CivilEng

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Degradation of Cycle Paths—A Survey in Swedish Municipalities

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Abstract: There is a need to move society in a sustainable direction. One way to contribute to this move is to change to more sustainable transport modes, such as cycling. To increase cycling, the infrastructure is important, and good quality cycle paths are needed. However, little is known about the degradation of cycle paths. This paper aims to investigate what modes of pavement distress are found on municipal cycle paths in Sweden, and what probable mechanisms lie behind such distress; these are determined based on questions from a state-of-practice survey, interviews, and a literature review. The main findings are that the most commonly stated distress modes are surface unevenness followed by longitudinal cracks, and the most commonly stated causes of distress are ageing, followed by structural interventions, and roots and vegetation. The results also show that for several distress modes, there are probable connections with climatic factors such as temperature and moisture, as well as with the population size of the urban areas. Objective data are needed regarding traffic load and the climatic factors that affect cycle paths, along with information on their structural design, to better understand their degradation.

Keywords: construction design; cycle paths; degradation; distress modes; maintenance; municipalities; survey

Citation: Larsson, M.; Niska, A.; Erlingsson, S. Degradation of Cycle Paths—A Survey in Swedish Municipalities. *CivilEng* **2022**, *3*, 184–210. https://doi.org/10.3390/civileng3020012

Academic Editor: Luis Picado-Santos

Received: 15 February 2022
Accepted: 21 March 2022
Published: 23 March 2022

1. Introduction

The effects of global warming have become an increasing problem in recent years, and there is a common conception that this should be mitigated by moving society in a more sustainable direction. An important way to achieve this is to lower emissions from the transport sector, as this is one of the major sources of global emissions and represents about a quarter of the total greenhouse gas emissions on a global scale [1]. Cycling causes low levels of greenhouse gas emissions in comparison to other available transport modes [2], and thus, makes it a sustainable and feasible alternative to motorized transport, at least for shorter trips. For instance, Brand et al. [3] found that about 8 kg CO_2 emissions per day per person could be saved as a result of changing in the main mode of travel from car to bicycle. Cycling also benefits public health; for example, the risk of mortality is decreased by approximately 40% when cycling to work compared to when other modes of transport are used [4]. Trips up to 5 km are generally considered cyclable, and a large portion of the total number of trips in cities is shorter than that [5]. With the introduction of e-bikes, the cyclable distance will probably have to be revised to a higher number [6], which enhances the potential for even more trips to be made by bicycle. However, the choice of transport mode is not only dependent on the travel length of trips, as an array of other factors has been shown to affect this choice, such as weather (precipitation, wind, and temperature), traffic safety issues, and cycle infrastructure [7,8]. The layout of the cycle network is important, but so is the condition of the links that make up this network [9].

A smooth surface and sufficient friction on cycle paths are key factors in the comfort and level of service for cyclists, but above all, for their traffic safety [10]. Some 10–15% of single bicycle crashes that are connected to operation and maintenance are due to either the unevenness of the bicycle path surface (i.e., potholes, cracks, bumps, and settlements) or to protruding edges (e.g., from manholes or inlets) [11,12]. These crashes, unfortunately, often happen at high speeds [11], which could indicate that the surface damage is not detected in time to avoid them. Moreover, these are crashes that are directly connected to the maintenance of cycle paths; hence, good knowledge of the factors that cause and drive the degradation of cycle paths is necessary to optimize maintenance and prevent such crashes. As mentioned above, the level of service and the comfort of cyclists are also negatively affected by a degraded surface, e.g., with a lessened effective width due to edge deformations, uncomfortable surface roughness, or cracking that causes vibrations in the bicycle and forces cyclists to slow down.

Apart from the functional perspective of the users—in this case, cyclists—there is also a societal interest in the structural condition of the infrastructure. If some of the factors of the degradation of cycle paths can be avoided thanks to increased knowledge of the processes behind them, then that knowledge could be valuable for stakeholders—and eventually for all of society—to better protect these assets. In general, knowledge on the degradation of roads is good, as there is a long tradition of investigation into road distress by the AASHO Road Tests 60 years ago [13]. Cycle paths, despite being constructed with the same materials and techniques as the roads, are not designed in the same way. In many cases, the structural design of cycle paths is conducted in a standardized manner compared to the mechanistic-empirical design approach of roads and highways; this is mainly because they will not be subjected to the same traffic loads. Due to this supposed lack of traffic load, it has long been believed that the main factor behind the degradation of cycle paths is ageing. However, this needs to be investigated further, as there are indications that this may not necessarily be the case.

Considering the above, a survey was sent out to municipalities in Sweden with the objective of obtaining an inventory of how they work with maintenance on municipal streets and cycle paths, and the main problems that they encounter. The survey was followed up by more in-depth interviews with some of the participating municipalities. This paper aims to investigate which modes of pavement distress are found on municipal cycle paths in Sweden and what the probable mechanisms are behind this distress, based on some of the questions from this state-of-practice survey, interviews, and a literature review.

2. Structural Design of Cycle Paths

Globally, a large part of road networks consists of Thin-Surfaced Asphalt Pavements (TSAPs) [14]; these typically consist of a thin asphalt concrete (AC) layer with a thickness between 25 mm and 50 mm, on top of one or more unbound granular layers (UGLs) placed on the subgrade [15]. This applies to a large proportion of paved cycle paths as well, even though there are cycle paths that have an asphalt base course in addition to the asphalted wearing course. On the other hand, cycle paths that are basically a thin AC layer laid directly on top of the subgrade should not even be considered a flexible pavement, since the combined layer thickness of the construction is less than 15 cm [16]. For the TSAP, it is assumed that the AC layer hardly contributes to the bending stiffness. The bituminous surface acts more like a waterproofing layer to the underlying unbound granular materials (UGMs), which provide the bearing capacity [17], and a smooth surface with low roughness but good friction properties for safe ride-quality. For instance, in the Swedish road- and street-design manual (*TRVK Väg*) [18], AC layers with a combined thickness of less than 45 mm should not be used in the calculation of structural stability in road construction. This is partly due to the use of studded tires, which cause rutting and raveling and, thus, gradually decrease the thickness of the surface course in the wheel paths.

The mechanistic-empirical design approach of the *TRVK Väg* focuses on two criteria for the structural design of roads, namely the horizontal tensile strain at the bottom of the AC layer and the vertical strain on top of the subgrade. However, this approach is not applicable for cycle paths, for several reasons. Firstly, the mathematical concept used for the calculations of the strain at the bottom of the AC layer is only valid for combined AC layer thicknesses of more than 75 mm, and supposes a hot-mix base at the bottom of the AC layers. In the manual, the recommended cycle path superstructure consists of a 45 mm AC surface course on top of an 80 mm unbound base course (Figure 1). If the subgrade consists of solid rock, then no further layers are needed, but if the subgrade consist of frictional or cohesive soil, a sub-base layer should be added as well. The thickness of the sub-base layer depends on the soil type of the subgrade and how susceptible it is to frost. A general requirement for frictional and cohesive subgrades, though, is that the combined thickness of the UGLs, i.e., base and sub-base, should be at least 250 mm. This gives the superstructure a minimum thickness of 125 mm if built on solid rock and 295 mm if built on frictional or cohesive subgrades.

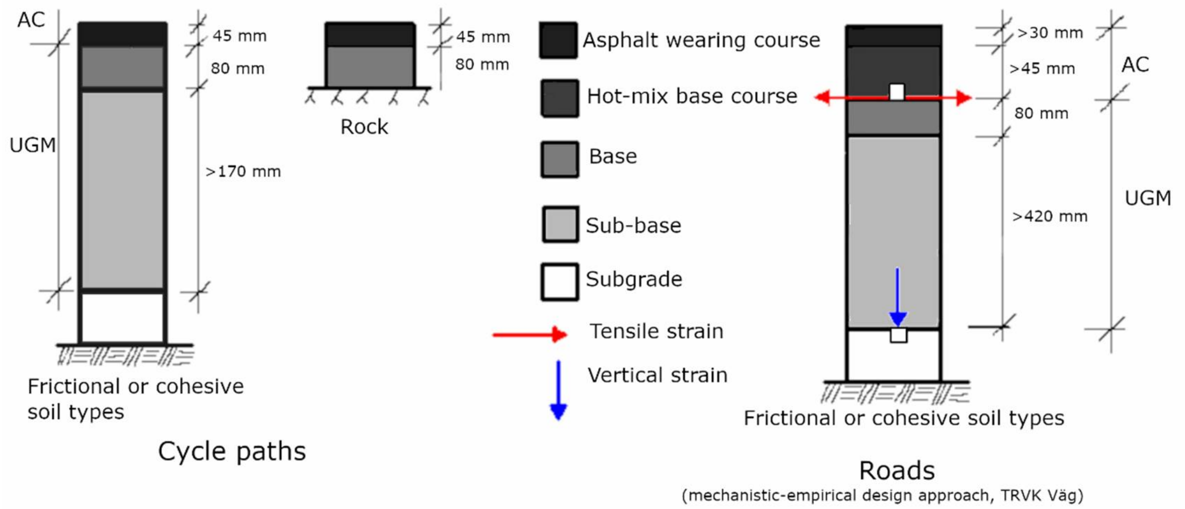


Figure 1. The structural design, with stipulated layer thicknesses of cycle paths and roads in the Swedish road- and street-design manual, *TRVK Väg*. The red arrows represent the design criteria of the tensile strain at the bottom of the AC layer, and the blue arrow represents the design criteria of the vertical strain on top of the subgrade.

The second reason is that the manual assumes a linear-elastic material behavior where the UGLs are assumed to be homogenous with isotropic properties. However, it has been suggested that this design model, though maybe adequate for thicker AC structures, is not applicable to the TSAP [15]. When subjected to traffic load from heavy vehicles, non-linear behavior including plastic deformation will occur in the upper 300 mm of the UGLs, close to the applied wheel load, due to the thin AC surface layer [15]. This is especially likely to occur in the thawing period when the moisture content of the UGMs is high [19,20]. The third reason is that, for low-volume roads, traffic load is not assumed to be the constraining factor; rather, they are designed to withstand the climatic conditions during the structural design period. Thus, the mechanistic–empirical design model of the manual is only to be used for traffic loads (100 kN axle load) with a Standard Single Axle Load (SSAL) of more than 500,000. As the manual stipulates that an SSAL of 150,000 should be assumed for the cycle path design period—normally 20 years—their structural design is based on an index method instead. The design manual is, however, only legally binding for the roads and cycle paths that are part of the national road network. For the municipal streets and cycle paths, the manual works as a guideline, but the municipalities are free to develop their own design principles. Table 1 compares the superstructures of cycle paths, according to design principles in the *TRVK Väg* [18], from different municipalities [21–23] and countries/states [24,25] with those of a typical street [18] and highway [26] in Sweden.

Table 1. Designs of superstructures with respect to layer thickness and materials for typical cycle paths, streets, and highways. The cycle paths represent the superstructures in *TRVK Väg* for small, middle-sized, and large municipalities in Sweden, and reference examples from Canada and Australia to represent cold and temperate climate conditions, respectively.

Type of Structure	Wearing Course	Binder Course	Bound Base Course	Unbound Base Course	Sub-Base Course	Total
Cycle path, *TRVK Väg*	45 mm	-	-	80 mm	>170 mm	>295 mm
Gällivare Municipality, Sweden	32 mm dense AC, max 11 mm aggregate	-	-	80 mm	>170 mm	>282 mm
Helsingborg Municipality, Sweden	25 mm dense AC	-	35 mm hot-mix base, max 16 mm aggregate	240 mm crushed rock	-	300 mm
Stockholm Municipality, Sweden	35 mm dense AC, max 8 mm aggregate	-	50 mm hot-mix base, max 16 mm aggregate	80 mm	420 mm	585 mm
Ontario, Province, Canada	40 mm HL3 max 13 mm aggregate	-	60 mm HL8 max 19 mm aggregate	Min. 200 mm Gravel A	-	>300 mm
New South Wales, State, Australia	60 mm AC, max 6 mm aggregate	-	-	-	150 mm crushed or uncrushed UGM	210 mm
Street, SSAL < 500,000, *TRVK Väg*	45 mm	-	-	80 mm	>420 mm	>545 mm
Highway	40 mm	50 mm	80 mm	120 mm	960 mm	1250 mm

3. Degradation of Cycle Paths

As for roads, there are mainly two factors that are considered in the structural design of cycle paths, namely traffic load and climate factors, i.e., temperature and moisture content. Analogous to roads, it is the heavy vehicles that constitute the biggest contribution to the traffic load [16]. Even though cycle paths are not intended for heavy vehicles, these vehicles still have a presence in the form of maintenance vehicles, emergency vehicles, trucks, and even tractors and agricultural equipment. For cold climate regions such as Sweden, it is the freezing temperatures, together with the subsequent thawing, that produce the largest negative effect on the pavements [27]. When the construction materials freeze during winter, the bearing capacity increases, and the strength is generally at its highest. There could, however, still be problems in the form of frost heave, as the water available as pore water in the road structure freezes and ice lenses are formed. Due to the cryosuction process, more water is attracted to the freezing front where the formation of ice lenses continues. When the ice melts in the thawing period, it could become trapped between the (relatively) impermeable surface AC and the still-frozen UGMs below, as both the freezing and thawing start from the surface and propagate downwards in the structure [28]. The thawing period is, consequently, the period of the year when the moisture content in the structure is expected to be at its highest level. The moisture content leads to a loss in bearing capacity in the structure, while the traffic load applied to the pavement results in increased damage [29]. Moisture can make its way into the construction either through cracks in the pavement, as capillary suction from the water table, or through pavement edges [30]. This should be especially true for cycle paths, as the edges, in many cases, lack a proper shoulder and, in some cases, even lack a well-functioning drainage system. Apart from being a thin construction, cycle paths are normally much narrower than roads, which makes it more likely that the heavy vehicles or maintenance vehicles that transit run closer to the edges. The maximum permitted width of a heavy vehicle in Sweden, such as a truck, is 2.6 m [31]. Even though the track width—about 1.85–2 m [32]— is somewhat smaller than the actual vehicle width, it is safe to say that when heavy vehicles/maintenance vehicles transit on narrow cycle paths, the load is applied close to the edges. According to the

Swedish condition assessment manual *Bära Eller Brista* [32], the edge cracks are likely to occur somewhere between 0.2 and 0.5 m from the edge of the path.

Another problem associated with the infiltration of water into the constructions is the growth of tree roots. The interface between different layers in the road structure is the most likely location for a root to penetrate the construction, as the difference in materials constitutes the location of least resistance [33]. The presence of oxygen, moisture and space underneath the pavement are optimal conditions for the growth of roots. As they grow, they push the overlaying layers of the structure upwards, resulting in lifting or cracking of the pavement [34]. Sidewalks are especially sensitive to this, due to the thinner AC pavements [35] and because the trees are often planted close to the sidewalk or cycle path. The general growth pattern of tree roots is radial, expanding outwards from the stem [36].

Ageing is often referred to as a main contributor to the degradation of low-volume roads and cycle paths. Ageing is divided into short-term ageing (STA) and long-term ageing (LTA). STA occurs in the mixing and transporting of the asphalt mix as the chemical properties of the bitumen are altered, through volatilization and oxidation, in the process of heating the binder when producing the hot asphalt mix. To minimize the effects of STA, strict upper temperature limits must, therefore, be maintained for the mixing process [37]. LTA occurs when the asphalt has already been laid on the road, and is a result of oxidation of the bitumen when in contact with the surrounding air. Moisture and UV-radiation from the sun are other factors that contribute to LTA. Oxidation, which makes the bitumen harder and, thus, more brittle and prone to cracking, is highly dependent on the air void of the asphalt mixture. A dense-graded AC undergoes much less ageing due to oxidation than a pervious AC. Additionally, a dense gap-graded mix will suffer less oxidation than a dense continuously graded mix, because the air voids in the gap graded-mix are discrete and not interconnecting, as could be the case in the continuously graded mix [38].

4. Materials and Methods

4.1. Description of the Survey

In autumn of 2020, a survey on the maintenance of municipal streets and cycle paths was sent out to the 290 municipalities in Sweden. To complete the information, the survey was followed up by interviews with personnel from 14 municipalities who had answered the survey. These municipalities were selected based on the following criteria: geographic location, population size of the biggest urban area of the municipality, and meter streets and cycle paths per inhabitant. The aim was to obtain a selection as representative as possible for Swedish conditions. From a total of 290 municipalities, 147 officially submitted answers to the survey, which gave a response rate of 51%. Another 15 municipalities answered several of the questions but did not officially submit their answers. However, these answers are still included in the results. Not all the responding municipalities answered all the questions and, therefore, the response rate differs slightly for each question in the survey. Geographically, the respondents were fairly distributed throughout Sweden (see Figure 2), with answers slightly more weighted toward the metropolitan region of the capital, Stockholm, with a slight underrepresentation of the south-eastern and western parts of the country. This reflects the distribution of population density quite well.

The survey consisted of 36 questions, divided into four general categories: general information about the municipality and the existing cycle path network; structural condition assessment; classification of cycle path damages; and budget. This paper focuses on the questions that concern the degradation of cycle paths and the stated mechanisms behind them. The first question was: "How frequent are the following distresses on the cycle paths?". The respondents were given a set of distress modes—taken from the Swedish condition Assessment handbook *Bära Eller Brista* [32], which is the state-of-practice alternative for visual condition assessments in Sweden—along with the following answering options: "Non-existing", "Not very frequent", "Quite frequent", "Very frequent", and "No information". This question was followed up by the question: "How frequent are the following causes of distress on the cycle paths?". This question was given a set of causes and the same answering options as the first question. This gives a rough estimate of the presence of different distress modes on cycle paths in general, but not the size of the distressed area—which varies from case to case—or the share of presence on the cycle path network. This information would have been valuable, but was believed to be too difficult to retrieve through a survey.

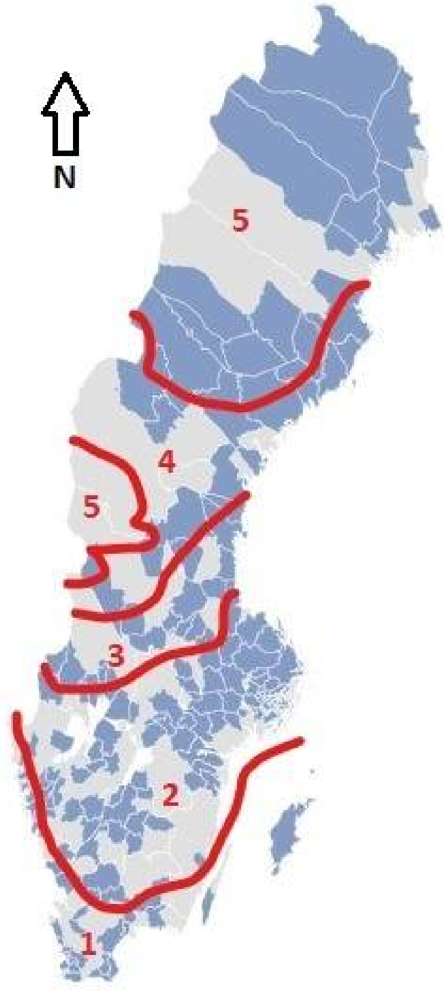


Figure 2. The responding municipalities (blue) in the survey are evenly distributed throughout Sweden, with a small overweight in the Metropolitan region of the capital Stockholm (salient in the central eastern part of the country). The red lines and numbers indicate the climate zones [18], corresponding to a freezing index of 300, 600, 1000, and 1200 °Cd, from south to north.

4.2. Method of Analysis

As described earlier, the two main factors that are considered in the structural design of roads are traffic load and climate factors, i.e., temperature and moisture. Therefore, the stated distress on cycle paths would ideally be analyzed with respect to traffic load, temperature, and moisture content. However, the traffic flow on cycle paths is seldom measured, and if it is, measurements are normally only conducted in a few spots on the network. In general, the measurements do not detect heavy vehicles that might transit on the cycle path, which makes it hard to estimate the traffic loads that affect cycle paths. From the conducted interviews, it was clear that the population size of the municipality influences not only the organizational level of the management, but also how the municipalities choose the structural design of cycle paths. Smaller municipalities may not have a technical handbook or guidelines for the construction of cycle paths, but instead, follow the recommendations of the Swedish Transport Administration; meanwhile, the municipalities of the major cities generally have technical handbooks with detailed information about cycle path sections and structural design. Even though the traffic flow on cycle paths is not measured—and especially not heavy vehicles—a correlation between the population size of the urban area and the number of heavy vehicles that transit on cycle paths is assumed. For instance, more cargo transport, which is mainly performed by heavy vehicles, is expected in bigger cities than in smaller ones. This was confirmed by the interviews, wherein the bigger municipalities stated that the main problem with heavy vehicles was not maintenance vehicles; rather, they stated that cycle paths were often used by other heavy vehicles for loading/unloading or in connection with construction sites. The smaller municipalities did not state this as a problem. The correlation between population size and the number of heavy vehicles transiting on the cycle path is also reflected by the total thickness of the cycle path superstructure chosen in the municipalities (Table 1). Due to the lack of data on traffic loads for cycle paths, the parameter of population size was used as a proxy for traffic loads in this study. The population data were collected from Statistics Sweden [39], and the categories used were based on intervals that, to some extent overlap with the Swedish definitions of Larger Cities, Medium-Sized Towns, Smaller Towns and Rural Municipalities [40]. To approximately comply with these definitions, the chosen categories doubled in population size for each category. For the municipalities that form part of the urban area of Stockholm and Gothenburg, special statistics developed by Statistics Sweden were used [41].

The effect of the climate on the degradation of cycle paths was determined using the climate zones in *TRVK Väg*. The climate zones are based on the Freezing Index, which describes the intensity and duration of the frost period and is defined as the maximum negative value of the summarized average daily air temperatures in the winter period, with the unit °C days [29]. The distribution of climate zones and their corresponding Freezing Indexes are shown in Figure 2. The effect of temperature on cycle paths was, thus, analyzed according to the climate zone in which each municipality is located. In cases where a municipality is split between two different climate zones, the zone that accords with the main urban area was used.

No measurements of moisture content were conducted; instead, precipitation data from the Swedish Meteorological and Hydrological Institute, SMHI, were used [42]. As the moisture content is at its highest during the thawing period [29], data for precipitation during winter and the thawing periods between the years 2000 and 2019 were used, to try to emulate the accumulative effects on the cycle path superstructure within a normal design period of 20 years. This may differ from the actual age of the cycle paths in the municipalities in the survey; however, it seems reasonable to use the design periods' length, as the actual ages are unknown. The estimation of the starting dates and the length of these periods were determined in two steps: First, an estimation of the start of winter for each measuring station was made, in accordance with maps from SMHI. The length of winter and the thawing period for each climate zone, according to *TRVK Väg*, was then applied for each municipality. Due to the division of road operators in Sweden—where responsibility is shared between the state, municipalities, and private operators [43]—most of the municipal roads and cycle paths are located in the urban areas of the municipality. Thus, the main urban area of each municipality was used as the reference point for the collection of precipitation data, i.e., the data were collected from the SMHI station closest to the biggest urban area in each municipality.

5. Results

In the following, the results of the questions in the survey concerning the degradation of cycle paths and the mechanisms behind them are presented and analyzed. To the question "How frequent are the following distresses on the cycle paths?", the respondents were given pre-defined answering options, as shown in Figure 3. The same question was also posed with respect to municipal streets. The answering options were the same as for cycle paths, but the listed modes of distress for municipal streets also included "Rutting".

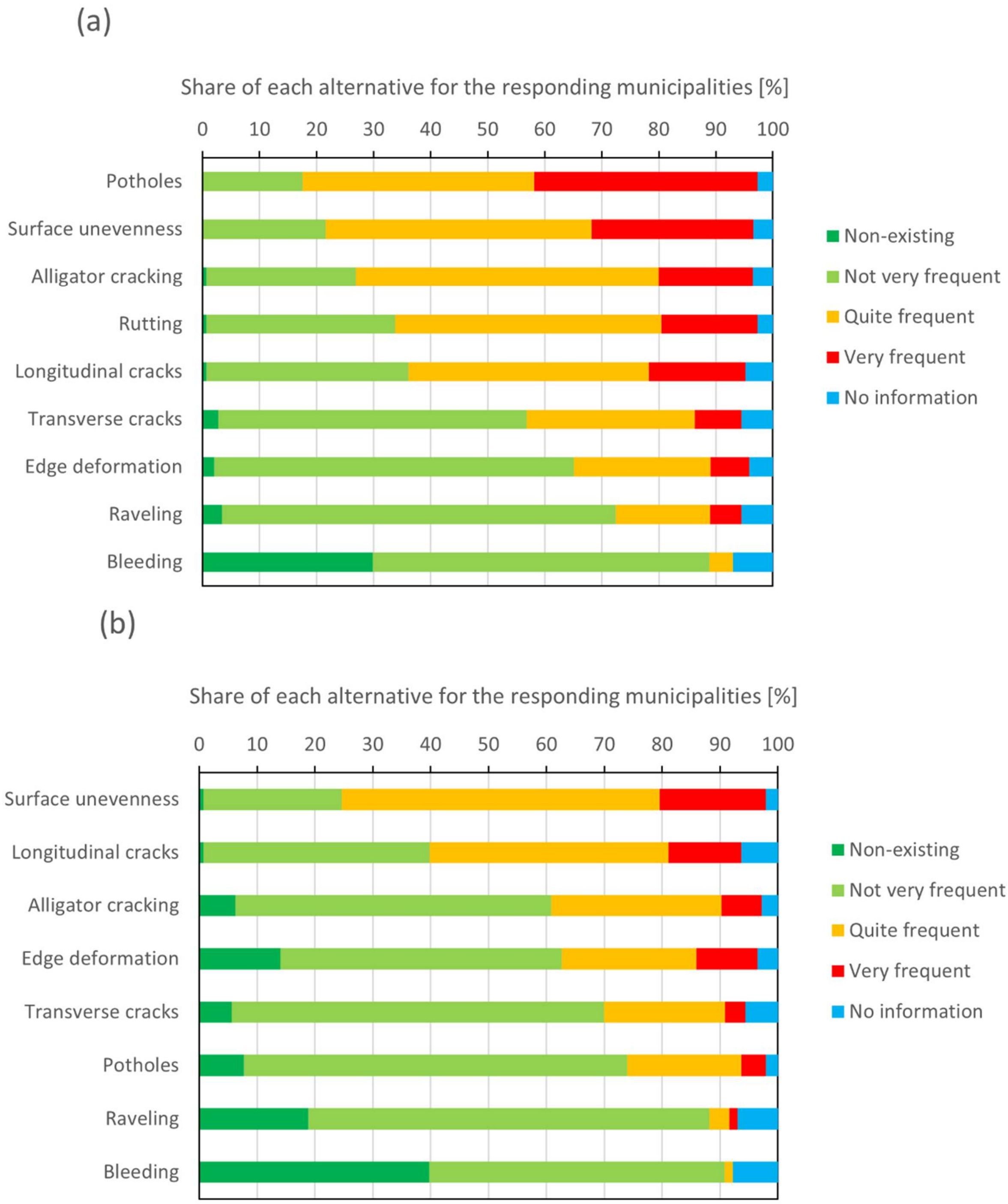


Figure 3. The stated frequency of distress by type on the municipal (**a**) streets and (**b**) cycle path networks, respectively. The response rate varies for the different distress modes and is marginally higher for streets (n = 144–148) than for cycle paths (n = 141–143).

As the figure indicates, generally, there seems to be more distress on streets than on cycle paths. Here it is important to bear in mind that the question concerned the frequency of different distress modes, not the severity of them. Uneven surfaces seem to be common on streets as well as on cycle paths; however, for streets, potholes are the most frequent distress mode, whereas on cycle paths, they are not very frequent. The consequences of the different distress modes differ between streets and cycle paths, e.g., cyclists are believed to be more sensitive to surface unevenness, and the impact on their traffic safety, comfort and level of service is likely to be of higher importance than for car drivers. The consequences of the degradation of the infrastructure, and of the road users' use of that infrastructure, are not necessarily the same. The effects should, in this case, be treated in accordance with how they affect the users, even though, in practice, much of the cycling is bound to happen on streets. This is due to another common problem with cycle infrastructure that came up during the interviews, namely, that there are many missing links in the networks; thus, cyclists are compelled to follow the street network, at least to some extent.

The different distress modes were analyzed with respect to climate, represented by the climate zone in which the cycle path is presumed to be located, and the accumulated amount of precipitation during winter and thaw periods. If the assumption is made that "Quite frequent" and "Very frequent" represent a problematic frequency of a certain distress, the share of municipalities that state this distress as a problem can be plotted with respect to climate zones, as shown in Figure 4. The distress modes that showed a probable connection with the distribution of climate zones, i.e., with a coefficient of determination (R^2 value) higher than 0.7, were surface unevenness (R^2 = 0.72) and transverse cracks (R^2 = 0.78). A list of correlations with respect to climate zones, for all distress modes, is found in Table A1 in Appendix A.

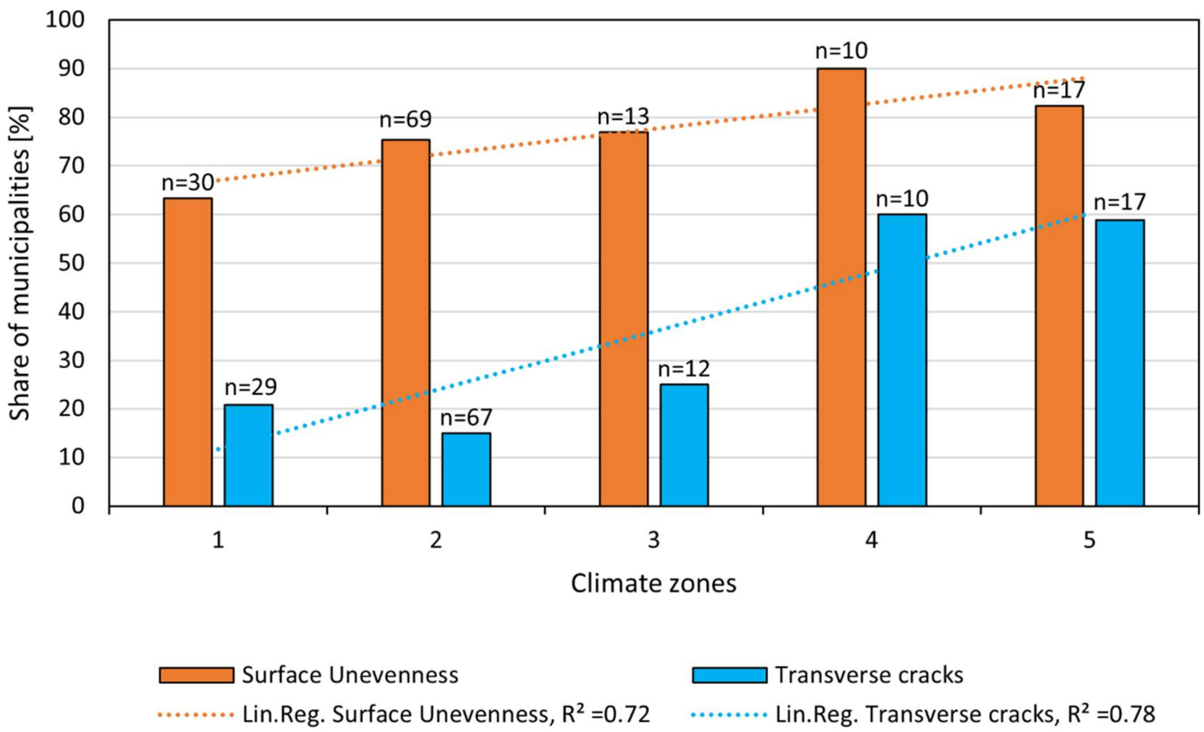


Figure 4. The correlation of the stated problematic frequency of surface unevenness and transverse cracks on municipal cycle paths with the climate zones in *TRVK Väg*.

When grouped by answering option, the results of the distresses can be plotted against the mean average amount of precipitation during winter and thaw periods during the period of 2000–2019 (see Figure 5). The two distress modes that seem to correlate with the amount of precipitation are alligator cracking (R^2 = 0.94) and edge deformation (R^2 = 0.80). Raveling and bleeding also have high R^2 values (0.82 and 1, respectively) but for raveling, this is based on only two respondents stating, "Quite frequent" and one respondent stating, "Very frequent". For bleeding there is simply no respondent stating, "Quite frequent" or "Very frequent". Consequently, the frequency of these distress modes on the municipal cycle paths cannot be considered to be problematic. A list of correlations with respect to mean average precipitation during winter and thaw periods during the period of 2000–2019, for all distress modes, is found in Table A2 in Appendix A. As seen in the figure, the greater the frequency of the distress occurring, the less the precipitation. This result is somewhat unexpected, as the assumption is that more precipitation during this critical period of the year would result in more damage to the cycle path structure.

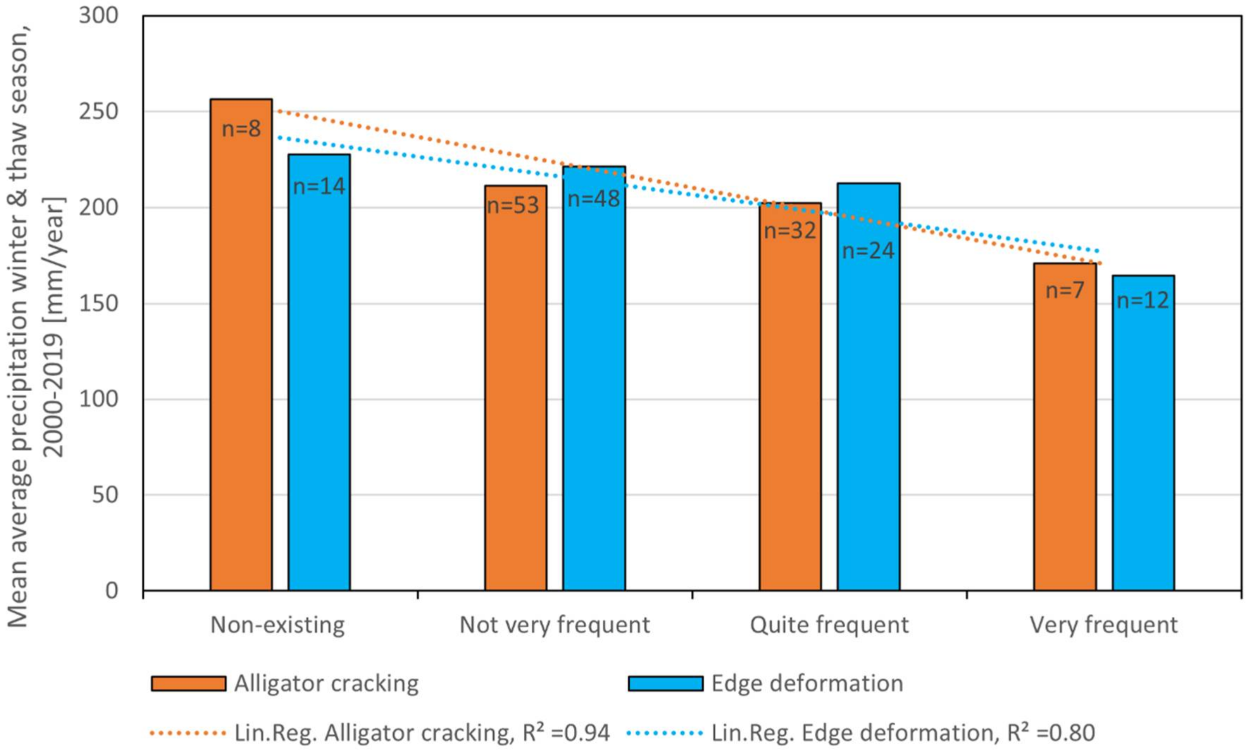
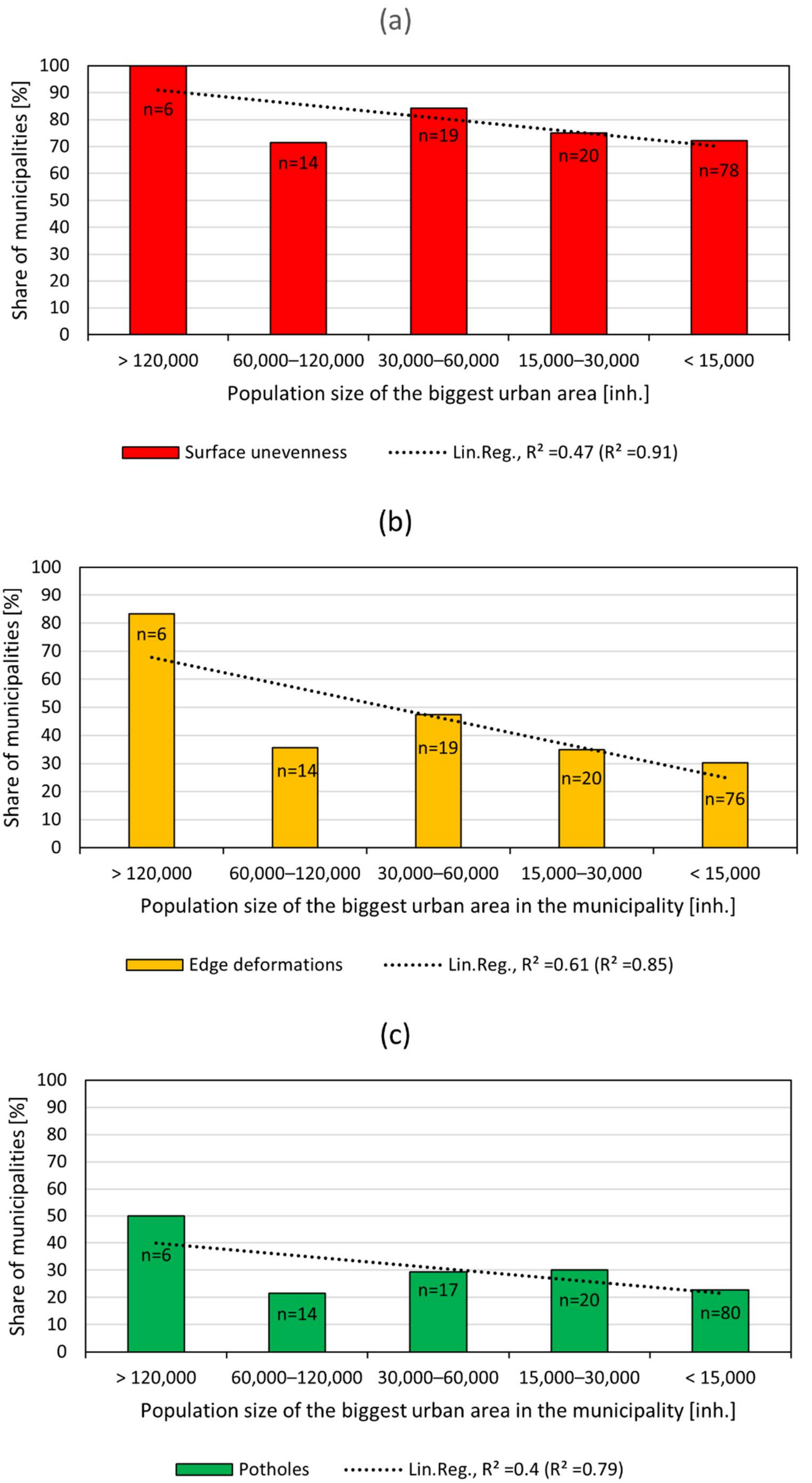


Figure 5. The correlation of the stated frequency of alligator cracking and edge deformation on municipal cycle paths and the mean average precipitation for winter and thaw seasons 2000–2019.

If, once again, "Quite frequent", and "Very frequent" exhibit problematic frequencies, figures could be plotted for the distress categories with respect to the population size of the biggest urban area of the municipality. For such a division, the four distress modes that correlate with the main urban area population size are surface unevenness (R^2 = 0.47), edge deformations (R^2 = 0.61), potholes (R^2 = 0.40), and transverse cracks (R^2 = 0.59), as shown by Figure 6. However, these coefficients of determination indicate weak ($0.3 < R^2 < 0.5$) or moderate ($0.5 < R^2 < 0.7$) correlations. These weaker correlations seem to be connected to an accentuated "dip" in the trend for the municipalities in which the main urban area has between 60,000 and 120,000 inhabitants. The R^2 values within the parentheses in Figure 6 show the adjusted correlation if this particular population category is excluded. The pattern, with a dip in the curve for the 60,000–120,000 inhabitants category, seems to also be valid for basically all the other distress modes, even though there does not seem to be a correlation between distress and population size for all modes (see Table A3) in the Appendix A. Nevertheless, the municipalities in the 60,000–120,000 inhabitants category state a less problematic frequency of distress for all distress modes except for edge deformations and bleeding, compared to the other population categories for each distress mode.



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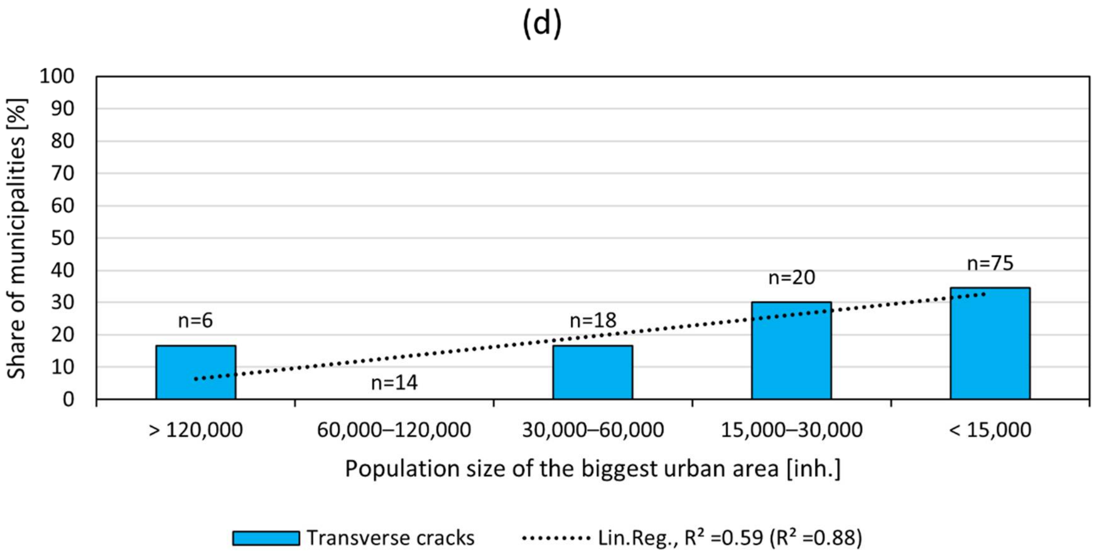

Figure 6. Correlation of the problematic frequency of (**a**) surface unevenness, (**b**) edge deformation, (**c**) potholes, and (**d**) transverse cracks on municipal cycle paths, with respect to the population size of the biggest urban area in each municipality. Note that the x-axis is logarithmic.

The municipalities were also asked to state which factors they, in their professional opinion, considered to be the most common causes of distress on streets and cycle paths. The results are shown in Figure 7.

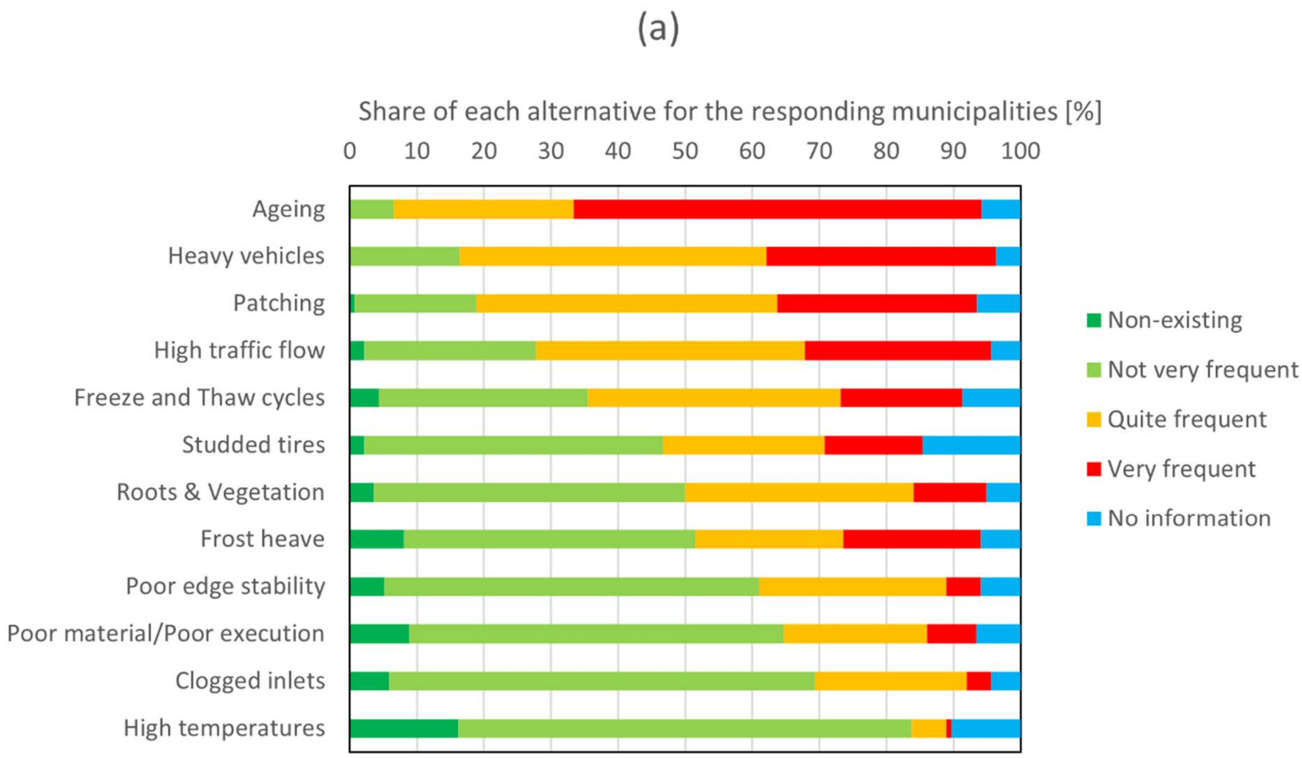

Figure 7. *Cont.*

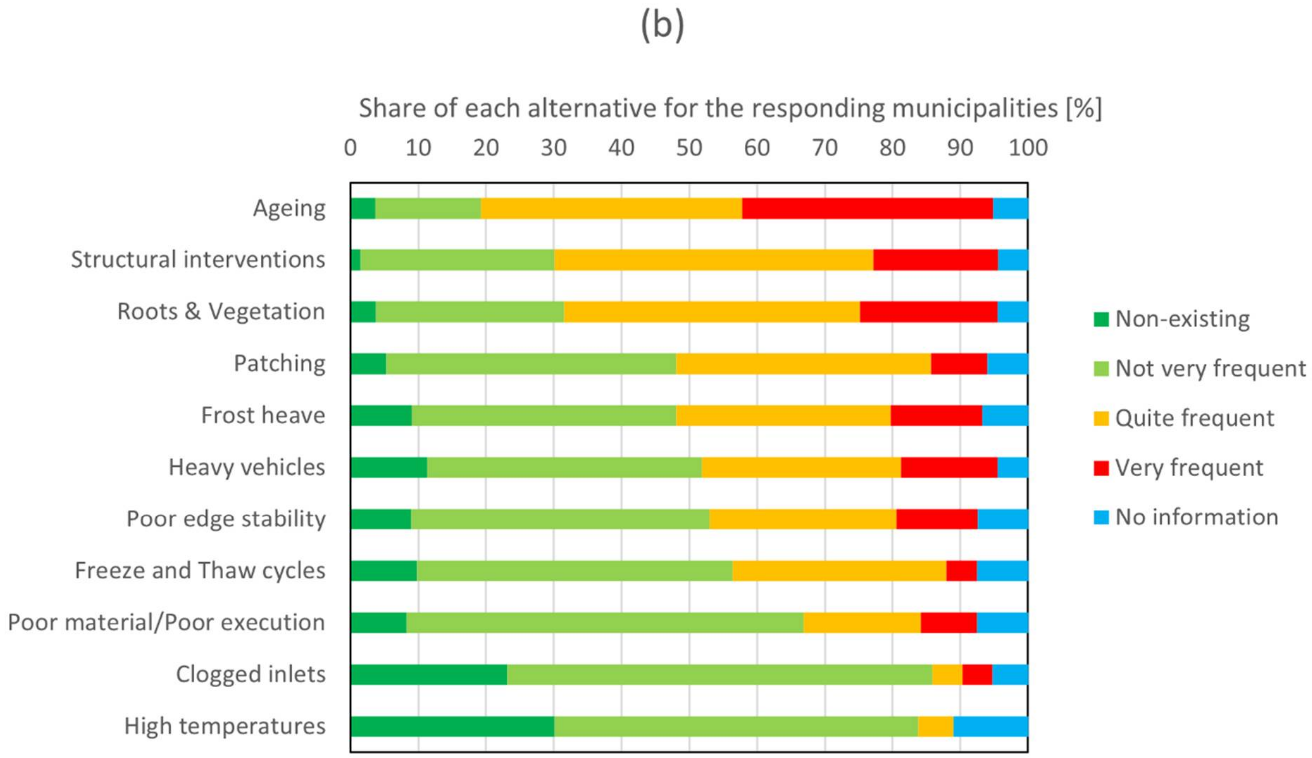

Figure 7. Stated causes of distress on the municipal (**a**) street- and (**b**) cycle-path network. The response rate varies for the different distress causes and is marginally higher for streets (n = 136–140) than for cycle paths (n = 133–136).

The stated causes of distress modes are generally more common for streets than for cycle paths, i.e., they have a higher level of frequency. The fact that ageing is stated as a cause that is even more frequent on streets than on cycle paths could explain, at least partially, the presence of more distress in general on streets than on cycle paths. For the results on the stated distress modes, the stated causes behind them can also be analyzed with respect to the climate and population size of the biggest urban area. If an analogous division of the answers, i.e., "Quite frequent", and "Very frequent" constitutes a problematic frequency, the prominent stated causes of distress can be plotted. The causes that show a strong correlation with climate zones are frost heave (R^2 = 0.89), freeze and thaw cycles (R^2 = 0.99), poor material/poor execution (R^2 = 0.90), and roots and vegetation (R^2 = 0.98) (Figure 8). As expected, the correlations are positive for frost heave and freeze and thaw cycles, with an increase in problematic frequency for higher climate zones. The correlation, with respect to climate zones, for poor material/poor execution is also positive, indicating that the access to materials and/or execution is higher in the south of the country than in the north. For roots and vegetation, however, the correlation is negative, which indicates that this distress cause is more common in the milder climate of the south of Sweden than in the colder climate of the north. With respect to population size, there is a strong correlation for patching (R^2 = 0.84), Figure 9, for which the problem is more extensive in the bigger urban areas.

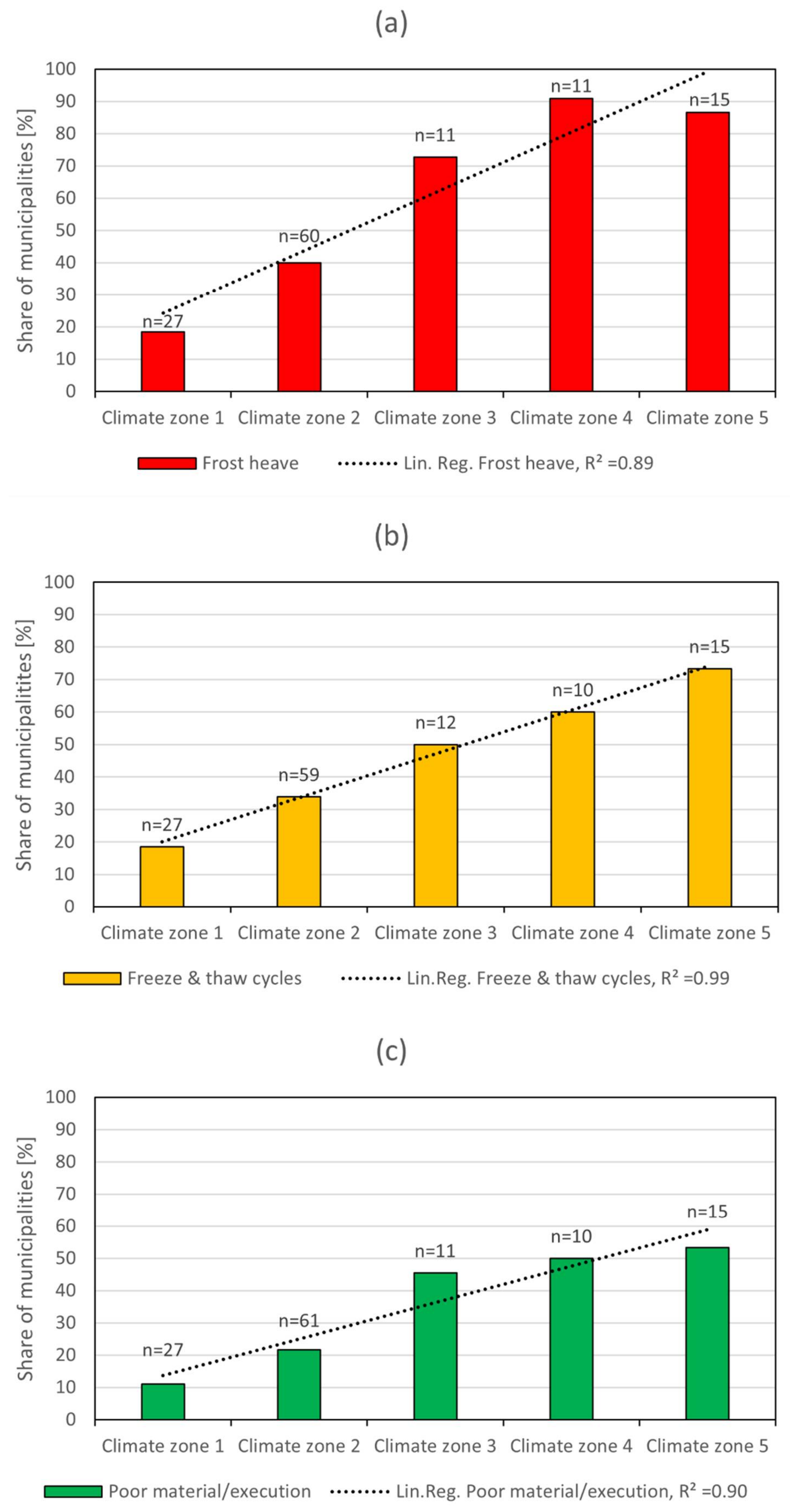

Figure 8. *Cont.*

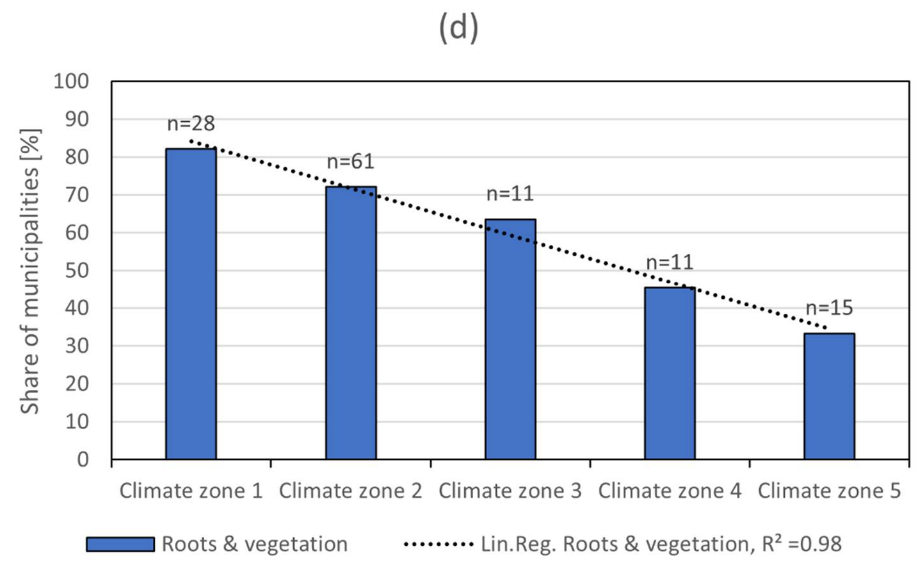

Figure 8. Problematic frequency of distress causes on the municipal cycle path networks with respect to climate zones for (**a**) frost heave, (**b**) freeze and thaw cycles, (**c**) poor material/poor execution, and (**d**) roots and vegetation.

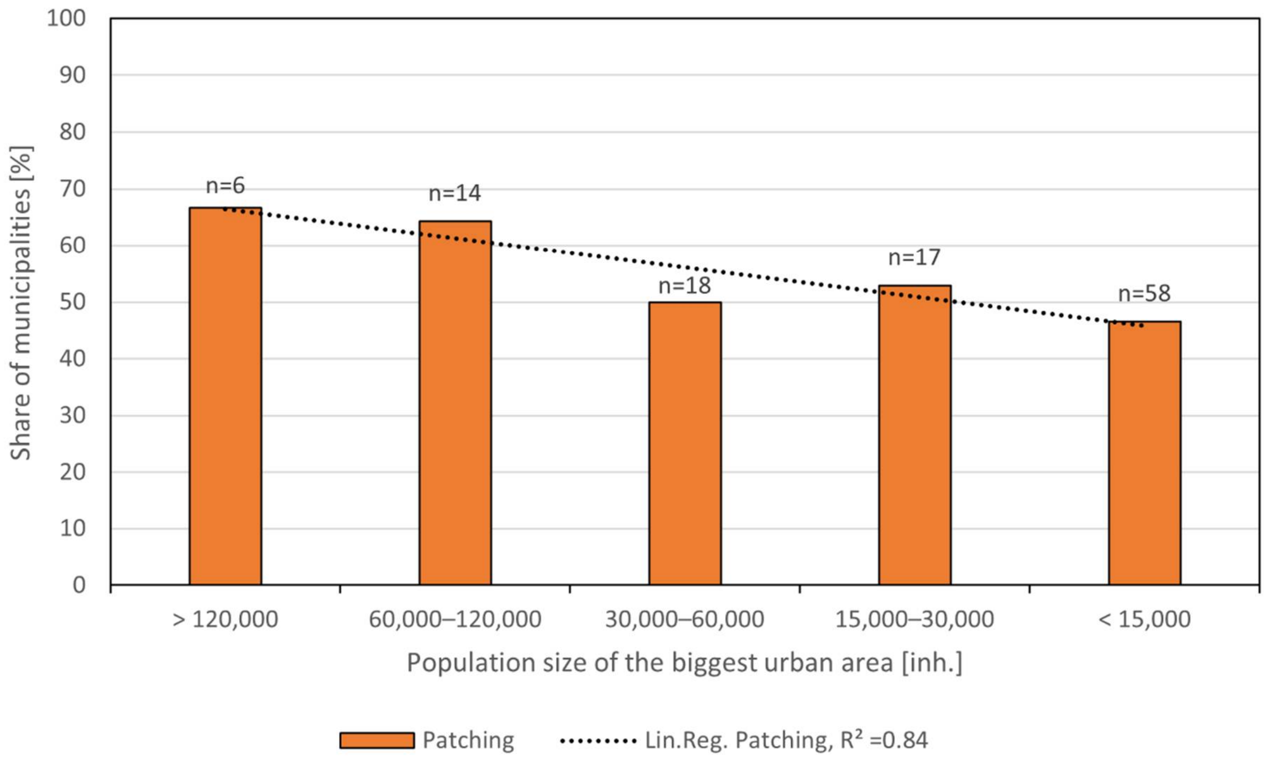

Figure 9. Correlation of problematic frequency of patching and population size of the biggest urban area for each municipality.

6. Discussion

6.1. Methodology

The survey was, in most cases, sent to the help desks of each municipality, who passed it on to the person who they deemed suitable to fill it out. This approach was chosen as direct contact information on the municipal road and transportation departments is generally not accessible in Swedish municipalities. As a result, respondents came from different professions—commonly those of manager, traffic engineer, or urban planner—and had varying knowledge of the design and maintenance of streets and cycle paths. This difference could potentially skew the results. However, in many cases, responding to the survey was a team effort, where other persons in the municipality were consulted in the case of lack of knowledge from the respondent; this became apparent from the interviews.

The questions in the survey were also posed in a way that made them difficult to analyze with statistical methods. However, this was not the intention of this study; the general method was a survey wherein the municipalities stated the condition of the municipal streets and cycle path networks, and was not a compilation of conducted condition assessments. The results should, thus, be used as an indication of problematic distress on the municipal cycle paths, rather than conclusions based on a solid quantitative analysis. The results shown in Figures 3–9 are, thus, not statistically significant, and the correlations are only assumed to be linear. In practice, it is possible that the correlation is non-linear; however, to assume a non-linear correlation, there must be good reasons to do so, e.g., a theory that supports this assumption. Based on the reviewed literature, this is not the case for this study. As there are a limited number of municipalities in Sweden, it is possible that the method used in this study, i.e., analyzing distress at the aggregated level of municipalities, may also have been too limited to obtain statistically significant results, even if all the municipalities in Sweden had responded to the survey. Ideally, a large number of cycle paths with known traffic loads and climatic conditions, gained through data from temperature- and moisture-gauges in their constructions, should be used to confirm the results of the study. However, the problem is that these parameters are not known for a large number of cycle paths. Nevertheless, in general, the stated modes of distress seem to be coherent with previous studies that are based on condition assessments of municipal cycle paths [44]. As some of the municipalities have a limited cycle path network, cyclists are, in many cases, compelled to cycle on streets instead of on cycle paths, which makes the distress on the local streets important as well, from a cyclist's perspective. Nonetheless, the focus of this paper is limited to distress on cycle paths, though comparisons are made with streets, as the similarities and differences should be highlighted.

The reason for choosing population size as a proxy for traffic loads may seem far-fetched. However, there are some studies that indicate that the lack of parking space for delivery trucks, which is generally a bigger problem in more populated urban areas, tends to generate illegal parking [45,46]; for example, more than 60 % of the operations of surveyed establishments in Paris were attended by an illegally parked truck (on a bus or bicycle lane, or on the sidewalk) [46]. This is in line with what was stated by the municipalities in the interviews as well, which gives some credit to the assumption, although this is something that needs further investigation. Similar reasoning could be applied to the precipitation data used for the analysis of the stated distress on cycle paths, as to whether it is a relevant approach for the purpose of the study. The same type of data were used for previous studies; for example, Mei et al. [47] used climate data and found that the fatigue life of asphalt pavement in rich rainfall areas was about 60% of the fatigue life of areas with a drought climate and no rain. Precipitation data in connection to temperature data, using the Thornthwaite Moisture Index, have also been used to analyze the deterioration of sealed low-volume roads in Australia [48]. As it is common to find roads with pavement failure that are evidently associated with prolonged exposure to high moisture content in cold regions [28], the method seems justified to use, even though the data are not directly connected to any specific cycle path but, rather, are analyzed on an aggregated level.

In the survey, the category edge deformation was used for the question "How frequent are the following distresses on the cycle paths?". Normally, a distinction is made between edge cracks and edge deformation in the literature, whereas in practice, they are often connected. A common course of events is that edge cracks are formed first, but may develop into alligator cracking and then raveling, or a loss of whole asphalt blocks on the edge of the road. It is likely that some of the municipalities do not make this theoretical distinction in their answers and, therefore, the concept edge deformation in the context of this paper refers to both edge deformation and edge cracks.

6.2. Results

The results of the causes that the municipalities state as the most common, i.e., ageing, structural interventions, and roots and vegetation, along with edge deformation, are discussed below. The reason that edge deformation is included in this context, even though it is a distress mode and not a cause of distress, has to do with the aforementioned practical instrumentalization of the concepts of edge deformation and edge cracks. They are treated in order of the stated frequency, and discussed with respect to the stated distress modes and the theoretical knowledge about these distress modes. The section ends with a discussion of the possible impact of design- and maintenance-strategies and budget on the degradation of cycle paths.

6.2.1. Ageing

The most common cause of distress on cycle paths according to the municipalities is ageing. This is not consistent with the stated distress modes, though, as ageing in pavement management generally refers to the oxidation of the bitumen. This oxidation hardens the bitumen and makes it more brittle, giving way to micro-cracks and loss of adherence to the aggregate. The distress modes that are normally expected in connection to this phenomenon would be raveling, potholes, and alligator cracking [30]. These are, however, not the distress modes that are stated as the most common. There seems to be a conception in the municipalities that just because many of the cycle paths are, in fact, aged—i.e., older than the 20 years of the normal structural design period—the distress would automatically be a consequence of this ageing. As the oxidation is, to a large extent, dependent on the air void of the asphalt mix—where a dense-graded asphalt is less prone to oxidation—theoretically, cycle paths should be less affected by LTA than a road or street with AC layers, which will not always be designed with a dense asphalt mix. According to the interviews and the consulted municipal handbooks, most of the cycle paths in Sweden are designed with a soft bitumen (pen 160/220). Because the oxidation hardens the bitumen, given the option of a softer bitumen, the municipalities have already taken LTA into account, as the hardening will theoretically occur later in time with the softer bitumen than with a harder bitumen. For the roads, however, a stiffer bitumen is often needed to avoid rutting from the traffic loads. LTA is, therefore, expected to develop faster on roads than on cycle paths, given that both are subject to the same climatic conditions. This is also what the results of the survey suggest, even though the actual age of the streets and cycle paths, as well as the design material for the streets of the municipalities in the survey, is not known. According to the interviews, at present, this type of information is not collected or saved in a systematic way to be retrieved for more detailed analyses. For maintenance management, such a systematic approach would be beneficial. There is no information on STA for streets or cycle paths in the survey either, but there should not be a difference between streets and cycle paths in this respect, as the asphalt mix is most likely mixed and stored in the same conditions for both.

6.2.2. Structural Interventions

Both "structural interventions and roots and vegetation are connected to cracking in some sense. Structural interventions and patching are closely connected as well, as patching is often a consequence of a structural intervention. Any joint that is built into the construction constitutes a potential weakness, and cracks are prone to form along these joints [49]. The structural interventions could also explain some of the surface unevenness, as it is difficult to ensure that the properties of the refilled UGMs are consistent with the conditions before the intervention, e.g., a similar degree of packing. Some of the interviewees explained that it is the responsibility of the utility line owners to restore the construction after the performed maintenance on the utility lines, and it is not always the case that the municipality can perform a control of this restoration of the cycle path. As structural interventions are the second most common stated cause of distress on cycle paths, further investigation is needed into the extent of the problem, along with the procedures and materials used. As patching appears to be more common in the bigger urban areas, the economic consequences of multi-utility tunnels versus increased maintenance costs are also an area that needs further investigation. There are studies that suggest that, at least for some locations with multiple installations, the life-cycle cost of such an approach with multi-utility tunnels could be more cost-effective [50].

6.2.3. Roots and Vegetation

The expansion of tree roots growing under a cycle path can cause the thin AC to crack from the deflection and stresses formed by the expanding root. As described, the roots will spread radially outwards from the stem. The cracks are, thus, expected to not only be transverse or longitudinal, but also diagonal. The respondents did not have the option of diagonal cracks, so there is reason to believe that some of the stated transverse and longitudinal cracks are produced by roots. In the Swedish condition assessment manual *Bära Eller Brista* [32], the severity of cracks is dependent on the crack type. For transverse cracks and joint cracks, if the cracks are over 10 mm wide, they are considered severe, but for longitudinal cracks due to frost heave or edge cracks, the cracks must be at least 30 mm wide to be considered severe. However, cracks caused by roots are not described in this manual. These measurements do not seem to be consistent with the risk they pose to cyclists. Longitudinal cracks are a bigger potential risk for cyclists, as a wheel could become trapped if the crack is wide enough, whereas transverse cracks are approached perpendicular to the crack and do not normally pose a safety risk to the cyclist, even though they can be uncomfortable to pass. Longitudinal cracks are, however, often easier to avoid than the transverse cracks, as in most cases, the cyclist can adjust his or her lateral position on the cycle path. A potential risk of diagonal cracks is that they are hard to avoid, but at the same time pose the risk of the wheel getting trapped.

The types of trees planted are important, as the root systems develop differently; however, from the interviews, it seems that the municipalities in general are aware of this, as they use the manual GCM-Handbok [51] in which the tree types most prone to causing root cracks are described. Considering that roots and vegetation is stated as one of the most frequent causes of distress on cycle paths, there seems to be a lack of knowledge on how to avoid this problem. The problem of root cracks shows a high correlation ($R^2 = 0.98$) with climate, where the frequency is higher the milder the climate. This does not necessarily mean that it is the milder climate, i.e., higher temperatures, that is the direct cause of the root cracks. It could be that there are more trees planted close to the cycle paths in the south of the country than in the north. However, it seems likely that the milder climate, with a longer annual period where the soil is frost free, will affect the possibility of root growth due to favorable conditions. Further studies are needed to investigate how these cracks surge and propagate, the consequences they pose to cyclists, and how this problem could be better attended in the construction design and maintenance of cycle paths.

6.2.4. Edge Deformation

Even though edge deformation is not the most frequent type of distress on cycle paths, it is still problematic as it poses a potential traffic safety risk to cyclists, as well as a potential problem with the level of service for cyclists due to a diminished effective width of the cycle path. The stated average widths of the municipal cycle paths in the survey varied from 1.2 m to 4 m, with 3 m being the most common width. The mean average width of a cycle path for all municipalities was 2.83 m (st. dev. 0.45 m). This indicates that for many of the cycle paths in the survey, the loads from heavy vehicles are applied close to the edges. Thirty-four percent of the municipalities state the average width of their cycle paths to be 2.6 m or less. This could be considered a width at which applied loads from a heavy vehicle are likely to cause edge cracks, based on the assumption that the cracks are most likely to occur within a range of 0.2–0.5 m from the edge, as described by Ekdahl [32]. In the survey, longitudinal cracks were reported as more frequently occurring than edge deformation. In practice, however, these two distress modes are often connected. As longitudinal cracks produced by the traffic load of heavy vehicles are likely to occur close to the edges, it could be hard to distinguish between cracks and edge deformation. Edge deformation often leads to the formation of longitudinal cracks and alligator cracking close to the edge of the road. As the edge is bent down by the outer wheel of heavy vehicles, tension is created in the AC layer, which manifests in the formation of cracks [30].

On off-road facilities, cycle paths are often laid in parks or green areas where, in many cases, the lack of a shoulder and permeable materials on the sides of the path, in combination with a poor crossfall of the path, makes the runoff insufficient. In the interviews, some municipalities also pointed to the fact that these cycle paths are often maintained by the park administration of the municipality rather than the municipal street department, and the focus of the maintenance may therefore differ. For example, edge cutting of grass is more highly prioritized from a street department perspective than from a park administration perspective, where aesthetic aspects are given a higher priority. The edge of the road is also more sensitive to damage as there is less lateral support [30]. The combination of these factors makes the cycle path especially vulnerable to edge deformation. This could be improved by better lateral support, e.g., in the form of curbs, in combination with minimizing the presence of heavy vehicles on cycle paths. In the survey, though, the municipalities stated almost as many problems with edge deformation on streets as on cycle paths. This could perhaps be explained by the fact that there seems to be more distress on streets in general, possibly, in part, due to more advanced ageing of streets. Another explanatory factor could be that most of the municipal street network consists of local streets that have more in common with cycle paths than with national roads or highways, in the sense that the road width is narrower, and they are generally not designed for high traffic loads and heavy vehicles. Thus, they are designed in a similar way to cycle paths, i.e., with respect to layer thicknesses and asphalt mix. As indicated by the respondents in the survey (Figure 6), heavy vehicles are stated as a frequent cause of distress on streets, with about 80% of problematic frequency, compared to a problematic frequency of about 45% on the cycle path network. However, poor edge stability is stated as more frequent on cycle paths than on streets.

The apparent correlation between accumulated precipitation and the distress modes alligator cracking and edge deformation is somewhat confusing, as it seems to be that the more frequent the distress, the lower the precipitation. Theoretically, this is expected to be the other way around, as described in Section 3. For the alligator cracking, the precipitation seems to coincide with population size in the biggest urban area for each municipality. A higher frequency of alligator cracking is connected to both lower accumulated precipitation and lower population size of the biggest urban area. This is contrary to the case of edge deformations, where a higher frequency of distress is connected to lower accumulated precipitation and to higher population size of the biggest urban area. Our suspicion is, thus, that there is an overlapping effect between edge deformation and accumulated precipitation on one hand, and of respective edge deformation and population size of the biggest urban area on the other hand. This could possibly explain the unexpected result of a correlation between the higher frequency of edge deformations and the lower accumulated precipitation. Nevertheless, this explanation does not seem to be valid for the alligator cracking, as there are alternative factors that could possibly explain the higher frequency of alligator cracking being connected to a decrease in accumulated precipitation. It could be that there is another factor—such as a lack of maintenance budget or age of cycle paths—that, for some reason, covariates with the precipitation; this could explain the correlation. However, the information available on the average age, structural design, runoff, and drainage of cycle paths in each municipality is insufficient, which makes it hard to determine an alternative explanation. Therefore, this is also something that needs to be further investigated.

6.2.5. Temperature-Dependent Cracks

If longitudinal cracks occur in the middle of the path instead of at the edge, it is more likely that they are caused by frost heave. These cracks are characterized by being both wide and deep. This would be expected to be more common in the northern parts of the country due to lower temperatures, and especially where the soil type is susceptible to this phenomenon. The longitudinal cracks did not show any correlation with the climate zones; however, as previously mentioned, there are various reasons for these cracks, not all of which are necessarily connected to the climate.

Transverse cracks, as well as surface unevenness, edge deformation, and potholes, show a correlation with the size of the biggest urban area in each municipality, and just as for these other distress modes, the category of 60,000–120,000 inhabitants differs from the general trend. However, the correlation between transverse cracks and population size is negative, unlike the positive correlation found for the other distress modes. This means that the general trend is the smaller the urban area, the larger the frequency of transverse cracks. There could be an overlapping effect in this case between the climate zones and population size of the biggest urban area, as the transverse cracks seem to correlate with both parameters—i.e., a decrease in temperature is connected to a higher frequency of transverse cracks, and a decrease in population size of the biggest urban area is, likewise, connected to a higher frequency of transverse cracks. In general, urban areas are often a few degrees hotter than the surrounding countryside, due to the heat-accumulating effect of the buildings and streets along with human activity. The results of this effect are known as urban heat islands, and have been proven to be connected to the population size of the urban area, where a more populated urban area results in a bigger temperature difference relative to the surrounding rural area [52]. Surface unevenness also correlates with both climate zones and population size, but in this case, the correlation is divergent—i.e., the problematic frequency of surface unevenness increases with lower temperatures, but decreases with smaller urban areas. In other words, there does not seem to be an overlap between the climate zones and the population size of the biggest urban area with respect to distress modes in general.

The transverse cracks are stated as more common on streets than on cycle paths. Normally, these cracks are produced by the impossibility of longitudinal movement of the asphalt when shrinking during low temperatures [30]. The difference between streets and cycle paths for this distress mode is not easy to explain, as a soft binder (pen 160/220) is used on both cycle paths and local streets, of which the latter constitute most of the municipal street network. However, main streets—which only make up a small part of the municipal street network—generally use a stiffer binder (pen 70/100) that would be more sensitive to cracking at low temperatures. The fact that there seems to be more distress in general on streets probably affects the presence of transverse cracks as well.

6.2.6. Strategies and Budget

Figure 6 indicates a positive correlation between the population size of the biggest urban area of each municipality and the stated frequency of surface unevenness, edge deformations, and potholes. This correlation could be attributed to a higher risk of heavy vehicles transiting on cycle paths in the larger cities. However, the municipalities with the biggest urban areas, in the range of 60,000–120,000 inhabitants, state a less problematic frequency than the general trend suggests. The municipalities in this range are, to a large extent, so-called "cycling cities"—cities with relatively high cycling shares and, thus, often more inclined to invest in cycle infrastructure [53]—or municipalities in the urban area of one of Sweden's three larger cities. These municipalities often have technical handbooks, where the structural design of cycle paths is based on empirical knowledge rather than on the index method of the Swedish road and street design manual. For the municipalities in this category that have technical handbooks accessible online, the average minimum total thickness of the cycle path superstructures is estimated as 18% thicker than what is recommended in the *TRVK Väg* [18], and the combined thicknesses of the AC layers are estimated to be 29% thicker. Still, due to the difference in population size, they will probably not have as many heavy vehicle transits on cycle paths as the largest cities. However, this is uncertain, as the number of heavy vehicle transits can be related to the winter maintenance strategy applied in the municipalities. Several of the "cycling cities" apply a certain winter maintenance method called "sweep-salting", which requires more frequent action but, on the other hand, generates a higher quality of service [54]. Only one of the fourteen municipalities in this category is in the north of the country, but the fact that they are underrepresented in the problematic frequency of edge deformations does not seem to have an overlapping effect with climate zones; this is because none of the six cities categorized as having a population bigger than 120,000 is in the north.

Larger populations generally have higher tax incomes, which potentially result in more investment and higher maintenance spending on cycle infrastructure. It also seems that the larger cities spend more, not only in absolute amounts but per capita as well. In the last decade, the municipalities in which the biggest urban area is in the category of >120,000 inhabitants have, on average, spent 24% more per capita on investment in new cycle infrastructure, and operations and maintenance, than the average municipality. The corresponding amount for the 60,000–120,000 category is 17% higher than average [52]. This is consistent with the response from the survey, wherein the budget for reinvestment in and maintenance of cycle paths seems to be higher in the bigger cities and cycling cities, of which most are located in climate zones 1 and 2. The budgets ranged from 54.4 SEK per meter in climate zone 1, through 50.5 SEK per meter in climate zone 2, 44.2 SEK per meter in climate zone 3, and 41.7 SEK per meter in climate zone 4, and down to 23.4 SEK per meter in climate zone 5. However, these numbers are uncertain, as not all municipalities divide the budget between streets and cycle paths in different categories. In part, the numbers are, therefore, estimates by the municipalities, but they still seem to support the trend that bigger cities and "cycling cities" spend more money on the reinvestments and maintenance of cycle paths.

7. Conclusions and Recommendations

This study is based on a survey in Swedish municipalities, in which they were asked about the distress modes on cycle paths and the causes behind them. The results show that ageing, followed by structural interventions and roots and vegetation, are the most common causes of distress.

Conducting this study as a survey was a methodological choice because of a lack of objective data, i.e., cycle paths equipped with temperature- and moisture-gauges and where the traffic loads are known. To be able to perform a more exact analysis on the degradation of cycle paths, these types of data are needed. As the heavy vehicles that transit on cycle paths vary from compact maintenance vehicles to agricultural tractors, more information is needed, not only on the number of transits, but also on the speed, wheel- and axle-configurations, and tire pressures. In connection to this, more information is needed on how different operations and maintenance strategies affect the number of heavy vehicles transiting on cycle paths. From this study, there are indications that the structural design of cycle paths differs a great deal from one municipality to another. Consequently, the different designs need to be further investigated with respect to width and layer thicknesses, along with the reasons behind the choice to use these designs and how they affect degradation processes.

In terms of ageing of the cycle paths in the survey, there is no evidence that cycle paths should be more exposed to ageing than the roads and streets. Rather, the results indicate that cycle paths are less prone to LTA due to the soft bitumen (pen 160/220) and the dense asphalt mixes used for their construction. This does not mean that the stated ageing of cycle paths is not real. It seems more probable that the reason is that many of the cycle paths have passed their design period; alternatively, distress produced by other causes, such as cracks, accelerate the oxidation of the bitumen and contribute to LTA. Based on the result of this study, the recommendation for preventing the ageing of cycle paths is to try to prevent distress produced by other causes, to keep the dense surface as intact as possible.

The structural interventions seem to be connected to the size of the urban area in the sense that larger urban areas have a higher problematic frequency of structural interventions. Roots and vegetation, on the other hand, seem to be connected to the temperature, whereby a milder climate is connected to more problems with root cracks. This could be related to the number and types of trees alongside the cycle paths, but no such information was gathered in the study. More knowledge regarding these distress causes is needed to optimize the design and maintenance of cycle paths.

The categorization of the severity of different type of cracks in the Swedish condition assessment manual *Bära Eller Brista* does not seem to be based on the traffic safety of the cyclists. The classification of cracks into transverse and longitudinal cracks is perhaps insufficient for the needs of cyclists, and the lack of classification of root cracks in the manual is problematic. The risk is that the diagonal cracks could be hard to avoid and could pose a greater risk to cyclists' traffic safety. The condition assessment manuals, therefore, need to be updated, with more focus on cycle paths and the consequences of different distress modes for cyclists.

The distress modes stated by the municipalities in the survey that show a correlation with both climate zones and population are surface unevenness and transverse cracks. This implies that bigger cities, located in the north of Sweden where the temperatures are lower, are more prone to these distress modes. This, in turn, suggests that more consideration needs to be given to the design stage, and perhaps to the maintenance of cycle paths, to prevent these distresses. As surface unevenness could be the result of various factors, the mechanisms behind them must be further investigated.

Author Contributions: Conceptualization, M.L., A.N. and S.E.; methodology, M.L.; validation, A.N. and S.E.; formal analysis, M.L.; investigation, M.L.; resources, A.N. and S.E.; data curation, M.L.; writing—original draft preparation, M.L.; writing—review and editing, A.N. and S.E.; visualization, M.L.; supervision, A.N. and S.E.; project administration, A.N. and S.E.; funding acquisition, A.N. and S.E. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Mistra, Stiftelsen för Miljöstrategisk Forskning, grant number DIA 2016/28, and the APC was funded by the library of the KTH Royal Institute of Technology.

Data Availability Statement: Publicly available datasets were analyzed in this study. These data can be found at https://www.scb.se/en/finding-statistics/statistics-by-subject-area/environment/land-use/localities-and-urban-areas/ (accessed on 14 February 2022); (Official Swedish Population Statistics); and https://www.smhi.se/data/meteorologi/ladda-ner-meteorologiska-observationer/#param=precipitation24HourSum,stations=all (accessed on 14 February 2022) (Official Swedish Meteorological Data). The data from the conducted survey and interviews presented in this study are available on an aggregated and anonymized level upon request to the corresponding author. The data are not publicly available to preserve the integrity of the respondents of the survey and interviews.

Acknowledgments: The survey and the interviews were conducted by the corresponding author in collaboration with a fellow student, as part of the research program Mistra InfraMaint, which focuses on smart maintenance of municipal infrastructure in Sweden: https://mistrainframaint.se/en/home/ (accessed on 14 February 2022).

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Appendix A

Table A1. The table shows the correlation between the stated distress modes and the problematic frequency with respect to climate zones in *TRVK Väg*. Bold R^2 values represent a strong correlation, as shown in Figure 4.

Distress	Climate Zone	Problematic Frequency (%)	n	R^2
Surface unevenness	1	63	30	0.72
	2	75	69	
	3	77	13	
	4	90	10	
	5	82	17	
Longitudinal cracks	1	45	29	0.30
	2	52	66	
	3	92	12	
	4	50	10	
	5	82	17	
Alligator cracking	1	43	30	0.12
	2	34	68	
	3	46	13	
	4	45	11	
	5	29	17	
Edge deformation	1	43	30	0.19
	2	35	66	
	3	28	13	
	4	45	11	
	5	24	17	
Transverse cracks	1	21	29	0.78
	2	15	67	
	3	25	12	
	4	60	10	
	5	59	17	
Potholes	1	27	30	0.56
	2	18	68	
	3	31	13	
	4	36	11	
	5	35	17	
Raveling	1	7	29	0.56
	2	2	66	
	3	8	12	
	4	11	9	
	5	12	17	
Bleeding	1	0	28	0.04
	2	26	88	
	3	0	12	
	4	0	11	
	5	6	16	

Table A2. The table shows the correlation between the stated distress modes and the mean average precipitation, according to SMHI, with respect to the answering options during winter and thaw seasons in 2000–2019. Bold R^2 values represent a strong correlation, as shown in Figure 5.

Distress	Response Option (%)	Precipitation in Winter and Thaw Season (mm/Year)	n	R^2
Surface unevenness	Non-existing	0	0	0.08
	Not very frequent	195	26	
	Quite frequent	223	57	
	Very frequent	183	17	
Longitudinal cracks	Non-existing	0	0	0.28
	Not very frequent	204	42	
	Quite frequent	215	42	
	Very frequent	212	12	
Alligator cracking	Non-existing	257	8	0.92
	Not very frequent	211	53	
	Quite frequent	202	32	
	Very frequent	171	7	
Edge deformation	Non-existing	228	14	0.80
	Not very frequent	221	48	
	Quite frequent	213	24	
	Very frequent	165	12	
Transverse cracks	Non-existing	230	6	0.47
	Not very frequent	201	68	
	Quite frequent	227	21	
	Very frequent	283	1	
Potholes	Non-existing	227	7	0.11
	Not very frequent	205	68	
	Quite frequent	212	19	
	Very frequent	238	5	
Raveling	Non-existing	220	19	0.82
	Not very frequent	208	74	
	Quite frequent	208	2	
	Very frequent	177	1	
Bleeding	Non-existing	221	40	1
	Not very frequent	201	54	
	Quite frequent	0	0	
	Very frequent	0	0	

Table A3. The table shows the correlation between the stated distress modes and the problematic frequency with respect to population size of the biggest urban area of each municipality. Bold R^2 values represent a strong correlation, as shown in Figure 6.

Distress	Population Size of Biggest Urban Area	Problematic Frequency (%)	n	R^2	R^2_{adj}
Surface unevenness	>120,000	100	6	0.47	0.91
	60,000–120,000	71	14		
	30,000–60,000	84	19		
	15,000–30,000	75	20		
	<15,000	72	78		
Longitudinal cracks	>120,000	83	6	0.12	0.58
	60,000–120,000	43	14		
	30,000–60,000	61	18		
	15,000–30,000	55	20		
	<15,000	61	74		
Alligator cracking	>120,000	33	6	0.26	0.17
	60,000–120,000	14	14		
	30,000–60,000	42	19		
	15,000–30,000	30	20		
	<15,000	45	78		
Edge deformation	>120,000	83	6	0.61	0.85
	60,000–120,000	36	14		
	30,000–60,000	47	19		
	15,000–30,000	35	20		
	<15,000	30	76		
Transverse cracks	>120,000	17	6	0.59	0.88
	60,000–120,000	0	14		
	30,000–60,000	17	18		
	15,000–30,000	30	20		
	<15,000	34	75		
Potholes	>120,000	50	6	0.4	0.79
	60,000–120,000	21	14		
	30,000–60,000	29	17		
	15,000–30,000	30	20		
	<15,000	23	80		
Raveling	>120,000	17	6	0	0.34
	60,000–120,000	0	14		
	30,000–60,000	11	18		
	15,000–30,000	5	20		
	<15,000	11	73		
Bleeding	>120,000	0	6	0.5	0.6
	60,000–120,000	0	14		
	30,000–60,000	0	17		
	15,000–30,000	0	18		
	<15,000	12	73		

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