climate smart technology and production**	**Evaluation of circularity/sustainability**	**Governance for increased recycling/circularity, resource and energy efficiency**
Road construction and Road Body	- Sampling and characterization of material technical properties, assessment and management of uncertainties - Sampling and characterization of environmental aspects, assessment and management of uncertainties - Sampling methods to evaluate functional requirements - Future requirements – increased load on roads	- Mapping of existing material in roads - Mapping of local material - Establishing a database of material resources - Connect to digital twin?	- Material flows Material logistics (storage/transport/processing) - Methods to improve alternative materials regarding 1) material technical properties and 2) environmental properties - Design of roads for future recycling of materials?	- Of alternative materials for road construction (road body) - Of masses and materials in road construction projects - Assessment of built-in energy, production and extraction of raw materials.	- Procurement and regulations linked to alternative materials for unbound construction materials - Procurement and regulations linked to the handling of masses during road construction - Shifting from material requirements to functional requirements - Capabilities for verification
Pavement	- Sampling and characterization of technical properties of the material, assessment and management of uncertainties - Sampling and characterization of environmental properties, assessment and management of uncertainties. - Sampling methods to evaluate functional requirements	- Mapping of existing material in roads - Mapping of local material - Establishing a database of material resources	- Solutions that reduce energy consumption - Solutions that increase energy efficiency - Sustainable energy transition (for increased recycling) Methods to improve alternative materials regarding 1) material technical properties and 2) environmental properties - Design of roads for future recycling of materials?	- Of alternative materials for road construction (road body) - Of recycling technology for road pavements	- Procurement and regulations linked to alternative materials for pavements - Procurement and regulations linked to handling of pavement materials during road constructions.
Winter operation and	- Traction sanding of roads - Alternative materials for traction sand and de-icing salt	- Recycling of sand, treatment of sand regarding pollution?	- Treatment methods for soils that includes invasive species - Treatment methods in order to better reuse generated masses during maintenance - Development of maintenance processes for increased recycling		
Gravel roads[1]	- Sampling and characterization of technical properties of the material, assessment and management of uncertainties - Sampling and characterization of environmental properties, assessment and management of uncertainties. - Sampling methods to evaluate functional requirements	- Mapping of existing material in roads - Mapping of local material - Establishing a database of material resources	- Treatment methods for soils that includes invasive species - Treatment methods in order to better reuse generated masses during maintenance - Development of maintenance processes for increased recycling - Design of roads for future recycling of materials - Design of road equipment for future recycling	- Of generated masses and materials in maintenance projects	- Upphandlingsformer och regelverk kopplat till hantering av massor vid underhållsprojekt - Procurement and regulations linked to the handling of masses in maintenance projects
Road equipment[2]	- Sampling and characterization of technical properties of the material, assessment and management of uncertainties (?) - Sampling and characterization of environmental properties, assessment and management of uncertainties (?) - Sampling methods to evaluate functional requirements (?)		- Design of self-instructional roads to reduce the need to use road equipment - Treatment methods to improve alternative materials regarding 1) material technical properties and 2) environmental properties	- Of road equipment made from alternative materials	- Procurement and regulations linked to road equipment made from alternative materials

[1] In this case gravel roads refer only to the maintenance perspective. [2] Road equipment refers to equipment that does not have an electric cable. Road equipment also includes road markings.

5.4 Digitalisation, automation, and electrification for a modern road infrastructure

5.4.1 Introduction

We are standing in the middle of the so called “Twin Transition”, indicating a transformation both in terms of green transition towards green energy with no carbon emissions and in terms of a digital transition. The transport sector is a large contributor and will, if succeeding, also be able to mitigate climate-related emissions on a large scale. Modern road technology can, with digital tools, provides a steppingstone towards transforming the road infrastructure and its current methods for construction and maintenance into an emission free sector.

To be successful in this transition it will be important to take on a holistic perspective to include all aspects of the road technology area. This will include both the infrastructure and the road contractor, as well as other stakeholders such as the road owners and road users. Knowledge of short-term and long-term challenges in the road infrastructure will be needed to be able to implement automatization and electrification on such a scale that they can contribute to making Sweden one of the first fossil free welfare states in the world by 2045.

It will be necessary to develop a toolbox for road construction, road body, road surfaces including pavement and gravel as well as roadside equipment based on new knowledge with focus on automatization, digitalization and electrification. Such a toolbox will be based on and include knowledge to sustain availability for everyone including the availability for people and organizations in rural areas. Innovation will be of utmost importance and such innovations will need to consider environmental, economic and functional aspects. Methods to follow-up performance of maintenance measures from life-cycle perspectives will be needed as well as knowledge of pavement management effects in an automated and electrified transport system.

5.4.2 The Swedish Transport Administration needs

5.4.2.1 Short term perspective

The transport sector is transforming both in terms of electrification and digitalization, alongside the progress of automation. This evolution is making it important to ensure that the road infrastructure will keep up with the changes needed to adjust to the new requirements that such a system demands. New ways of collecting information digitally from embedded sensors as well as from sensors used by road users such as information collected from mobile phones, i.e. crowd sourcing creates vast opportunities for research but also challenges with huge amounts of data needing processing. It is important to make sure that the correct data is collected. In the near future it will be important to understand which data is needed to be able to build and manage modern road infrastructure. What ways can and should such data be collected. Which new types of data can be used and which new methods can be used without violating someone’s integrity.

The development of digital tools combining data and methods helping decision making for planning, construction and maintenance of road infrastructure, including how contract design may be adjusted. Data and digitalization can and should be used to increase productivity in construction and maintenance of roads. Research is also needed to understand how to best use digitalization to understand the environmental and economic impacts of the new technology on the transport infrastructure. Development of Digital Twin encapsulating digitalized tools and data in order to monitor/assess the entire life span (planning, construction, use and maintenance) of new road infrastructures is then needed.

Research toward the decarbonization of road construction and maintenance equipment with automated and electrified solutions is required. Furthermore, digital tools able to assess the effect of decarbonization of road construction and maintenance need to be developed in order to ensure a positive environmental and economic impacts of these new technologies on a whole perspective.

Automated transport is an area of research that is coming closer to realization, but there are still a lot of jurisdictions before such a technology can be used in full-scale traffic. On a short time scale it will be more interesting to use automated elements in maintenance actions, which can contribute to efficiencies both in terms of energy and economy.

5.4.2.2 Longer time perspective?

In a short time perspective, new technologies or components will be added to the existing road network but to ensure the objective of a fossil-free fossil free transport infrastructure, the entire system has to be changed. This includes rethinking the entire way of planning, building, using and maintaining the future infrastructures. This can be achieved with the use of knowledge arising from the data collection as well as the digital tools developed for optimizing every stage of the road infrastructure's lifetime. This can result in an appropriate combination of planification, materials, and equipment for a specific new technology in a particular environment.

5.4.3 Relevant knowledge fields?

From the digitalization aspects, digitalization in road engineering encompasses the integration of cutting-edge digital technologies to enhance the planning, design, construction, and maintenance processes of road infrastructure. This paradigm shift leverages big data, the Internet of Things (IoT), and artificial intelligence (AI) to improve road management, safety, and environmental sustainability. It enables precise modelling of road networks, predictive analytics for road networks, real-time infrastructure monitoring, and efficient road management/maintenance, using emerging data. Digital tools can help to facilitate more efficient project execution, higher quality roadways, and adaptive responses to evolving transportation needs, representing a cornerstone in the development of more efficient and sustainable road management, planning and construction.

From the automation/electrification aspects, the interests from Swedish Transport Administration are to quantify the impacts of automated vehicles and electric vehicles (due to changed vehicle weights, traffic patterns/loads etc.) in road systems in terms of deterioration, management and maintenance, and how to prepare the road systems to adapt to the new challenges induced by transportation automation and electrification. Moreover, the integration of automated vehicles and transportation electrification in the future significantly influences road engineering by necessitating advanced infrastructure capable of supporting these new technologies. This includes the development of connected roadways and roadside communication for improved vehicle communication, as well as the establishment of widespread infrastructure for electric vehicles such as electric roads and charging stations.

For the three areas, five dimensions of research are discussed including winter road management, gravel road management, pavement management, construction management and safety for workers.

5.4.4 State of the art

5.4.4.1 Digitalization in Road Engineering

Digitalization in the field of road engineering is leading the way toward more sustainable, efficient, and collaborative design, construction, and management practices. Key technologies such as Building Information Modelling (BIM), Geographic Information Systems (GISs), Big Data analytics, the Internet of Things (IoTs), and Artificial Intelligence (AI) are revolutionizing project lifecycle management, spatial analysis, traffic and infrastructure management, real-time monitoring, and predictive maintenance. Furthermore, the applications of cloud computing, Unmanned Aerial Vehicles (UAVs), and Augmented Reality (AR) in data management, aerial surveillance, and visualization training also show potential. These technologies aim not only to automate analysis and optimize resource use but also to reduce environmental impacts and enhance collaboration among interdisciplinary professionals. The precise environmental impact assessments, efficient road operation management, and the application of advanced data analytics play a crucial role in improving the sustainability of road management, optimizing infrastructure project lifecycle management. Global initiatives like the U.S.'s Infrastructure Investment and Jobs Act (IIJA), the UK's National Highways digital twins project, and Japan's I-Construction strategy highlight the commitment to digitalization for modernizing transportation infrastructure, boosting productivity, and ensuring safety through data-driven decisions.

5.4.4.2 Automation in Road Engineering

Automation in road engineering represents a crucial trend in the evolution of transportation infrastructure today. It includes the application of automated technologies not just in construction processes but also in considering the impacts of Autonomous Vehicles (AVs) on road design, construction, and maintenance. The employment of automated construction equipment and UAVs onsite, alongside the application of 3D printing technology for constructing bridges and road facilities, enhances efficiency, reduces costs, and improves safety. Advances in AV and intelligent transportation systems (ITS) necessitate revised road design standards to meet current and future traffic needs, potentially changing road usage and maintenance strategies. The capability of AVs to recognize road markings, lane widths, and traffic signals may lead to revisions in existing road design standards. The operational characteristics and usage patterns of AVs could modify how roads are used and wear over time, affecting maintenance strategies. These vehicles have the potential to alter traffic flow patterns (e.g., even distribution of AVs across roads) and peak times, impacting not only daily road usage but also the planning for maintenance and upgrades. European governments are encouraged by the European Union to set standards for smart roads and fund pilot projects for digital road construction, involving alliances with private-sector firms to define digitization strategies and partnerships with tech companies for innovative solutions. Companies like Kilgore and ABB Robotics are leading the integration of smart road technologies and sustainable construction practices to streamline operations, employing data analytics for decision-making and predictive maintenance, thereby fostering productivity and infrastructure resilience.

5.4.4.3 Electrification in road engineering

The electrification of road engineering is a key strategy to reduce carbon emissions and enhance sustainability, aligning with global decarbonization efforts to combat climate change. The shift to Electric Vehicles (EVs) and construction equipment is quickening, with an initial emphasis on light vehicles now expanding to larger vehicles, buses, and off-road construction machinery. Political initiatives, climate change mitigation, cost factors, and the demand for cleaner construction methods fuel this transition. Various countries and regions are enacting policies to endorse the electrification of transport and construction machinery. For instance, the U.S. aims for carbon-free electricity by 2035 and net-zero emissions by 2050, highlighting electric vehicles in its climate strategy. The European Union's European Green Deal seeks climate neutrality by 2050, with efforts to promote renewable energy and cleaner transport. Despite the evident push towards electrification, challenges related to infrastructure and technology integration persist, such as the need for adequate power supply for electric vehicles and electric machinery recharging on construction sites, vehicle range limitations, and the adaptation of electric machinery into current workflows. Electric road infrastructure to save charging needs of electric vehicle is a promising and under development research area. The demonstration of electric roads with charging functions in Lund of Sweden is a good example and how to utilize the new technology of electric roads in the future road systems are worth to be investigated. Another aspect is the impacts of electric vehicles with heavier weight on the road systems in terms of dynamic loads, road deterioration and maintenance. Its impacts need to be explored based on quantitative modelling and analysis.

5.4.5 Research agenda

Data needs, acquisition, and potentials for future road infrastructure (short term):

- Identify and utilize the currently available and usable data resources from various new technologies (vehicle on-board sensors, intelligent collection devices, embedded sensors in roads, and social media feeds etc.) for the digitalization and better management (in terms of construction, maintenance and recycling) of road infrastructure including different types of roads (e.g. asphalt, concrete and gravel roads; cycling lanes, highways, urban roads, pedestrian roads etc.) in different seasons (e.g. summer and winter). Especially, the data for the monitoring and maintenance of winter roads. This aims to provide a clear and comprehensive roadmap about what data could be utilized for intelligent road infrastructure and digitalization.
- Identify the new data needed for future road infrastructure digitalization and the techniques required to obtain such data resources. Some necessary and useful data that are needed for future digitalization of road technologies may not be able to be collected by the current data collection technologies, so such new data needs need to be appropriately identified and new data collection technologies should be developed to satisfy the future needs for digitalization.
- Develop advanced techniques and approaches for processing and integration of heterogeneous data sources into a unified format for digitalization such as data from vehicle on-board sensors, vehicle front cameras, embedded sensors in roads, geospatial data and social media feeds. The diversity nature of multiple data resources for road infrastructure digitalization in terms of data formats, processing requirement, compatibility and quality asks for solid and reliable data processing, fusion and management to make data from diverse resources compatible for digitalization.
- Real-time data processing and analysis to enable dynamic data collection, fusion and rapid processing of data into digital tools and information. Data processing, analysis and management can be conducted offline and online in real time. For some digitalization application of road infrastructure, real-time updates are required, for instance the winter road status (e.g. ice and friction situations) monitoring, foresting and warning. This asks for high time efficiency in data processing and analysis. Beyond offline data management, new approaches and techniques for real-time digitalization are required.
- Explore the various utilization of digitalized road infrastructure. Beyond conventional road monitoring and maintenance, fruitful data from road infrastructure enables utilization potentials extending the boundaries and interdisciplinary application. For instance, real-time road surface information (e.g. friction and deterioration) can be provided to intelligent vehicles to assist velocity and vehicle control to be safer and more efficient. Extending and revisioning broad boundaries of utilizing road data for future road and transportation systems are required to provide clear potentials and usage cases of road digitalization.
- Privacy-preserving data collection and management. A relevant issue of some data collection technologies such as video and GPS data is privacy protection. It is important to ensure data collection and management using different data sources respect the privacy regulation in Sweden and EU, and safeguard user data while utilizing them for road digitalization.

Assessing and utilizing new technologies on road infrastructure (short term)

- Comprehensively assessing the impacts of electric and automated vehicles on road infrastructure. One important challenge of transport automation and electrification is to ensure the long-term performance of the road infrastructure. The sustainable benefits of these new technologies should not be overshadowed by extra infrastructure and maintenance required to keep the infrastructure functional with a great standard. Comprehensive assessment of the new technologies on different types of roads are required in terms of safety, efficiency and sustainability aspects. Quantitative approaches and empirical analysis in Swedish contexts for multiple-scale assessment (at the road segment and road network levels) from different perspectives are required. For example, how will the automated and electric vehicles with different vehicular features affect road deterioration, geometric design and maintenance in the future; Performance prediction tools such as Finite Element Analyses are useful for decision making during the construction and anticipate the required maintenance in the context of automated and electric vehicles. In combination with LCA/LCC models, performance prediction tools can ensure the increase of sustainability of the road-vehicle infrastructure over the entire life span.

- Analysing and predicting the consequences of new technologies on traffic flow patterns, the spatiotemporal dynamic loads on roads from vehicles (e.g. loads distribution in different lanes and load frequency and amplitude) and corresponding consequence on road infrastructure. This is aimed to provide solid inputs for predicting and assessing how the traffic distribution and changed dynamic loads due to automated and electric vehicles will affect road performances, maintenance, road structure and materials needs.
- Assessing and utilizing the potential of automation and electrification of road construction and maintenance equipment/vehicles and processes to improve safety, efficiency and sustainability. Utilizing automated vehicles or automated functions of equipment for road cleaning, construction and maintenance especially in some dangerous situations, can help to improve efficiency and safety of workers. Electrifying the equipment can reduce the emission of construction and maintenance from vehicles. The potential challenges of automation and electrification of road equipment (e.g. extraction force requirement etc) should be identified and researched as well. such as energy.
- Assess and identify the new road infrastructure needs and potential for automation and electrification, for examples electric roads for charging, roadside equipment for automated vehicles etc.

Intelligent monitoring of future road construction, use and maintenance (short and long term)

- Develop and implement IoT-based monitoring systems on offline or real time road conditions, traffic, and road environment factors based on continuous data collection and processing. This focuses on developing monitoring techniques the road status and environments based on various collected data, including feature extraction, metric framework/systems of reflecting road status and environments and models/approaches to calculate/derive/estimate the commonly used metrics. Develop systems for automated detection of issues/road disaster and automatic response, to improve the efficiency of road issues detection and monitoring, and to reduce the time between an incident occurring and corresponding responses and human workload in issue detection and monitoring.
- Utilize V2X communication and interactions between roads and vehicles to improve safety during road construction and maintenance in work zones for both civil cars and construction/maintenance equipment/workers. Demonstration and real applications with various stakeholders are encouraged.
- Utilize V2X or automated vehicles to improve traffic safety at some critical road segments. Demonstration and real application with various stakeholders are encouraged.

Digital tools helping in decision making for planning, constructions, use and maintenance of future transport infrastructure (short and long term)

- Develop and implement high-fidelity digital tools (e.g. road digital twins) of road infrastructure to simulate the road conditions and predict revolution patterns and potential issues in the future.
- Develop and implement integrative digital technology with live data feeds for real-time monitoring, analysis and decision-making for road construction and maintenance. For instance, digital twins of road systems in Sweden to show the up-to-date status and information of roads; digital warning and reminding of road issues and road segments that need treatments. This focuses more on developing and producing digital tools such as software or dashboards.
- Develop digital tools (e.g. BIM with materials information) for design, construction and maintenance processes that can be used for the entire life of the road infrastructure for performance analysis and management. For instance, developing the digital tools for assisting geometric design of vertical and horizontal road alignment, road surface and structure design, and road material design.
- Develop digital tools for procurement strategies for services of road construction and maintenance. This focuses on intelligently and strategically selecting procurement types and subcontracting strategy based on detected road issues and risks to make the procurement decision making and selections more efficient and effective and to assist human experts to make most appropriate procurement choices.
- Procurement strategies and business models for cost-efficient contracting and service procurement. Given needed construction and maintenance service, formulating sustainable, efficient and reliable procurement models to minimize monetary expense and to maximize the final positive outcomes (e.g. the procurements improve the road systems as or beyond expected).
- Develop predictive maintenance models and strategies to predict and prevent road infrastructure failures and disasters when they occur or before they occur. Based on identified road issues and disaster types, corresponding effective and cost-efficient maintenance solutions are generated based on developed models (e.g. expert model or AI) to support and assist effective maintenance decision making and procurement. This focuses more on models and methodology developments.
- Develop digital tools and user-friendly interfaces to general potential maintenance solutions with expert knowledge to reduce workload for formulating maintenance solutions by human, reduce the needs for subcontracting the maintenance tasks to companies or guide the decisionmaker to make more efficient and effective decisions about subcontracting of maintenance. This focuses more on digital tool developments beyond the models.
- Develop and invest in automated and electric maintenance technologies, such as maintenance machines, drones and robots, for efficient infrastructure inspections and repairs to reduce human workload and improve work safety of maintenance workers.

New road design and construction adapting to the new technologies (long term)

- The new technologies (e.g., automated vehicles/electric vehicles) lead to changes in many driving-related factors such as reaction time and safety parameters of road design different to traditional vehicles, proper new rules and regulation for geometric design dedicated to new technologies should be defined to ensure safety, efficiency and sustainability of future road systems.
- The new technologies (e.g., automated vehicles/electric vehicles) also bring new challenges for road integrity in terms of pavement, road structure and roadbed, new and high performing pavement materials (e.g. Polymer Modified Bitumen) and structures need to be researched, developed and implemented to adapt to the requirement of new technologies and ensure the safety and sustainability of the infrastructure.

- Automated and intelligent construction equipment and vehicles for road infrastructure to improve efficiency and safety. The road construction equipment and vehicles need high performances (e.g. extraction force) compared to passenger cars. Advanced Driver Assistant Systems specific for road construction and maintenance equipment can be developed to reduce human workload and improve safety during construction and maintenance.
- Consider new vehicle design/technology to make vehicle-infrastructure integrative design and management, involving vehicle manufacturer stakeholders.

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7 Remittance and comments

A research agenda draft version was remitted 2024-10-14 by e-mail to the following instances:

- The Swedish Transport Administration (Trafikverket)
- The Swedish Transport Agency (Transportstyrelsen)
- The Swedish Environmental Protection Agency (Naturvårdsverket)
- ShiftSweden
- The Development Fund of the Swedish Construction Industry (SBUF – Svenska Byggbranschens Utvecklingsfond)
- Svensk Beläggningsförening (SBF)
- Svenska Vägtekniska Föreningen
- Swedish Association of Local Authorities and Regions (SKR - Sveriges Kommuner och Regioner)

of which the following responded:

- The Swedish Transport Administration
- The Swedish Transport Agency
- The Swedish Environmental Protection Agency

Here follows a general response to the comments:

- The remittance instances are thanked for their comments which all are relevant to the agenda and raises interesting perspectives that needs to be considered. Since this is a living document it will be by the time of update considered these proposals.

8 Appendix

Appendix 1 – Trafikverkets inbjudan

Available upon request. Submit requests to info@kcvag.se.

Appendix 2 – Förslag på inrättande av Kompetenscentrum vägteknik

Available upon request. Submit requests to info@kcvag.se

Appendix 3 – Trafikverkets forsknings- och innovationsplan 2024

The Swedish Transport Administrations Research and Innovation plan for 2024 – 2029 is available in the DIVA – Digitala Vetenskapliga Arkivet (the Swedish Digital Scientific Archive). Link: https://urn.kb.se/resolve?urn=urn:nbn:se:trafikverket:diva-12505