

# MANAGING AND PREDICTING THE CONDITION OF PAVED ROAD NETWORK IN FINLAND: ESSENTIAL TECHNICAL INFORMATION

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**Abstract.** The condition of roads is recognised as a critical foundation for economic prosperity and, therefore, requires continuous maintenance. Effective management of roads necessitates a clear understanding of the road network's condition. This study aims to identify the technical condition information currently utilised, needed, and missing within the context of paved roads in Finland. The study is qualitative, with data consisting of fifteen semi-structured interviews: road authorities (7), maintenance specialists in road condition analysis (6), and contractors (2). Based on the results, recommendations were given for monitoring the road network. For monitoring functional conditions, a new method for detecting defects must be introduced, with other measurable parameters being better managed. For monitoring structural conditions, it is recommended to start regular deflection measurements and define the condition criteria. Additionally, more up-to-date information is needed on the condition of drainage structures. With the help of these findings and recommendations, it is possible to enhance the monitoring, management, and optimization of the road network's condition in a more data-driven manner.

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## Introduction

Roads constitute a crucial component of infrastructure. The condition of these established infrastructure systems is recognised as a critical foundation for economic prosperity and, therefore, needs continuous monitoring and maintenance. Without sufficient funding and appropriate operations, the condition of the road network deteriorates. For instance, in Finland, the total length of paved roads in poor condition has doubled over the past decade, from 3500 to 8000 km (Traficom, 2023). Issues related to the state of paved roads arise from factors such as constrained budgets, heavy axle loads, climatic conditions, and aging infrastructure.

Harvey (2012) listed the most important measurable parameters for monitoring the condition of roads:

- “Roughness, measured in metres per kilometre (International Roughness Index, IRI);
- Rutting, measured by rut depth;
- Cracking, measured by the percentage of area cracked;
- Pavement strength, measured by modified structural number.”

The first three parameters, as stated by Harvey, remain the most used in the USA (Marcelino et al., 2019). Due to recent technological advancements, numerous new methods and indicators have been evaluated and implemented worldwide (e.g., Ranyal et al., 2022; Shtayat et al., 2020). Barbieri and Lou (2024) present a review of field investigation methods for monitoring road conditions, covering image acquisition, profile and skid resistance appraisal, stress, strain, and deflection measurement, tomography tests, environmental parameter evaluation, and traffic volume determination. While the studies conducted offer valuable insights into potential monitoring methods and currently utilised information (e.g., Peraka and Biligiri, 2020), they fail to address the crucial question of what information is necessary at the network level for managing and predicting road conditions. It is important to note that each country or region may experience distinct weather phenomena and other load-related factors, in addition to having access to specific materials and regulations. The primary research question in this study is: What technical data and information are required to manage and predict the functional and structural condition of paved roads in Nordic climates?

## 1. State of the art

### 1.1. Background

The rational selection of road condition measurement methods and indicators requires an understanding of local conditions. In Nordic countries, winters are typically cold, and the frozen road structures have a high bearing capacity. During winter, studded tires wear down the surface of the pavement, where there is no compacted snow covering it (e.g., Abaza et al., 2024). Towards the end of winter, in early spring, frost bumps may appear on the road surface due to the formation of ice lenses (e.g., Jones, 1980). Additionally, in spring, the bearing capacity of the road structure decreases as seasonal frost melts, making the road structure at its weakest (e.g., Simonsen and Isacsson, 1999). In summer, as the temperature of the road surface rises, the stiffness of the bitumen-bound layer decreases (e.g., Halle et al., 2012). By autumn, rains become more frequent, and the upper part of the road structure may undergo several freeze-thaw cycles before eventually freezing.

Furthermore, the allowed vehicle loading on the Finnish road network, with the maximum truck weight of 76 t (Finlex, 2020), is among the highest in Europe. Due to the climatic conditions, design guidelines, and available building materials, road structures in Finland are typically thicker compared to those in many other countries. In contrast, road surfaces (pavements) tend to be thinner and are bound with bitumen. In Finland, paved roads are categorized into three maintenance management groups, with each group having five condition levels: very good, good, acceptable, poor, and very poor. If a road's condition is rated as poor or very poor, it qualifies for unfulfilled demand procedures (FTIA, 2021).

A key principle of road maintenance is that investments made today can help reduce future costs. Neglecting maintenance can have consequences for safety, the environment, the economy, the integration, and the accessibility (e.g., World Road Association, 2014; Thiessen et al., 2017; Granlund, 2008).

### 1.2. Functional and structural condition

The functional condition refers to the quality of the pavement surface experienced by road users, while the structural condition pertains to the pavement's strength or its ability to carry loads and accommodate traffic flow. Peraka and Biligiri (2020) listed 21 additional pavement condition parameters found in the literature, beyond those listed by Harvey (2012) in the introduction chapter of this study, of which typically 5–10 are used.

Another key question is what information is truly essential for predicting the future condition of the road network. In the summary by Peraka and Biligiri (2020), the Pavement Condition Rating (PCR), International Roughness Index (IRI),

the Pavement Condition Index (PCI), and the Urban Distress Index were used. The PCI includes a measurement procedure for each distress type, severity, and extent, and is rated on a scale from 0 to 100 (Peraka and Biligiri, 2020). Additionally, the Urban Distress Index incorporates factors such as age, annual average daily traffic, and drainage in predicting the future performance. The parameters included in the PCR vary by the state (USA) but may encompass factors such as roughness, cracking (fatigue, longitudinal, transverse, block alligator), rutting, raveling, patching, and potholes. Distinguishing between different types of defects is crucial when investigating potential causes of deterioration (e.g., Adlinge and Gupta, 2013). Image recognition, computer vision, and deep learning techniques are increasingly used to monitor and assess defects (e.g., El Hakea and Fakhr, 2023). Although IRI has been a widely used indicator for pavement deterioration, the results indicate that unevenness values in Finland do not solely reflect pavement conditions (Herronen et al., 2022). Therefore, careful timing is essential. Furthermore, the primary purpose of assessing longitudinal evenness and sudden horizontal variations is to describe the driving experience. To address these needs, the RIDE-classification index has been introduced in Finland (Virtala et al., 2016).

The contemporary literature primarily introduces two distinct methods for measuring load-bearing capacity: the Falling Weight Deflectometer (FWD) and continuous deflection measurement techniques such as the Traffic Speed Deflectometer (TSD) (e.g., Zhang et al., 2023; Levenberg et al., 2018; Jia et al., 2021). Studies have compared the differences and results of these two methods, and appropriate indices have been defined for specific purposes. The most common indices are the Surface Curvature Index (SCI), the Middle Layer Index (BDI), and the Base Curvature Index (BCI) (e.g., Horak et al., 2015). These indices, which can be calculated from the FWD and TSD measurements, are crucial for evaluating the performance of pavement and road structures. Again, the timing of these measurements is crucial in cold climate areas, as demonstrated in Canada (Deblois et al., 2010).

Moisture content in the road structure has been empirically linked to the rate of rutting, load-bearing capacity, and susceptibility to frost heave (e.g., Henning et al., 2014; Niu et al., 2021). The functionality of drainage structures can be assessed not only through field observations but also, for example, through Ground Penetrating Radar (GPR) (Curtis et al., 2010). It is important to note that for effective drainage, the functionality of all components, including side ditches, outlet ditches, main road culverts, side ditch culverts, and the cross-fall of the road, is crucial. This also includes the early removal of snow from the road shoulders (Saarenketo and Männistö, 2021), as well as other material blocking the functionality of the drainage.

## 2. Methods

Qualitative research was chosen as the research method due to its effectiveness in addressing the research questions. This method enables an in-depth exploration of the quality and meanings of phenomena, aiming to uncover the “what,” “why,” “when,” “where,” “who,” and “how,” rather than simply quantifying events (Lim, 2023; Islam and Aldaihani, 2022). Interviews were selected as the primary data collection method because they provide valuable insights into experts’ perspectives, experiences, and ideas. Moreover, interviews facilitate a deeper understanding of causal relationships (Islam and Aldaihani, 2022; Qu and Dumay, 2011).

Fifteen semi-structured interviews were conducted, as this format allows for a more flexible dialogue between the interviewer and the interviewee compared to structured interviews. The number of interviewees ensured a diverse range of perspectives on the research topic, while also fitting within the available resources and timeline. Among the Finnish road authorities, four individuals (I1, I2, I3, I4) from the Finnish Transport Infrastructure Agency (FTIA, asset owner), and three individuals (I5, I6, I7) from the Centres for Economic Development, Transport, and the Environment (ELY centres, operational level) were interviewed. Of the FTIA participants, three focus primarily on road maintenance development tasks, while the fourth manages the condition register. The ELY Centre interviewees are involved in operational work related to road maintenance. Additionally, six maintenance specialists from four different companies specialising in road condition analysis (I8-I13) and two contractors (I14, I15) were interviewed. Maintenance experts were selected based on their tasks and experience in data collection, road condition measurements, and analyses. Two of these maintenance experts participated in a pilot project and had access to additional technical data on road conditions by using GPR, lidar, accelerometer, digital videos, and traffic speed deflectometer technology. Contractors were selected from two distinct companies involved in road maintenance operations. All interviewees hold at least a Bachelor’s degree in civil engineering, with approximately half holding a Master’s degree. Their years of experience in the field range from 10 to 40 years. The profiles of the interviewees are presented in Table 1.

Table 1. Profiles of the interviewees (created by the authors)

Interviewee	Position	Category	Company
1	Head of Unit		Public, No. 1
2	Specialist	Developer	Public, No. 1
3	Specialist		Public, No. 1
4	Specialist		Public, No. 1
5	Project Manager		Public, No. 2
6	Specialist		Public, No. 2
7	Head of Unit		Public, No. 2
8	Team Leader	Data User	Private, No. 3
9	Head of Unit		Private, No. 4
10	Specialist		Private, No. 5
11	Senior Designer		Private, No. 6
12	Specialist		Private, No. 3
13	Project Manager		Private, No. 6
14	Head of Unit	Contractor	Private, No. 7
15	Project Manager		Private, No. 5

The interviews were analysed using qualitative content analysis. For this article, eight initial codes were applied to analyse the data: (1) use of information, (2) condition information concerning functionality, (3) road structure, (4) drainage, (5) other information, (6) predicting, (7) general development suggestions, and (8) miscellaneous quotations. Based on the analysis, the interviewees were grouped into three categories: developers (I1–I3), data users (I4–I12), and contractors (I14, I15). Developers were not directly using condition data in their daily tasks, but focused on developing processes or methods related to condition measurements. Data users, who utilise information from registers and other sources daily, exhibited no significant differences in their responses regardless of their workplace. Contractors, on the other hand, rarely utilised condition information from registers.

During the analysis conducted after the interviews, it was observed that theoretical saturation was achieved. The findings consistently reflected the general responses of each group, ensuring the robustness of the results.

### 3. Results

#### 3.1. Need for information

The condition information (CI) needs of individuals in development tasks varied depending on the specific tasks. Their position enabled them to delegate information retrieval from the registry to others if required. Individuals who used CI daily needed information for monitoring road conditions, predicting changes in conditions, analysing, and reporting, planning programs and interventions, and conducting various investigations. Contractors utilised CI in arranging interventions, preparing compensation responses, and fulfilling obligations mentioned in contracts.

#### 3.2. Auxiliary information and registry

Both data users and contractors emphasised the significance of historical information during interviews. Currently, previous operations and their timeframes are recorded in registries. Other essential information includes traffic volume and distribution, speed limit, and lane width. Information on paving history covers details of paving material and method, grain size and ball mill value classification of aggregate, remixing percentage, and binder classification. Regarding environmental information, knowledge about groundwater and flooding areas is necessary. For planning operations, additional important details include information on pavement thickness, bridges, guardrails, lighting, and intersections.

In addition to the registry, all interviewed groups used the road image service and videos. Furthermore, road authorities receive feedback from road users and other stakeholders, and this information is available to data users. For planning purposes, soil maps are also used, depending on the specific planning requirements.

#### 3.3. Information on functional condition

According to the interviewees, there is already useful information on the functional condition of roads in the registries. At the national and regional levels, the interviewees emphasised the need for information related to overall condition classification. The most frequently mentioned information in the interviews included rut depth, road unevenness, and the need for repaving.

In addition to rutting, the cross-fall and especially rapid changes in the cross-fall were deemed important, particularly from the perspective of drainage and heavy traffic safety. Creating an indicator for this purpose was desired, although it was acknowledged that various factors (such as curvature and intersections) contributed to determining the desired value.

*“The only thing we can honestly say now, in my opinion, is that rutting development can be predicted. There has been extensive discussion about cross-fall, and it has likely been recognized as a potentially significant key factor. In principle, it is a variable that can be found, but it serves as an indicator of how much deviation exists and what the optimal cross-fall for a specific target would be.” (17)*

On the contrary, opinions were divided regarding longitudinal unevenness. While all respondents recognised the importance of measuring longitudinal unevenness, there was no unanimous consensus on the specific indicator to use. In addition to the previously employed indicators, IRI, RMS, and a recently introduced indicator called RIDE were also in use, although the RIDE indicator’s applicability had limited practical experience. RIDE indicator simulates the driving experience encompassing several parameters from a dynamic vehicle (Virtala et al., 2016). On the other hand, RMS refers to the texture of the surface.

*“There has been extensive discussion about whether the IRI is suitable for measuring longitudinal unevenness. Well, technically there have been developments in other indices like the RIDE, which are probably used at the network level, but they may not have spread to the operational level. Perhaps in the future.” (11)*

On low-traffic roads, the need for repaving has emerged as the most significant condition indicator, replacing rutting and longitudinal unevenness. However, interviewees emphasised that developing this indicator is a key area for improvement to enhance the reliability of assessing and predicting the condition of the lower-level network. Currently, the measured variable does not accurately reflect the road conditions experienced by road users. Instead of focusing solely on repaving needs, it should be possible to measure and, if necessary, emphasise different types of defects. Additionally, beyond addressing slower-progressing deterioration on low-traffic roads, the method should also be applicable for assessing rapidly deteriorating roads with potholes, if feasible. Therefore, most data users visited sites to evaluate the condition. Two data users were also using back-calculated moduli values of pavement layers and digital video data, as this information was exclusively available in the pilot project.

*“The poor condition resulting from surfacing needs is based on factors such as longitudinal cracks, which don’t necessarily need to be very large to be considered for repair. Additionally, even if the road surface is not significantly uneven in those areas, it can still lead to extended repaving requirements. On the other hand, the challenge lies in the fact that there*

*may be severe potholes at suitable intervals, yet they do not exceed the repaving threshold.” (15)*

*“We should obtain information from the nature of the defect, it’s severity and location.” (112)*

*“If traffic volumes are extremely high, there is condition information observed visually that does not appear in measurement results. For example, the pavement looks somewhat brittle, and it seems that when spring arrives and thawing starts, it begins to develop potholes. None of this information is visible in any data.” (112)*

Based on the interviews, it was revealed that while not all indices registered are necessary for network-level assessments, they still serve a purpose in target-specific analyses and other investigations. Currently, the functional condition is assessed every 1 to 5 years, depending on the road class. Over the course of five years, road conditions can change significantly, which is why increasing the inspection frequency for lower-class roads (e.g., to three years) was considered reasonable.

### 3.4. Information on structural condition

Currently, the structural condition index is calculated using functional indices. Changes in structural condition ultimately manifest in functional changes. However, among the interviewees, there was consensus that the structural condition should be investigated more thoroughly using more suitable methods. Although all interviewees agreed on the importance of monitoring structural condition, three interviewees felt that, due to the complex nature of road structure issues, no single measurement method can reliably address this challenge. Contractors emphasise that overlooking the structural condition poses a significant risk in paving due to overly optimistic operations, which can lead to issues during the guarantee period.

*“I think it’s really good that we have a structural integrity indicator, which we do, but now I can’t quite say whether I agree or disagree with that indicator. Since it doesn’t directly include anything related to load-bearing capacity, I find it challenging. In my opinion, it would be beneficial if bearing capacity were included.” (15)*

*“It doesn’t fit into my philosophy that a single method could reliably depict the condition of the road structure.” (18)*

In addition to the structural condition index, the registry includes key figures obtained through surface condition monitoring, which pertain to settlement. Furthermore, interviewees highlighted the need to measure frost heave, road structure behaviour under loading, and the total thickness of road structures.

This information enables proactive and more precise decision-making. Since measurements are not currently conducted at the network level, most of the data users acquire information on deflection measurements and the overall thickness of the road structure on a case-by-case basis concentrating mainly on low-volume roads requiring structural improvement. Deflection measurements primarily utilise the statistical indicators SCI and BCI but also include calculated values of horizontal strain at the bottom of the pavement, vertical strains of the subgrade surface, and back-calculated modulus.

*“Load-bearing information is generally used in those designs if available, or it is measured separately. Mainly, values such as BCI, SCI, and pavement horizontal strain are commonly used. Additionally, we obtain structural drilling information to verify the ground penetrating radar measurements.” (I11)*

Traditionally, information regarding drainage structures has been collected and transferred to the previous registry, primarily focusing on road culverts (including location, size, and material). Additionally, the asset owner compiled data on private access junction culverts, soil verges on road shoulders, side drainage ditches, and outlet drainage. Notably, this information was gathered from a moving vehicle. However, the process of migrating this information to a new registry, and consequently its usability, has encountered challenges. When data users or contractors require information about the condition of drainage structures, they often receive it separately or commission specific measurements and site visits on a case-by-case basis to assess the situation. In such cases, additional details are collected, including the depths of side ditches and the inner slope of road embankments, if feasible. Interviewees emphasised that drainage-related information becomes outdated quickly, impacting its reliability and usability.

Based on the interviews, it is justifiable to assert that there is still room for improvement in the nationwide management of drainage structure conditions. First, the information is not available in the registers, and therefore, the road authorities lack a comprehensive view of the condition of the drainage structures at the network or aerial level, making it difficult to assess the need for repairs. Second, the collected data lacks information on the current condition of the culverts. If the culverts are not in good condition, raised water level in ditches leads to saturation of the pavement structure and thus decrease bearing capacity. This, in turn, accelerates road damage and rutting.

*“Culverts are still inspected within the maintenance contract and, if necessary, cleaned once during the maintenance contract. But what I mean generally is the overall functionality of drainage. Unfortunately,*

*there hasn't been comprehensive management of the whole system, even though there should be." (13)*

### 3.5. Predicting

Data users specifically highlighted that rut depth is the most crucial measured factor on major highways and is often further calculated as rut growth. The model calculates and predicts rutting development based on measurements taken. Additionally, it would be essential in the model to display either the typical rutting rate by road classification or the growth rate of ruts relative to the specified traffic volume. This would enable immediate detection of whether rutting is occurring faster or slower than usual and facilitate investigations into the underlying reasons for any discrepancies.

Data users had a unanimous view that prediction based on other official indicators could be used on a national level but did not meet the desired accuracy on a regional level. However, regional road authorities had experiential knowledge of how much roads deteriorated in each area annually, which provided additional information for predicting road conditions in the future.

Typically, predictions regarding road condition changes were made operationally for a period of 1–3 years ahead. On busy road networks, changes in road conditions occur more rapidly than on lower-traffic volume roads. Forecasts extending beyond three years involve more assumptions, leading to reduced reliability in predicting road conditions for major highways.

### 3.6. General improvement possibilities

Data users emphasised that when information from completed paving or construction projects was stored in registries, it was overly simplified. For instance, in a 20 km road repaving project that utilises three different binding materials, only one type is recorded, and the quantity of added surfacing material is not broken down based on the actual implementation. Additionally, information about the origin of aggregate materials would facilitate the analysis of the impact of various materials on road condition. Other improvement suggestions related to the registry include enhancing information accuracy, visibility, and the ability to add notes. Knowing precisely where and how information was measured would enhance understanding of its accuracy. Furthermore, allowing data users and contractors to add notes regarding planned operations, pothole filling needs, executed work, frost bumps, and periodic weight limitations would be valuable.

*"The information about those paving methods has been simplified, treating the entire object as one. However, the object can have a*

*significantly different surfacing history beforehand, where quite distinct materials have been used.” (114)*

*“At the moment, we capture very little of the information that we generate. Instead, we somehow take a narrow slice of the information we have at hand and condense it into a few lines in registers. Unfortunately, we leave unused all the valuable insights we possess.” (19)*

*“I would like to know more about the future, especially the planned renovations or repaving. It is now depending on the client, how well we have been informed on upcoming projects.” (115)*

## 4. Recommendations

When examining the results of interviews, it is possible to recommend the measurements presented in Table 2 for both national and regional road condition monitoring. In addition, other measurements can be applied in detailed planning and specific analyses.

**Table 2. Recommendations for national and regional level road condition measurements  
(created by the authors)**

<b>Condition / measurement</b>	<b>Comments</b>
<i>Functional Condition</i>	Monitoring frequency: 1–3 years
Classification	Important on a network level
Depth of rut	Information already reliable
Rut growth rate	Further information on rut growth rate at specific traffic volume in the prediction model needed.
Rapid changes in cross-fall	Information exists, but not as an indicator
Longitudinal evenness	Needed to identify the driving experience, settlement, and frost heave. Therefore, different indicators and monitoring seasons are required.
Pavement distress assessment	Important, especially, on low-volume roads: improvement needed
Pavement thickness	Information exists
<i>Structural Condition</i>	Monitoring frequency: 3–5 years
Classification	Important on a network level: improvement needed
Pavement thickness	Information exists
SCI, Surface Curvature Index	Classification criteria and monitoring are needed
BCI, Base Curvature Index	Classification criteria and monitoring are needed
Horizontal strain in pavement	Classification criteria and monitoring are needed
<i>Drainage Structure Condition, if drainage primarily operates through open ditches, not through a rainwater harvesting system</i>	Information expires fast: frequency between 3–5 years
Classification	Important on a network level: improvement needed
Functionality of the ditch and outlet	Information exists, expires rapidly
If the depth of the ditch is < 1.1...1.5 m: Difference of the ditch depth and thickness of the road structure	Required value 0.3 m: It can be assessed as OK / not OK, if the functionality of the ditch is good
If the depth of the ditch is > 1.1...1.5: no need to measure	
Functionality of culverts	Information exists, but it expires rapidly
Size and material of culverts	Information exists
Inner slope of the road embankment	Required min value according to the road class needed

According to the interviews, information related to road functionality was generally considered reliable, except when assessing the need for repaving the road surface. Additionally, there was a demand for more effective indicators of unevenness. The RIDE-classification index, introduced in Finland to address unevenness (Virtala et al, 2016), has only been in use for a short time. Experiences using this index must be researched to assess the reliability of this index.

The literature highlights various methods for surveying and predicting road deterioration that could potentially replace the current repaving indicator. Many of these methods leverage image recognition, computer vision, and deep learning techniques (e.g., El Hakea et al., 2023). Insights from the interviews underscored the importance of not only identifying obvious defects but also predicting deterioration factors that lead to potholes, such as poor winter maintenance, faults in paving works, uneven road surfaces, or combinations of these issues. Further research is required to identify suitable and cost-effective methods tailored to the specific context.

Moreover, there is a need for an indicator to monitor rapid changes in cross-fall. On straight road sections, the centre of the road is typically higher than the shoulders. In curves, however, the outer shoulder should be higher than the inner one to enhance vehicle dynamics. In both cases, it is critical that the road maintains sufficient cross-fall to ensure proper water drainage and effective functioning of the drainage system. Rapid changes in cross-fall pose health and safety risks for road users, potentially leading to vibrations and skid accidents (Granlund, 2008).

Although predicting pavement condition based on rutting was considered reliable, the underlying reasons for certain conditions could be analysed more easily if the rutting growth rate was directly linked to traffic volume information.

However, identifying maximum frost bumps cannot be conducted simultaneously with other unevenness measurements; instead, their localization should be deferred until late spring (Dettenborg et al., 2021). It is important to note that the height of frost bumps is influenced by the amount of water within the road structure. Therefore, road maintenance should prioritize preventing excess water infiltration into the structure (Saarenketo and Männistö, 2021), while also giving attention to repairing frost bumps that compromise traffic safety. Information about the most hazardous frost bumps can be gathered not only through measurements but also by interviewing local maintenance contractors and professional drivers who regularly use specific roads.

Currently, the structural condition index is calculated using functional indicators, such as the International Roughness Index (IRI), the need for repaving, and settlement, with the value of pavement thickness also taken into account. However, this index only partially and reactively reflects the structural condition. In a pilot project conducted in Finland, continuous deflection measurement data were used to assess the structural condition of roads. The results showed that the SCI and BCI,

along with the horizontal strain at the pavement bottom, were correlated with the surface, sub-base, and overall condition of the road. Based on these findings, the use of these indices is recommended. Similar conclusions have been reported in the international literature (e.g., Zhang et al., 2023; Hamidi et al., 2024). In addition, in a Transportation Research Circular workshop in 2019, countries, which were planning or conducting continuous deflection measurements, included, e.g., Australia, New-Zealand, South-Africa, and Germany (TRB, 2019). Thus, combining indices with factors such as pavement thickness can support the development of a more comprehensive structural condition indicator (Katicha et al., 2022). These indices provide insights into the condition of different components of the road structure, helping identify the root causes of structural issues and enabling the selection of appropriate maintenance actions and accurate cost estimates.

Investigating the root causes of drainage malfunctions was beyond the scope of this study. However, it is evident that documenting and enforcing the desired drainage conditions is essential. To comprehensively assess drainage functionality, in addition to the data currently collected, it is necessary to evaluate the difference between ditch depth and the total thickness of the road structure. Previous research suggests a range of 0.2 to 0.3 m for this purpose (Heilala et al., 2023). This evaluation is particularly important in cases where the road surface is less than 1.1 to 1.5 m higher than the ditch bottom, depending on the road class and geographic location.

Moreover, for traffic safety and road edge stability, the inner slope of the road embankment must not be too steep, and water must flow unobstructed into the ditches. These measurements can serve as indicators of drainage conditions.

Finally, it should be emphasised that not all recommended measurements need to be conducted independently; they can be combined in a cost-effective manner. Furthermore, if a proactive approach is desired, the threshold values for these measurements must be carefully selected.

## Conclusion

The aim of this study was to present what technical condition information would be required in managing the road network in Finland. Road authorities, specialists, and contractors were interviewed, and reports were studied to thoroughly assess the technical condition requirements. Although there already exists useful information on technical condition, certain missing information and imperfections in processes were discovered:

- There is a need for an indicator to assess rapid changes in cross-fall;
- The evaluation of repaving needs should be conducted more precisely, and appropriate method for this should be developed;

- Improvements are necessary for the structural condition classification, including assessment methods and criteria;
- Further definition and measurement of parameters are required for classifying drainage structures;
- Completed project information should not be overly simplified, and the registry should enhance accuracy, visibility, and note-making capabilities;
- Incorporating rut growth rate based on specific traffic volume into prediction models would enhance analyses.

With the help of the findings and recommendations, it is possible to improve monitoring, managing, and optimising the condition of road networks in a more data-driven way. As a result, road users' safety and health may improve, rolling resistance of vehicles and road unevenness decreases, which in turn reduces fuel consumption and emissions. Additionally, the reduction in road unevenness decreases the dynamic loading on the road, which in turn slows down the rate of rutting. Indirectly, the condition of roads has an impact on people's well-being and the national economy, and, therefore, the significance of road conditions should not be underestimated.

Finland served as the target country for this study. However, we believe that the results can be adapted and modified for other industrialized nations with similar geographical characteristics.

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