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Information Needs of Gravel Road Stakeholders

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Abstract: Within any ecosystem, information sharing is essential. In this paper, the Swedish gravel road ecosystem is studied, where information plays a crucial role for the effective management of operations and maintenance. However, efficient information sharing is not enabled due to the lack of appropriate information systems. For addressing this issue, this paper intends to elicit information needs of gravel road stakeholders to support the design of a cloud-based information system. The main purpose is to explore the information needs of stakeholders within the Swedish gravel road ecosystem. Data were collected through in-depth semi-structured interviews with 11 participants representing key stakeholders in the ecosystem. Template analysis was used for analyzing the interview results. The major findings were a set of information needs covering road identification and condition, weather conditions, accessibility and traffic, maintenance policy, and sensor data. The results form a comprehensive information model for the further development of a cloud-based gravel road management system that would contribute to increased traffic safety and comfort, lower maintenance and management costs, and better decision-making abilities.

Keywords: information needs; gravel road ecosystem; stakeholders; gravel road maintenance

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1. Introduction

According to [1], most information is used by data owners and are not shared with other stakeholders. Consequently, transmitted information constitutes only a small proportion of all available information. Within an ecosystem, intra-organizational as well as cross-organizational information sharing is crucial, as it allows for efficient decision-making. A common information system entails many benefits, such as the ability to share data online with remote control [2]. Thus, it is important to understand the information needs of not only individual stakeholders but also the shared needs within an ecosystem.

Gravel roads are a branch of the transportation system that need continuous maintenance. In Sweden, they form almost 20% of the total road length [3]. Recently, the European Commission [4] addressed challenges to rural areas, which suggests the need for a well-functioning road network. Some of the challenges are the need to improve production efficiency, to enhance the delivery of goods and services, and to empower citizens. Those challenges affect citizens, municipalities, technicians, policy makers, and others, and indicates the need for keeping the rural roads in good condition. This calls for suitable information systems and technology that could manage the challenges in an efficient and effective way. Already in the 80s, Alfelor and McNeil [5] acknowledged the need for appropriate information systems for the management and improvement of gravel road maintenance. Saarenketo [6] addressed the need for a system that deliver up-to-date information about poor driving conditions, which can be attainable using radio transmissions, or an information system attached to the vehicle. Saarenketo also foresaw an increasing application of sensors and predicted the development of the internet and wireless communication system to facilitate the exchange of information between the gravel road owners and road maintenance contractors. The Swedish Transport Administration recognized the need of appropriate information systems for maintenance management and decision support and concluded that information and knowledge available at the authority was not shared among other stakeholders [7]. Reference [8] found that the level of cooperation between the local road authorities and professional transporters, who use the road network, was low. While efforts have been seen in developing appropriate information system support for gravel road maintenance, see for instance [9–14], these initiatives either do not support efficient data sharing between stakeholders or are too specific in their application and thus do not cover the total information need. For the efficient sharing and management of information, cloud-based information systems are suitable.

Reference [15] defines the term 'cloud' as an open resource system that involves many stakeholders and offer multi-granular services at a defined quality level of services. Cloud-based systems offer several benefits over traditional, locally installed systems; users can manage and access data faster and easier through the internet, and the solution enhances control management processes, reduces configuration problems and maintenance time, and improves production rates. In the area of maintenance, several cloud applications have been developed. Applying data mining techniques to transmit railway maintenance data was suggested in [16], in addition to using an asset cloud to gather and manage data. Continuingly, Reference [17] used cloud-based technology as a solution to enhance the process of railway maintenance. This technology was used to form the information logistics, which managed different railway system-related data. Problems related to distributing vital information on the status of machine and cutting tools to concerned departments were addressed in [18]. The proposed cloud-based monitoring system handles updated information of machine tool failures and would contribute to reduced maintenance time and higher production rates. Reference [19] suggested using a cloud-based maintenance system for problems related to the maintenance of warehouse equipment. Reference [20] proposed a cloud-based cyber-physical system for flexible shop floor management and maintenance dependent on the shop floor situation. This system aims to increase awareness, improve maintenance of machine tools, and enhance decision-making. In [21], an information system for gravel road maintenance is developed that allows organizations to share work order and planning data. However, limited applications of the cloud-based concept are seen within gravel road maintenance. Further research is, thus, required regarding cloud-based and open source-based information sharing for gravel road maintenance [22].

Several factors influence the operations and maintenance of gravel roads and, therefore, forms the basis of the information need. References [23,24] refer to road standard, traffic factors, geometric factors, physical factors, and meteorological factors. The road standard reflects the overall required standard of a road, often determined by traffic volume and the condition of the road. The frequency of the maintenance depends on the road standard classification. A higher road standard decreases traffic costs but increases road maintenance costs. Therefore, it is important to find the optimum level of standard that minimizes the total cost [23]. Traffic dependent factors are considered vital to the extent of maintenance work. Such factors are traffic volume, traffic composition, and vehicle speed [23,25]. Geometric factors refer to the width and alignment and profile of the road [24], and physical factors refer to the composition of the wearing course, as well as to type of landscape and the surroundings of the road and buildings [26]. These factors reflect the structural conditions and thus the asset value for the owner, while the functional conditions are connected to the use of the road in terms of traffic safety, driving comfort, vehicle damage, and fuel consumption [6]. Poor functional conditions could be due to the unevenness, potholes, wash boarding, dusting, and firmness, while the structural conditions are related to, for instance, drainage and frost heave [26]. Reference [9] highlights the importance of historical condition data of high quality as a basis for decision making and road classification.

On one hand, classification of road condition is performed using parameters reflecting the functional condition of the road, such as cross fall and road edges, irregularities on the road, loose aggregate, and dusting [14,27–30]. On the other hand, the conditions for gravel road maintenance are dependent on the geographical location, which are reflected in the meteorological factors, such as sunshine hours, road conditions when it snows, and humidity [23]. According to [6], road users need information about traffic safety issues, such as frost bumps, steep hills, and tight and narrow curves, accessibility to roads, which can be limited due to snowstorms, avalanches, spring thaw, erosion after heavy rain, and other specific issues related to functional and structural conditions. Spring thaw happens when ice on the road surface begins to thaw because of the rise of temperature in spring. The water is trapped under the surface as the sub layer stays frozen, which results in weakening the gravel materials. Reference [11] concluded that historical data regarding inventories, road condition, and repair actions form the essential information elements of a gravel road management system. Other information to consider are maintenance plans, performance and deterioration prediction models, and financial data for maintenance optimization and surface upgrade decisions. Information about structural capacity, drainage, traffic characteristics, road geometry, and opinions of residents are used as a basis for analysis and decision making.

Various sensors can be applied for measuring the condition of gravel roads, such as acoustic sensors [30], image sensors [31], vibration sensors [8,32], light detection and ranging (LIDAR) [33], or radar sensors [28]. The measures could be performed using dedicated measuring vehicles, such as the Laser-RST or in a general-purpose car using smartphone devices [28]. Manual measures using, e.g., a cross fall meter and a yardstick are also made [27,28]. The design of a suitable monitoring system would take into consideration sensor type and amount, location and positioning of sensors, data collection density, data transfer, storage and processing, and the utilization of the data for information sharing and decision-making [6].

Effective planning and decision-making with limited resources requires collaboration and thorough understanding of the context specific requirements. This paper addresses the need for more research on cloud-based and open source-based information sharing for gravel road maintenance, and in specific, the need to understand the information requirements of individual stakeholders as well as the shared needs within an ecosystem. Stakeholders have a major role in any cloud-based system; they are the main users of the system who rely on the service providers to design a system that offers demanded services. Thus, knowing the stakeholder's needs is vital as they are involved in defining the cloud services [34]. The purpose of this paper is to explore the information needs of stakeholders within the Swedish gravel road ecosystem. In this context, the stakeholders refer to actors involved in the management and maintenance of the Swedish gravel road network: the Swedish transport agency; municipalities; road maintainers; road associations; and gravel road users, whereas the ecosystem refers to the gravel road ecosystem that comprises those stakeholders [28].

The structure of this paper is the following: In the next section, the research methodology is presented. Main results from the study with respect to information needs are accounted for in Section 3, and a proposal for an information model serving a cloud-based system is given in Section 4. In the last section, conclusions are drawn.

2. Materials and Methods

The research aims to support the design of a cloud-based information system targeted for the use of gravel road stakeholders. Therefore, a design-driven research approach is used [35]. The focus is on utility and deep understanding of the context dependent needs and requirements. Consequently, the selection of study participants is made to ensure richness of information and high internal validity and, therefore, defining the correct target group is important. Information needs could be elicited using several types of data collection methods, such as semi-structured interviews [36,37] or focus group interviews [38]. Some studies also develop information needs models, see for instance [39,40].

The study design is explained in Figure 1. In this research, the study design is exploratory and based on Creswell guidance on the qualitative research approach [41]. This is a design that starts inductively; it focuses on specific themes to build general themes or meanings. Thereafter, it turns into a deductive approach, looking back at the data to check if the evidence collected is sufficient to support the themes, or if more data is needed. Thus, the aim was to conduct as many interviews as needed until data saturation was reached following the reasoning of grounded theory. In practice, this was performed by the main investigator when the respondent answers became similar, while the decision to add more interviews or not was made after discussion with the second author.

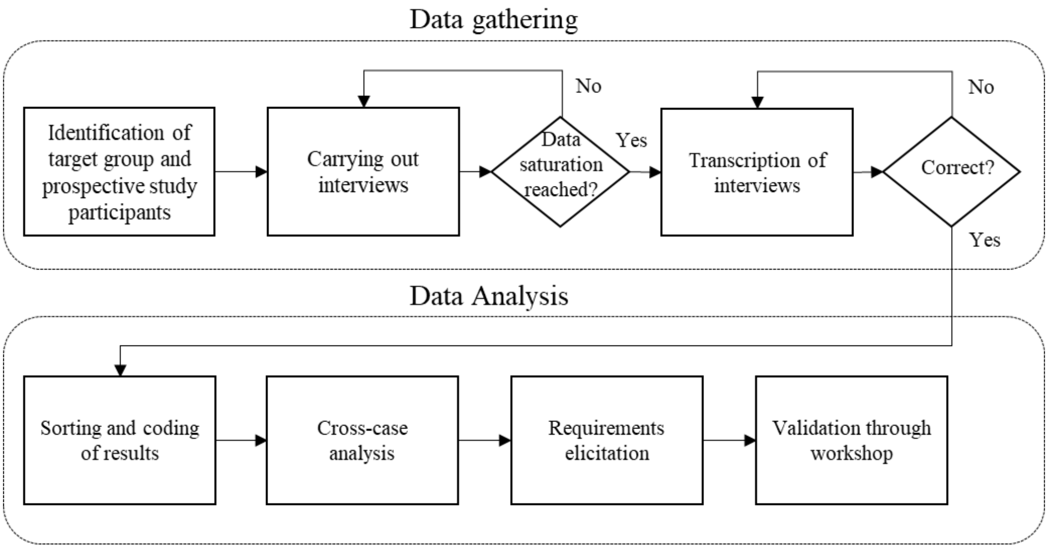

Figure 1. Study design.

Data were collected using in-depth semi-structured interviews with a total number of 11 participants. The semi-structured interview is suitable in exploratory studies, as it allows freedom to alter and reformulate questions during the interview session. The full list of interview questions is found in Appendix A. Table 1 presents the participants and the mode of the interview. Telephone or online interviews were conducted, in which audio and/or video was taped and transcribed. The default language of the interview was English, but, if the interviewer preferred using Swedish, a Swedish version of the questions was also available. The interview transcripts were sent to the interviewees for feedback to ensure the correctness of the results. The target population was actors representing the Swedish transport agency, municipalities, road maintainers, road associations, and gravel road users. This target group represents the main stakeholders whose perspectives are the basis of this research. As a delimitation, stakeholders representing the context of Southern Sweden were selected. The Swedish transport agency is responsible for the long-term planning of the transport system in Sweden, including road, rail, flight, and shipping. They also own roads. Municipalities that are actively involved in the maintenance usually maintain the roads each year and plane three times a year. In addition, they sometimes take care of the Swedish transport agency's roads and public-private roads. Maintainers are those contractors who maintain the roads, assigned by the road owners, municipalities, or the Swedish transport agency. Responses from this stakeholder category adds a lot to this research paper, as it directly defines the needed information when maintaining a gravel road. Road associations support the needs of road owners and report problems regarding road status, and they have a direct contact with the corresponding municipality. Road users are those who use the road and drive to reach a certain destination. In this study, road user representatives have been selected to represent only users, i.e., they do not belong to any other stakeholder group. The respondents were selected based on their contribution potential, i.e., being representative of the stakeholder group and knowledgeable in the subject area of gravel road maintenance. The participants were purposefully selected using a list of contact information to relevant stakeholder parts that was established during the stakeholder analysis phase of the project. All potential respondents fulfilled the basic criteria of being representative of the stakeholder group and knowledgeable in the subject area of gravel road maintenance.

Table 1. List of interviews.

Interview #	Stakeholder Type	Interview Type
1	Swedish transport agency	Telephone
2	Swedish transport agency	Online skype
3	Municipalities	Telephone
4	Municipalities	Online via Zoom
5	Maintainers	Telephone
6	Maintainers	Telephone
7	Maintainers	Online via Zoom
8	Road association	Telephone
9	Road association	Telephone
10	Road user	Online via Zoom
11	Road user	Online via Zoom

The interview results were analyzed using template analysis. Template analysis is appropriate especially when a researcher aims to investigate and compare different perspectives of different participants within a certain context [42]. Template analysis underlines the use of hierarchical coding, while combining both high levels of structure in the analyzed data with the ability to adapt to the research's needs [43]. As a first step, the recordings were transcribed and/or key answers were written in a joint Excel sheet to sort data in a clear way. A transcription website called Amberscript "https://www.amberscript.com/en/ (accessed on 1 December 2022)" was used for the transcribing to increase the accuracy of the written data. Swedish transcriptions were translated into English, where the basic terms were defined according to Skanska's construction dictionary [44]. An a priori codes list was established after reading the transcripts several times, and all collected codes were gathered into one file to define relationships. The interview results were thereafter transformed into formal information requirements in the form of an information model. As a validity measure [35], the results from the interview study were presented and discussed at workshops where representatives from maintenance contractors, municipalities, road associations, researchers, and system developers participated.

3. Results

In this section, findings from interviews are presented. In addition, the similarities in answers are accounted for in a cross-case analysis.

3.1. Stakeholders' Information Needs

The main results from the interview study are presented and grouped by stakeholders. For exemplification and illustration of the results, quotes are utilized. The quotes are found in Appendix B, while a reference to each quote is found in the continuous text.

3.1.1. The Swedish Transport Agency

The paved and unpaved roads owned by the Swedish transport agency are often managed and maintained by private companies after a bidding process that ends with writing contracts. The contracts are based on achieving a certain road condition, where the parameter value "1" is the highest condition and "4" is the lowest. The Swedish transport agency needs information about the road status as well as road network information [Q1]. In addition to using the four parameters to assess the roads, they pay much attention to choosing the right affordable road standard level considering the traffic factors [Q2].

When asked about the frequency of road maintenance, the answers relate primarily to the condition of the road, such as in [Q3]. Both respondents agree that weather does affect gravel roads significantly. Gravel roads are in an acceptable shape during winter and summer, but the respondents emphasized the problem of spring thaw when heavy transport moves forest products to factories and thus damages the gravel roads. One respondent mentioned that the surface of the road could change completely after heavy rain. Dusting is another weather-related condition that occurs in very dry weather [Q4].

Accessibility problems occur due to poor drainage. Drainage problems are avoided by installing road culverts, which handle both stormwater and other water, such as streams. Functional issues, such as unevenness, potholes, wash boarding roads, dusting, and weak road firmness occur very often in addition to another problem, loose gravel, which might be related to the road firmness. It affects traffic safety as well. Usually, all these issues depend on the composition of the wearing course [Q5]. In addition to the composition, the quality of the rigid material in the road is also important; it should not be very loose or very rigid material. The loose materials will be broken by passing vehicles, whereas the bigger stones are eventually broken into smaller fractions and into fine materials, which means that they lose carrying capacity. Thus, the respondents concluded that a certain stone quality is desired. Continuingly, traffic factors affect the gravel roads. The traffic intensity as well as the traffic type directly affect the quality of the road, according to the respondents. Heavy vehicles could have a major impact on the road quality [Q6].

The respondents were also asked about their departments' dependency on technology to retrieve information. Some applications are used for measurement purpose, such as lasers used for measuring road profile and unevenness, but they also depend on personal inspection of roads through assigned consultants. Moreover, they use an application that utilizes the GPS on contractor's vehicles to keep track of contractor's work. There are applications that measure unevenness, which also translates into different data regarding loose gravel and potholes. Techniques that could be useful to the Swedish transport agency were mentioned, such as cameras [Q7] and sensors, to measure the road condition [Q8]. The agency, as mentioned by one respondent, needs to have more control over the roads, but it does not have to be in real-time. On the question 'Which information is important to access?', one of the respondents mentioned weather forecasts for the efficient preventive maintenance planning [Q9]. Having access to this kind of data, the Swedish transport agency could help companies plan their work and maintenance efficiently, especially after knowing where the spring thaw weakening occurs on the gravel roads.

3.1.2. Municipalities

Municipalities that carry out maintenance work usually have a direct contact with road associations, who inspect roads and report to the municipality. Regarding the quality of the roads in winter and summer, both respondents replied that it is acceptable, but in winter it gets worse because of the weather. One respondent mentioned problems with dusting. Both participants said that it is important to know about the upcoming weather status to plan work in a better way [Q10]. In addition, the respondents said that drainage and spring thaw weakening are common accessibility issues, and one mentioned the problem of drainage [Q11]. Regarding the functional issues, such as potholes, dusting, and wash boarding roads, these issues occur to a limited part of the gravel roads. One participant said that they form because of heavy rain and the other said that they form because of heavy traffic [Q12].

None of the respondents reported their dependency on technology to obtain access to road condition data and maintenance needs. The communication with other stakeholders is commonly obtained through the telephone or emails [Q13]. They did mention an application used by gravel roads owners, but usually they rely on personal observations of the condition of the road. As for their opinion about a future cloud-based system and the ability to communicate with other stakeholders, both agreed that this is a good idea [Q14].

3.1.3. Maintainers

Maintainers carry out maintenance work for public and private actors. The municipality has a scheduled maintenance plan; public gravel roads should be paved every year and private roads every three or four years. In addition, private forest owners call maintainers and report problems of the roads. The maintenance need depends on the type of ground the road is constructed on [Q15]. Access to road identification and road standard, as well as material use, is important for carrying out maintenance [Q16]. Maintenance is performed during different times of the year, so a person needs to maintain gravel roads in different ways [Q17,18]. It is important to know about the upcoming weather status because this helps in planning the work. One advantage mentioned was being able to plan maintenance just before rain occurs [Q19]. When asked about the quality of the roads, lengthy answers were provided, which reflects the huge effect of the weather on the condition of these roads. In autumn, when it rains, potholes and grooves form, and some close-knit patterns form, which need to be paved. In winter, when roads are usually freezing and slippery, maintainers tend to sand the roads. Plowing also affects the road; if the road is not frozen when plowing, the gravel is plowed into the ditch. In spring when snow/ice begins to defrost, one of the major problems occurs, i.e., thaw weakening [Q20,21]. Regarding accessibility issues, avalanches are not a problem as municipalities usually are responsible for moving the snow off the roads. Drainage is usually not a complete flow of water. Instead, it tends to be like a curly flow that ends up in the ditches. Ditches need to be maintained every six years in spring and/or summer. Another accessibility issue occurs due to the surrounding trees [Q22].

As for the functional issues, vehicles cause gravel to move and disappear into ditches. One respondent commented that potholes are not always a result of the destruction of the road. Instead, they could occur because of the poor construction in the sub layer of the road. This means that the quality of the gravel material affects the condition of the upper road [Q23]. According to the maintainers, the traffic safety of gravel roads was seen to be acceptable. The respondents agree that gravel roads are the least busy. Still, traffic does affect gravel roads status, especially if there are lots of forests nearby [Q24]. Maintainers obtain access to information regarding traffic intensity and maintenance work to be executed [Q25]. In addition, they usually inspect the roads themselves and obtain reports of any problems from those who live nearby.

All participants use telephone and email to communicate with other stakeholders. When asked about a future cloud-based system, one respondent found it to be a good idea, for instance, for failure reporting [Q26]. Regarding which information about gravel roads needs to be available in the future system, mainly weather-related information is important so maintenance at the appropriate time could be planned [Q27]. One respondent said that it is good to know about the road status to control heavy traffic on the roads. It also depends on what could be measured by sensors in the future system, such as road structure and condition using ground-penetrating radar [Q28]. Another respondent said that this system would benefit everyone, as it gathers information specifically about gravel roads. Adding on to this point, not all gravel roads need to be re-graveled so often, which means that the future system can save costs of extra work and material. The third respondent said that no such system is available nowadays, but there was one a few years ago that used sensors on cars, which drive around the roads continuously to record changes in road condition. When asked which information is important to access on the system, the answers varied between road standard, source depth of the road, smoothness of the road, dustiness, and if there are any irregular patterns or washboard patterns on the road.

3.1.4. Road Associations

The municipalities handle many road associations, who are responsible for a certain number of road kilometers. They hold meetings annually to keep track of the updates and further plans. Afterward, the road association applies for government grants and financial support. Regarding the maintenance policy, the road associations do check the roads at least once a year, and the paving is performed three or four times a year. According to the respondents, they are notified of the need for maintenance, and the maintenance is performed as soon as possible. The main aims of road associations are resource and cost efficiency [Q29]. Maintenance requirements are both in short term and in long term in the form of a 5-year plan, and the traffic frequency and type are examples of information needs [Q30,31]. When asked about the effect of weather, they said that it does affect roads, and it is important to know about the upcoming weather. As for the functional issues, both respondents said they happen and agreed that the quality of the road materials reflects on the condition of the road; for example, the likeliness of wash boarding to happen depends on the materials of the road. Maintainers usually build up to a 30-cm wearing course in the road body. Regarding the traffic factors, both respondents agreed that these affect roads, especially with the increase in heavy traffic. Therefore, it is best for vehicles to adapt their speed to the road status. One of the reasons for the traffic volume is that, according to one respondent, many people move out into the countryside, which increases traffic.

The respondents said that they prefer to obtain information through the Swedish transport agency. They communicate with road owners through meetings and text messages. Nonetheless, telephone and email are necessary for communicating with all stakeholders. When asked about their opinions of a future cloud-based system, they both mentioned that this would lower costs [Q32]. Any kind of information that would benefit all stakeholders is good to have, as said by one participant, especially weather status and information regarding maintenance activities and resources.

3.1.5. Road Users

Two respondents who are private users that drive to reach their work were interviewed. Unlike other stakeholders, they did not perceive information on road standard as important. The road users had opinions of the quality of the roads in winter and summer, though [Q33–34]. The respondents never experienced avalanches, but poor drainage of water was a very common issue. Moreover, functional issues, such as potholes, wash boarding, and unevenness, were noticed from time to time. When asked about the importance of knowing the upcoming weather, they both mentioned that they usually obtain notifications on their smartphones regarding the upcoming weather. However, it did not occur to them to check the weather status specifically in the area where gravel roads are located. When asked what they do when a road needs maintenance, one replied that he/she did not know whom to contact.

The road users were also asked about technology and their dependency on technology to obtain information. One respondent said that Google and YouTube are the main sources of information. The other respondent uses apps, preferably apps that do not have a cost [Q36]. Regarding which information on gravel roads that they need to obtain notifications, one responded that information about maintenance works on the road or serious functional issues, such as potholes, would be useful. The other respondent mentioned navigation support [Q37]. Moreover, the respondents were asked which information is important to access on the system. This question included both needed information as well as needed functions. Except navigation and maps, the respondents mentioned ability to call emergency services and share their position, animal crossing detecting sensors, information on road status, and contact information to the one responsible for the road [Q38–40]. When asked about having a function to communicate with other stakeholders in the system, both respondents found it acceptable. It was also mentioned by both respondents that there is a need for a function to connect directly to those who can pull cars when they get stuck in the ditches.

3.2. Cross-Case Analysis

Table 2 displays the similarities in stakeholders' information needs. The first category of similarities presents the analyzed information needs, and the second presents the need for sensor data.

Table 2. Similarities in interview answers.

	Swedish Transport Agency	Municipalities	Maintainers	Road Associations	Road Users
		Information needs			
Road standard	x		x		
Road name, number, and dimensions	x		x		
Road owner and responsible maintainer					x
Carrying capacity	x		x		
Rain and snow	x	x	x	x	
Humidity		x	x		
Temperature			x		
Unevenness	x	x	x	x	x
Quality and composition of materials	x		x	x	
Potholes	x	x	x	x	x
Wash boarding	x	x	x		
Dust	x	x	x	x	x
Loose gravel, surface firmness	x	x	x	x	x
Drainage	x	x	x	x	x
Edge cutting of ditches			x		
Road culverts				x	
Spring thaw weakening	x	x	x		
Branches and tree logs barriers					x
Speed			x		
Traffic volume	x		x	x	
Heavy vehicles	x		x	x	
Maintenance policy			x	x	
Ongoing maintenance work					x
		Sensor needs			
Measure source depth	x		x		
Measure moisture ratio	x				
Smoothness of the road	x		x		
Animal movement detection					x

The Swedish transport agency and maintainers are stakeholders that reported a high level of information needs. These stakeholders also recognized the need for sensor data. Information regarding drainage and road condition (unevenness, potholes, and loose gravel) were categories identified as crucial by all stakeholders. Weather conditions, traffic factors, and road condition information representing various types of quality defects were also seen as important.

4. Information Model Supporting a Cloud-Based System for Gravel Road Management

An information model, forming the basis for a cloud-based gravel road management system, is presented in the following figure. The model is based on the interview results in Section 4 as well as the literature presented in the Introduction. UML notation is used for the information model, where related pieces of information are grouped together in classes, see Figure 2. The name of the class is found in the top of the box, while attributes describing the information are found below. Associations between classes are represented by connectors.

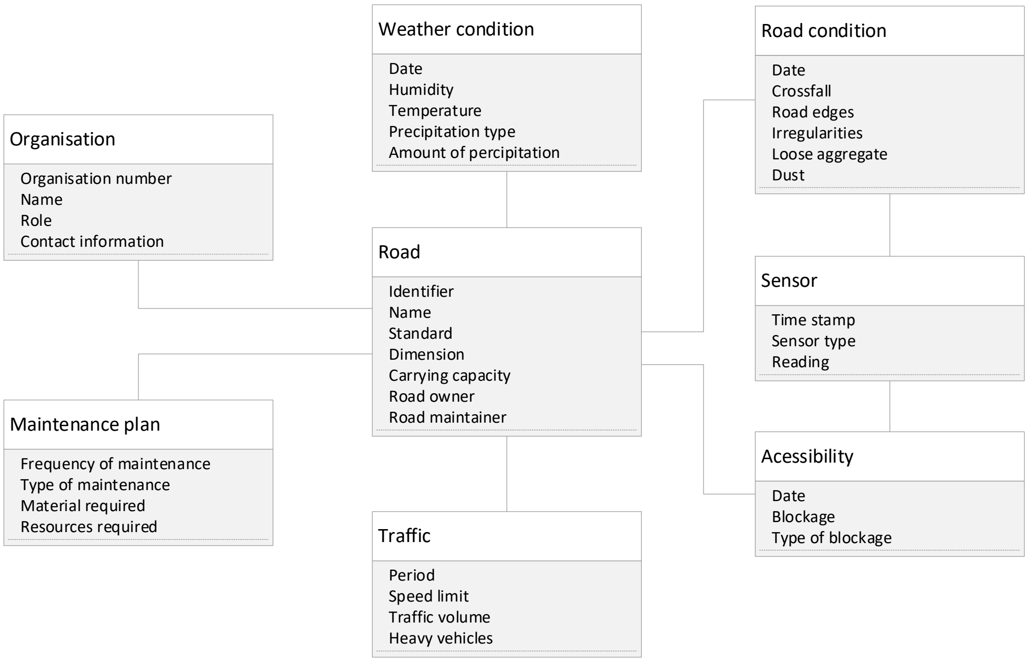

Figure 2. Proposed information model.

4.1. Road Information

The road standard in Sweden is classified into seven levels depending on the road type, which determines the need for maintenance. Based on the collected data, both the Swedish transport agency and maintainers showed a need to know these standards when gravel roads are being maintained. Therefore, the Swedish transport agency as well maintainers would need to know the road standard. This is in accordance with [24]. In addition to road standard, related information needed by the Swedish transport agency and maintainers is data about the road number, road names, and dimensions of the road. Information regarding the carrying capacity is also needed, as it is affected by factors, such as traffic and weather. Moreover, information about road ownership and the organization or contractor responsible for maintaining the road is important, especially for road users, who needed such information, in case they want to report a problem on the gravel road. In the information model, road information is represented in the class Road, while contact information to the road owner or maintainer is represented in the class Organization.

According to the interview study, road and organization information is important for the Swedish transport agency, maintainers, and road users and should, therefore, be openly accessible for them. Municipalities and road associations use such information locally but have no need for open access and sharing of information.

4.2. Weather Information

According to [6,24], weather is a factor that affects roads, and the results from the interviews confirm this. Weather conditions affect directly and indirectly the gravel road condition. It causes accessibility issues in winter to those who drive along the road, and it causes functional issues in the summer that affects stakeholders as well. In addition, it affects the maintenance plan as sometimes a little rain is needed after constructing and maintaining the roads and sometimes knowing if there is a storm coming is important to change the maintenance plan. Consequently, information about the weather was needed by the Swedish transport agency, municipalities, maintainers, and road association. The road users did not need such information because they might use a dedicated application for weather status, or they are not regular users of the road. Weather information is represented in the class Weather condition.

Weather information is, in many countries, openly accessible from national weather institutes or similar agencies and could be imported into the cloud-based system as it is important information for several stakeholders. An alternative is to capture the information by sensors. However, this was not addressed by any of the interview participants. The interview results indicate that weather condition information is needed by all stakeholders except road users. Current and forecasted weather conditions affect the planning and execution of maintenance. On one hand, access to this information in combination with information regarding maintenance plans is important for the maintainers. On the other hand, for maintenance improvement purposes, weather conditions could be relevant in combination with road condition information [22]. Weather conditions affect the accessibility of the roads, making it potentially important information for municipalities and road users for planning purposes.

4.3. Road Condition Information

Unevenness and other functional issues are used for classifying road conditions [27,28]. The Swedish transport agency needs this data because it defines the current condition of their roads, and thus if these roads need maintenance, they hire maintainers to enhance the road to a pre-decided level. They base their assessments of the roads on four parameters: cross fall and road edges, irregularities on the roads, existence of loose aggregate, and dust, as mentioned in [28]. These kinds of problems are faced by all stakeholders and affect the usage and maintenance of the roads. Usually, these kinds of problems are detected with eyesight or using sensors. Irregularities, such as potholes and wash boarding, are related to the quality and composition of the wearing course. Therefore, information about the road material is important for maintenance purposes. Dust is a problem that occurs in dry weather, and dust information is needed for dust prevention. Moreover, information on loose gravel is needed by the Swedish transport agency when assessing the roads. Loose gravel depends on the composition of the wearing course, which is why high speed vehicles can cause gravel to become loose, as mentioned by one respondent from a municipality. Information regarding road conditions is represented in the class Road condition.

This type of information is important and should be openly accessible for all stakeholders. Especially, the Swedish travel agency, municipalities, and maintainers would benefit from the information, as it improves the planning and execution of maintenance. The main problem today is lack of detailed information regarding the different faults [28–30]. This could be solved with better condition monitoring equipment and methods, whereas the sensor information described in 4.7 becomes crucial.

4.4. Accessibility Information

According to [6], avalanches could have major effect on accessibility. In this study, however, the respondents replied that avalanches are not a common issue; with the advancement in machines and communication, any snow blockage on the road are removed so that the traffic is not affected. It should be noted that all interviewed stakeholders live in the Southern Sweden where avalanches are rare, unlike Northern Sweden where avalanches could cause severe accessibility problems, as pointed out by one respondent from the Swedish transport agency. As for the problem of erosion after heavy rain, this was not mentioned by any respondent, probably because gravel roads have ditches, and thus, any soil erosion would not reach the roads in the first hand. When it comes to the drainage of water, all stakeholders consider this as a major problem and need information when it occurs. This finding is supported by [6,11,24]. The excess water is transferred from the roads to the ditches and then to the culverts. Therefore, information about the road ditches and culverts is important; if they are checked regularly, serious problems are avoided. Drainage does not only affect the road surface but also the sublayers if water leaks into the ground. This could be why it is important to know about any poor drainage, in addition to the condition of the road ditches and culverts. Another issue is spring thaw weakening when water from the snow and ice begins to defrost in the beginning of spring. Spring thaw affects the carrying capacity of the road and was mentioned repeatedly throughout the interviews because of its importance. Spring thaw causes a problem when forest products are transported with heavy vehicles on gravel roads. Moreover, because of having forests near these roads, some branches and tree logs ends up on the roads. These branches and logs damage maintainers' trucks and hinder the passage of users on the road. Information regarding road accessibility is represented in the class Accessibility.

According to the interviews, the information need differs between stakeholders with respect to what kind of obstacle that causes blockages and accessibility problems and how the information is used. Road users need this information for route planning while the Swedish transport agency, municipalities, road associations, and maintainers use it for planning of corrective and preventive maintenance actions.

4.5. Traffic Factors

Traffic factors relate to vehicle speed and to traffic composition and volume [24]. According to [6,11,24], information about traffic factors is needed for road maintenance. This was confirmed by the interviews; the Swedish transport agency, municipalities, maintainers, and road associations do need information about these factors. The Swedish transport agency mainly mentioned how heavy vehicles tend to destroy gravel roads. Heavy vehicles increase in number the more a forest is nearby, because they carry wood products to factories, as mentioned by one maintainer. In addition, traffic volume was mentioned by most stakeholders as being a factor that affects the road condition. If the traffic volume of a gravel road exceeds the capability, then the road tends to get paved with asphalt to increase the carrying capacity. Traffic information is represented in the class Traffic.

Traffic information was mentioned by several stakeholders in the interview but is important mainly for the ones involved in the management and maintenance of the gravel roads, i.e., the Swedish transport agency, municipalities, maintainers, and road associations.

4.6. Maintenance Policy Related Information

The maintenance policy relates to the maintenance plan that is followed to maintain roads. It includes for example what roads to maintain, how much material to use, and the frequency of specific maintenance activities. All this information is considered needed for the maintenance of gravel roads as mentioned by maintainers and road associations. One maintainer mentioned that a road consists of many layers and much work is needed, therefore the plan saves time and resources. These findings are in accordance with [11]. Maintenance policy information is represented in the class Maintenance plan.

This type of information should be shared between road owners and road maintainers for efficient planning and coordination of maintenance activities [21]. The cloud-based system should, therefore, include the information in a separate module with restricted access.

4.7. Information Created by Sensors

Some stakeholders proposed having sensors to collect information about different parameters on the roads, such as sensors to measure source depth of the gravel road. This is beneficial when maintaining the roads because the depth gives information about the surface and sublayer when digging, to check if the wearing course is sufficient and when constructing the ditches. Another type of sensor suggested is one that measures moisture ratio in the road body because when paving and sanding the roads, maintainers benefit from the natural moisture in the road body. In addition, sensors that measure smoothness of the road, as mentioned earlier, seem to be of interest to obtain information about the status of the roads. Finally, sensors that detect animal movements were also mentioned as being beneficial. Information created by sensors could describe not only road conditions but also road accessibility, and therefore, the class Sensor that captures sensor information is associated with both the class Road condition and the class Accessibility.

The sensor information should be managed and stored in the cloud-based system as they provide opportunities for optimizing the maintenance policies and plans [11], but access to the information should be restricted to road managers and maintainers. Aggregated information is openly accessible for everyone in the form of road conditions and accessibility information.

5. Conclusions

This paper aimed to explore the information needs of gravel road stakeholders. Common reasons for why information needs are not met in software projects are neglecting to consult stakeholders, ignoring the users' perspectives, poor communication, or high computerization costs. These drawbacks can be avoided by applying a stakeholders' and ecosystem approach to requirements elicitation, as it exclusively concerns the needs of users. Consequently, the study was designed for supporting an explorative approach to requirements' elicitation. The main contributions of this paper are twofold: the structured method for information requirements elicitation that was applied in the study, as well as the common information model that was the outcome of applying the method. The key findings suggest that stakeholders need information about road identification and road standard, such as name, number, and dimensions of the road, road owner and responsible maintainer, the carrying capacity, and weather conditions. Moreover, information needs regarding road condition issues that are categorized either as accessibility issues or functional issues were identified. Other needed information is traffic factors and information on maintenance policy and ongoing maintenance work. In addition, some sensors were suggested by stakeholders to be included in a future information system. Today, condition measurements on gravel roads are mainly performed on a non-regular basis using dedicated vehicles and costly equipment or carried out manually. However, the rapid development of technology allows for measurements to be performed using a regular car and smart technologies, such as the Roadroid smartphone application [45]. Frequent collection of real-time condition data allows for data-driven and fact-based decision making, which would improve maintenance planning and reduce the maintenance costs. Moreover, open access to road condition data increases the quality and quantity of road information, which is crucial in the development of, e.g., road safety systems and infrastructure solutions for autonomous vehicles.

As a conclusion, a cloud-based information system is considered a useful system for sharing vital information among future gravel road stakeholders. Most of the participants showed interest and willingness to use a cloud-based gravel road management system, as it will help road owners, farmers, users, and others to report problems faster. Another advantage is material cost savings and will save time as shared information about the gravel roads conditions will decrease the time needed to inspect the large number of roads in Sweden; only those that need maintenance would be inspected and maintained effectively. A cloud-based information system would add benefits not only to the direct stakeholders but also to the society, as sharing information regarding gravel roads maintenance affects the production of road materials, enhances the condition of the roads for heavy transport that delivers goods, and increases citizens' or stakeholders' knowledge regarding these roads.

The development of a cloud-based information system for gravel road maintenance is a natural extension of this study. One of the study limitations is the number of interview respondents included. Although a grounded theory reasoning was used, in which data are collected until no further new information is gained, this does not guarantee that important information could have been added if the number of respondents was increased. To counteract this, a workshop with representatives of the target group was held for validation purposes. Nevertheless, further verifications and validations should be made iteratively in the design, construction, and testing phases of the systems development to assure the correctness of the information model. The information model represents the information needs of the target group, i.e., stakeholders in the Swedish context, which is another limitation. Road deterioration processes might differ due to road standard, traffic factors, geometric factors, physical factors, or meteorological factors, which in turn might affect the information needs. Therefore, an international comparative study of information needs is suggested. Further work on defining the detailed information needs for maintenance management, condition monitoring, and assessment is also suggested, for instance, using the standards OSA-CBM and MIMOSA [46].

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Appendix A. List of Interview Questions

1	What kind of information do you need to maintain a gravel road?
2	What is your opinion about the quality of the road in winter? In summer?
3	Is it important for you to know about the upcoming weather status? And why?
4	How likely is it for accessibility issues to occur, such as having avalanches that block the road, erosion after heavy rain, drainage of water, or spring thaw weakening?
5	How likely is it for functional issues to occur, such as unevenness, potholes, wash boarding, dusting, and road firmness?
6	What is your opinion about the current traffic safety?
7	How are gravel roads affected by traffic factors (vehicle's type and speed, traffic volume)?
8	Can you tell me shortly about the maintenance policy of gravel roads?
9	When was the last time the gravel road was maintained and what kind of maintenance was performed?
10	Can you tell me shortly about your/the department's dependency on technology to get needed information?
11	How do you communicate with other stakeholders?
12	What is your opinion about including a function in the cloud system to be able to communicate with other stakeholders?
13	In the cloud application, and regarding the previous gravel road questions, which information do you need to get notifications about?
14	Is it important to get real-time (updated) information while using the app?
15	Will you use such a system? Are you willing to pay for the system or the provided support?
16	Would you like to add something more that I might have missed?

Appendix B. List of Interview Quotes

Quote #	Quote
Swedish transport agency	
1	*The dimensions of the road, if it has potholes, and so on. Whether the road is uneven at x level; the water should go to the ditches. Whether the road is loose or not; the particles should bind together. Dust; can you drive in a certain speed and still see the car in front of you.*
2	*We try, on socio-economical matter, to decide which type of road is a good level to have.*
3	*It depends on road standards, the best roads are maintained two times a year, the worst types maintained once a year or even every second year.*
4	*Partly if it rains, we get a certain impact on the road. As well as if it is very dry for a longer period, it also has its effect on the road surface. Additionally, this is when one usually hears that there is quite a lot of dust on the gravel road during certain periods of time.*

Quote #	Quote
Swedish transport agency	
5	*Wash boarding and potholes form because the composition is not one hundred percent correct; the material does not bind with each other properly because it is either lacking fine material or coarse material. It is the composition that is very important on the gravel road to get a good evenness and bonding unit so that it binds together properly. Partly the composition, but also the quality of the rigid material in it, so that it does not consist of either too loose or too rigid material.*
6	*These are quite bad roads. I mean, the drainage is not very good, which means that big lorries, heavy vehicles tend to, especially when it comes to spring, destroy the roads almost completely. So, people actually need to reconstruct them from almost the bottom of the road.*
7	*It'll be great if ordinary cars or trucks have cameras that tell us that now it's beginning to form potholes.*
8	*Sensors that measure unevenness, some type of moisture ratio in the road body or similar, maybe the profile of the road, to ensure that the water can run off the road surface then.*
9	*Preventive maintenance, which means we need to know the climate and temperature and weather conditions next week, after two weeks, and so on.*
Municipality	
10	*... especially now at the beginning of spring, it is important that when you pave and sand the roads that you make it as clearly as possible, to get advantage of the natural moisture in the road body.*
11	*Drainage can happen, then it is important that the water pour off, otherwise water will gather in the road body.*
12	*When driving fast gravel can become loose.*
13	*We usually get a call from road associations about those gravel roads that need maintenance.*
14	*It is not wrong for the public and farmers to report their point of views; surely, it does provide some maintenance assistance.*
Maintainer	
15	*An important thing that affects the need for maintenance is what type of ground the road is on. Roads that lie on mountains or moraine often have little need for maintenance. Roads that lie on mud or old seabed often end up worse and need to be maintained more.*
16	*First and foremost, we need to know which road it applies to; there are usually either road numbers or road names. You also know what the standard road has, how much gravel needs to be applied, is it on all the road or just part of the road. And if it needs edge cutting of the ditches.*
17	*This is performed during different times of the year, so you need to maintain gravel roads in different ways. It is best to have a plan because the gravel road consists of the superstructure section and partly the wearing course. The wearing course can simply be refilled. Additionally, there's a lot of work to do with it.*
18	*In the summer, gravel roads almost always get pits and potholes, which must be repaired about once a month. However, since you plane a gravel road 1–2 times a year, the road, in addition to the potholes, is often more even than a road that is paved with asphalt or oil gravel.*
19	*... it can be good if it rains a little after so that the gravel fits slightly ...*
20	*As the layer of snow and ice melts, the road surface becomes soft. Because the road is still frozen in the bottom, the melted water from the surface cannot sink down into the road. When the road keeps on thawing, it makes so much water in the road that it loses its carrying capacity.*
21	*Most of the roads need gravel in the spring when it is dry. Certainly, you get to gravel in the autumn and summer, but you have to do it when it's not too wet and messy on the road.*
22	*The most important thing for us who drive a truck on the roads is not to have too many branches from trees that stand out because it can damage the truck.*
23	*Unevenness may depend on the quality of the gravel material ... Washboard roads also depend on the quality of the gravel.*
24	*To cultivate forests, you also manufacture paper. So, you have a percentage of some very heavy traffic because of trucks and things that move woods, which are often very heavy.*

Quote #	Quote
Maintainer	
25	*The government documents what to do, for example, installation. It is primarily what it looks like on the roads. Then, we have someone who is responsible for the owners; to understand what should be completed.*
26	*It can be good. There was an app before where members or residents could report things to the board about problems* e.g., *lighting pole. They took a picture on the telephone and the administration system, such as the road association and contacted each other.*
27	*Preferably, when you have a large area to gravel the road, you can perform another coordinated gravel if you know that the weather looks the same there.*
28	*… sensors that measure how much is the source depth in the road; when the cold or frost goes out of the way, then it loses a lot of its carrying capacity.*
Road association	
29	*… to reduce manufactured gravel, reduce the number of road planes, to make better roads and save the municipality money.*
30	*An active management of the roads that can point out any shortcomings. Additionally, how much heavy traffic goes on the road, such as wood/gravel and other heavy traffic. A road clerk who fills pits and potholes and ensures that road culverts are cleaned so that water can pass unimpeded and who assesses what needs to be performed according to a 5-year plan.*
31	*To see if the road body needs action. All gravel roads need to be reinforced by increasing carrying capacity; you plane in material that makes the road stronger.*
32	*Sweden has 37,000 miles of separate roads, and there is a lot to look at every year; so, it is important to have a good road from the ground up.*
Road user	
34	*In summer, the quality is good. In winter, there are potholes and water gatherings. Sometimes there are tree branches and logs.*
35	*There are rocks on the sides of the road. If these are for lining the road then these should be bigger and be marked, because when you go backward you do not see the rocks if they are small.*
36	*Nothing and I keep going because I do not know much about the road, for example, what to do, who is responsible for fixing the road, who owns it, and whom to inform about problems.*
37	*I would drive very slow, and, if I could, I would change the road if I knew from the beginning that there is a big pothole ahead.*
38	*While I use the app to obtain navigations of the roads with sound orders just like Google Maps.*
39	*Having a navigation system, having sensors for detecting animals crossing the street to increase safety. To have services, such as ability to call ambulance or police directly from the app, which shares location.*
40	*Information about maps, navigation, current road status, time to destination, and to be able to see the current time. It would be nice to have data about the road owner and responsible maintainers, as well as if there are any animals that cross the road.*

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