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Challenges in Arctic Navigation: the User Perspective

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***Abstract*— This paper underlines the challenges of navigation in the Arctic from the user perspective by means of an online survey. The main target of the survey was to find out the users' views and real-life experiences on the challenges in navigation and geospatial information-based services in the Arctic region. The paper studies relations between the represented industry, encountered challenges and areas of operation. Navigation in the Arctic area and similar circumstances in high latitudes is known to be challenging in terms of weather conditions, lack of services and infrastructure. As the novel technologies, e.g., intelligent transport systems mature, the need for exact and timely geospatial information will increase. According to the results, the most significant challenges are uneven coverage of positioning, untimely weather information, and telecommunication issues. Although the number of respondents was lower than expected (83 complete responses), the results indicate the differences in navigation and location-based services between countries and public versus commercial actors. We found two major dependent variables (nationality and market segment), which are analyzed further. The results suggest guidelines for the future developments of the navigation and positioning services in the high latitudes.**

Keywords—arctic navigation, positioning, satellite navigation, communication systems, user survey

I. INTRODUCTION

Interest towards the Arctic region has been growing rapidly during the recent years. The search of new natural resources and tapping the unveiled potential of arctic areas to create economic growth has been in the center of political discussion, whereas the main focus of academic research has been in studying environmental and ecological issues as well as the ice and weather conditions [1] [2] [3] [4] [5] [6]. To name one key indicator behind the recent interest towards the Arctic, climate change and the side effects have been the main contributor in this development. The Arctic has substantial potential of growth in several business sectors, such as tourism, transport, and mining.

When addressing the challenges in the Arctic, the first question is to explicate the Arctic region. The most well-known definition is the geographical Arctic Circle, comprising the area where the summer solstice can be seen and currently running 66°33′47.5″ north of the Equator. Geographical Arctic Circle is defined as an area where the average temperature is below 10 °C during the warmest month of the year while arctic researchers define arctic as any land area north of the growth of upright trees. However, in this paper, the Arctic is not strictly tied with any of these definitions [7]: we focus on challenges that are encountered within the Arctic Circle and in similar conditions. For example, the White Sea and the Gulf of Bothnia suffer from ice and significant darkness during the winter months.

In addition to the remoteness, a variety of challenges are specific to the Arctic. These include, for example, high ionospheric activity which reduces the general accuracy and availability of satellite positioning. Furthermore, due to the lack of natural light and snowing, visibility is often poor, ice conditions change rapidly, increasing the need for real-time maps and nautical charts, and telecommunications connectivity is not always available due to degraded coverage of satellite navigation augmentation systems.

Moreover, sparse population and services, harsh climate with major changes between seasons and highly sensitive ecosystem, call for sustainable and well-planned actions. Although, from the economic perspective, Arctic would be under exploited are with rich natural resources, the risks of possible environmental catastrophes and losses are high.

The future scenarios of the Arctic development have been studied in various research projects. For example, EU FP7 funded ICE-ARC programme has involved large pool of researchers and scientist across 12 countries. The program targeted on studying the environmental changes and creating frameworks and prediction models for these purposes [8]. To understand and predict the environment, three essential tools are named: 1. satellites, 2. autonomous robotic platforms, and, 3. good communication. As a satellite and autonomous navigation focused ICE-ARC project report implies: "the fusion of these elements leads to advanced situation awareness" [9].

The main motivation of this paper is to analyze the challenges in Arctic navigation from the user perspective, based on real-life experiences and knowledge of the Arctic environment. For this purpose, we conducted an online survey to collect end-users' experiences and opinions on navigation challenges in the Arctic. Preliminary results of the survey have been discussed at [10] as an introduction to expert working groups; in this paper, the entire survey data are analyzed in detail. The paper offers an overall analysis of Arctic navigation challenges, suggesting the development goals for improved navigation services. As demonstrated in previous research projects, the availability of global navigation satellite system (GNSS) and satellite-based

augmentation system (SBAS) constellations in the high latitudes (>60º) is very challenging due to their low elevation angles [11]. Therefore, this paper aims to provide empirical knowledge to complement the scientifically proved and help to further aid the future improvements and expected performance levels of navigation accuracy in the Arctic area.

The remainder of this paper is organized as follows. Section 2 gives an overview of Arctic-related navigation challenges, section 3 addresses the background of the user survey and sections 4 and 5 present the analysis of the survey results. Finally, Section 6 concludes the paper.

II. Overview of Navigation Challenges in the Arctic

Currently, GNSS is utilized as a preferred navigation method in the Arctic, due to the challenges of visual-based navigation. Remarkably, the role of exact satellite navigation is emphasized when visual perception is not available. However, due to the low elevation angles and absence of satellites overheading the Arctic, the coverage of GNSS constellations is suboptimal in the area. Despite the developments of multi-frequency and multi-constellation GNSS and entailed improvements in the continuity and reliability of positioning, the increased ionospheric activity sets some limitations in the high latitudes. [12] [13]

Ionospheric disturbances are stronger in polar and equatorial latitudes than at mid-latitudes, causing delays and scintillation in satellite signals. Scintillation effects show as rapid signal power fluctuations and are a challenge for high-precision applications requiring centimeter-level accuracy. In contrast, ionospheric delays cause position biases affecting any receiver. However, if the receiver is dual frequency capable, the differences of measured signal travel times can be examined, and the ionospheric delay error can be compensated. [13]

Furthermore, some advancing technologies, for instance autonomous road transport and maritime operations, are dependent on high precision positioning. Therefore, they are more prone to latency and interference in navigation. Due to developing means of transport, extreme weather conditions, and highly sensitive nature, current coverage, reliability, and integrity of satellite-based augmentation systems need to be improved to guarantee flawless navigation in the Arctic. In addition to the technical challenges affecting navigation in the Arctic areas, scarce infrastructure, economic, and political situation are playing a central role.

Contemporary navigation applications are strongly dependent on telecommunication, along the whole modern society. Due to the sparse population in the Arctic, the telecommunication infrastructure and therefore, cellular coverage, are underdeveloped in the high latitudes.

Traditional telecommunications satellites located on geostationary (GEO) orbits do not solve the coverage problem: when seen from Arctic latitudes, GEO satellites are located close to the horizon, or even below it, making the signals susceptible to blockage by trees, buildings, or landforms [14] [15]. This challenge is also often encountered by users of SBAS services.

Other navigation and geospatial data related challenges in the Arctic include the maintenance of maps and, in particular, nautical charts, which can be obsolete at times. Furthermore, terrestrial radio navigation systems, e.g., distance measuring equipment, are scarcely available to back up GNSS outages, and reference stations necessary for providing precise GNSS positioning services do not cover the entire Arctic region.

Finally, when developing technical solutions to address challenges in the Arctic, one must not forget the indigenous peoples living in the area: their traditional way of life, including activities such as reindeer herding, hunting, or fishing, should not be unnecessarily disturbed. However, these social challenges are beyond the scope of the online survey presented in this paper.

III. User Survey: Background and Purposes

The main target of the ARKKI survey [16] was to find out the user's views on the challenges in navigation and geospatial information-based applications in the Arctic region. The results formed background material for the "Challenges in Arctic Navigation" workshop held in Olos, Finland in April 2018. In the workshop, expert working groups continued discussion about the challenges faced by different market segments and user groups.

The questionnaire was accomplished as an online survey which was distributed via mailing lists, personal contacts and public project website. The number of experts operating with the Arctic navigation challenges is rather limited. Therefore, the target audience, having enough understanding about the circumstances and navigation challenges, was plausibly reached without simple random sampling. The total amount of completed surveys was eighty-three.

The survey consisted of questions that can be divided into four topics: 1. Background information and the activity in the Arctic 2. Recognized challenges related to navigation in the Arctic 3. Potential consequences of several navigation technologies and/or purposes in area 4. Feasibility of the already existing and upcoming solutions. The survey mainly consisted of multiple-choice questions with the possibility to leave open answers and further comments to each subtheme. In this report, the answers are grouped according to these themes and illustrated in figures.

A. Background Information and Activity in the Arctic

1) Country:

In total, 89% percent of respondents represented the Arctic council member countries (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden, and USA) where Iceland was the only country without a participant. The distribution of represented countries was: Finland 44%, USA 16%, Denmark 10%, Norway 9%, Canada 6%, Italy 3%, Sweden 2%, and Belgium, France, Greenland, Netherlands, Poland, Russia, Ukraine, and UK 1% each, respectively.

2) Activities taking place above the Arctic Circle:

Majority of the respondents operate at least sometimes in the Arctic area. From the 83 participants, 66 answered "yes", 12 said "no" and five did not answer. Since 79.5% of the respondents operate in the Arctic, we can assume that the survey reached targeted experts and the evaluation of recognized challenges, potential consequences and feasibility of solutions is based on real-life experiences and scientific knowledge.

The activities taking place above the Arctic Circle varied slightly between the market segments. 90.6% of the maritime segment, 87.5 % of the aviation segment, 80% of the road segment, 77.8% of the rail segment and 79% of the other market segment participants operate in the Arctic area.

3) Position in work

The biggest participant group, with 28% representation, were public authority representatives, which most probably also involves the defense sector as this was not asked separately. End-users of (Arctic) navigation were second largest group by 21%. Managers of service users and scientists/researches studying navigation-related were third largest groups, both forming identical 14% of survey participants. 4% reported that their position was either Professor or manager of researchers.

One fifth (19%) of the survey participants replied that their position in work is something else and belongs to the "other" category. The participants who selected the "other" category work, for instance, as a GIS expert, design engineer for a private company, manager of a vessel traffic service, commanding officer, navigation officer, cruise industry representative, hydrographic expert, funding agency representative, and information officer.

4) Involvement in different market segments

As seen from Fig. 1, almost half of the participants are active in maritime segment whereas the other market segments are seemingly smaller. In addition, nineteen of the participants reported that they are operating in more than one segment and are implicated with the striped areas. Other market segments included, for example, surveying and/or monitoring, seafloor mapping, hydrographic surveys, people flow solutions, geodesy, indoor navigation, weather services, inland water transport and subsistence hunting and fishing/observational reporting.

Because of the high number of participants from the maritime segment, we have settled a specific emphasis to analyze the answers of this group. In some cases, the survey results seemed to be slightly skewed due to the major appearance of the maritime segment. These results are discussed separately and encountered challenges are analyzed in comparison to the represented market segments.

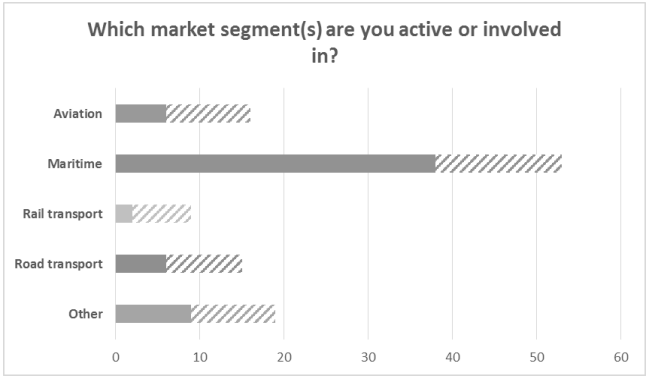

Fig. 1. Market segment involvement, the amount illustrated in solid color represents participants operating only in one segment. Striped part indicates the proportion of participants active in several segments.

IV. Encountered Challenges in the Arctic Navigation

At first, this section provides empirical data for comprehensive analysis of challenges characterizing Arctic navigation. The challenges, as described in earlier sections, cover themes related to environmental issues, weather conditions, ionospheric scintillation, and unavailability of navigation, augmentation, or telecommunication services. Secondly, the consequences of these challenges are evaluated according to their potential impact on navigation practices.

A. Encountered Challenges

In the survey, respondents were asked to evaluate how often they had encountered certain challenges related to navigation in the high latitudes. The frequency of the challenge occurrence was rated on an ordinal scale with following alternatives: 1. Regularly, 2. Sometimes, 3. Never, but I would know I had, and 4. I don't know. Results are illustrated in Fig. 2.

To sum up, almost 90% of participants had experienced *regularly* or *sometimes* insufficiency in telecommunications, e.g. issues with coverage or bandwidth. This option stands clearly out from the others and stated that lacking telecommunication capability affects every market segment. Over half of the participants had confronted untimely weather or ice information, lack of maps and nautical charts, outages in satellite-based navigation as well as unavailability of augmentation services.

Unavailability of terrestrial radio navigation, unawareness of accidents, ionospheric scintillation and inadequate road maintenance or icebreaking were among the least encountered occasions since under 50% of participants had experienced these issues or were noticeably affected by them. However, the remarkably high amount of *I don't know* answers discloses that these challenges are difficult to detect without specialized instruments.

In addition to the questions illustrated in Fig. 2, it was also asked whether participants had encountered challenges related to lacking physical infrastructure (ports, roads, and airports) or telecommunication functionality. Based on the answers, respondents had regularly encountered challenges with insufficient or inactive telecommunications bandwidth.

When comparing the answers given by the operators from different market segments, a few differences were found. For example, maritime users had encountered fewer considerable outages in augmentation services for satellite-based navigation than others. They had also encountered lacking nautical charts and/or maps (*regularly + sometimes* 86.4%) and untimely weather or ice information more often than other groups.

Regarding the aviation segment, the most encountered challenges are considerable outages in satellite-based navigation, untimely weather information, lack or unavailability of SBAS, and insufficient telecommunications capability which over 75% of the aviation segment had confronted *regularly* or *sometimes*. Participants from aviation segment had also faced lack or unavailability of SBAS more often than maritime.

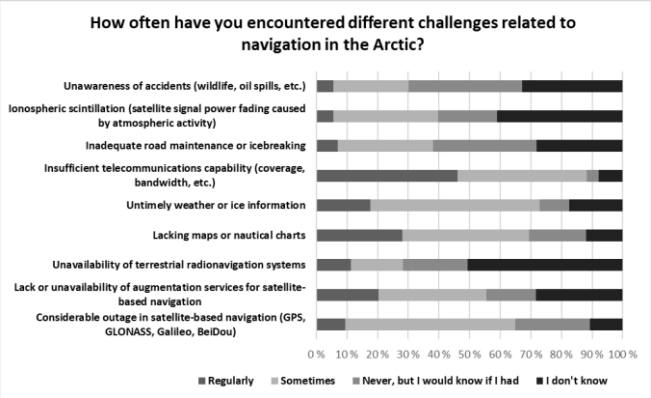

Fig. 2. Empirical evaluation of the frequency of several challenges related to navigation in the Arctic.

Lacking maps/nautical charts was reported to be rather wide problem among the road segment since 11.1% had encountered these issues *regularly* and 66.7% *sometimes*. In comparison, 14.3% rail segment representatives had encountered issues with maps/nautical charts *regularly* and 42.9% *sometimes* whereas inadequate road (rail) maintenance was encountered *sometimes* by three (42.9%) or *never* by four (57.1%) participants. All rail segment participants had been affected by insufficient telecommunications capability *regularly* or *sometimes* while 85.7% had encountered considerable outages in satellite-based navigation *sometimes*. Majority did not know whether they had encountered unavailability in terrestrial navigation or not.

According to the survey, lacking maps or nautical charts was not that severe problem within other segments as it was with maritime, aviation, road, or rail segments. Overall, unavailability of terrestrial navigation and ionospheric scintillation gained most *empty* or *I don't know* answers. These slightly skewed results may be due to the high representation of maritime actors.

Open comments related to the most encountered challenges revealed that the spectrum of challenges is versatile, ranging from day-today communication issues to outages in emergency tracking to missing ice information. Several respondents expressed maps were either outdated or their charts were not exact enough for successful navigation.

Significant lack of Internet and mobile connectivity as well as lack of reliable means of communication was encountered in several areas, especially in the high latitudes. Both insufficient EGNOS coverage and limited satellite coverage were mentioned by several respondents and these deficiencies are seen to be hindering the functionality of LPV, B2, and B3 approaches. Accuracy, reliability, and positioning frequency of GNSS aren't good enough for autonomous vehicles.

B. Potential Consequences

The survey examined the user's impression of the potential impact of several challenges, including 1. Snow, ice, and situational awareness; 2. Telecommunications; 3. Satellite-based navigation; 4. Other radio navigation than satellite-based; and 5. Maps and nautical charts. The ordinal scale of severity is defined as follows:

- **Catastrophic**: Incident may lead to persons being killed or severely injured, severe damage to property and significant economic impact.
- **Critical**: Incident may cause severe damage to property and significant economic impact. Small chance that a person gets killed, still a reasonable chance of injuries.
- **Major**: Incident may cause damage to property and economic impact. Reasonable chance that people may panic or get distressed. A small chance that people get injured.
- **Minor**: Incident causes mainly economic loss. There is a small chance of damage to property. May cause minor distress.
- **Negligible**: People may be alerted and feel uncomfortable. A possibility of damage to people, property, or business is very unlikely.

In most questions, the basic response trend followed the normal distribution where response options in center gained most answers. For example, issues were more often voted to have minor or major impact than catastrophic or negligible impact.

1) Snow, ice and situational awareness

Regarding the different aspects of weather conditions, there was no significant variation between the effects of consequences. Fig. 3 shows that majority of the participants stated that each of these weather-related issues has at least *major effect*, varying from 57.6% to 81%. However, untimely information about the surroundings and lacking road maintenance or ice breaking services gained fractionally less *negligible* answers that unawareness of accidents or darkness and bad visibility. The answers illustrate the impact of expectations towards pre-eminent services – lack of services was seen more crucial than unavoidable nature phenomena.

According to maritime segment, consequences with maps and nautical charts were severe since the clear majority of participants voted for them to be *major*, *critical* or *catastrophic*. Darkness, bad visibility, and lack of ice information can lead to catastrophic situations, especially in areas with polar ice. In open comment section, survey respondents specified that snow makes identification of ice type even more challenging. Information about ice, its sort and movements were considered to be progressive but receiving the overall information with a minimal delay was rated as the most important improvement. With real-time data, evading risks and optimizing the routes to prevent delays and economic losses is possible.

For the road sector, the most *critical* or *catastrophic* issues were related to untimely weather information, lacking road maintenance where unawareness of accidents, issues with telecommunications were classified to be *major* challenges. Otherwise, satellite-navigation as well as other radio navigation than satellite-based related issues were reported to have either *major* or *minor* influence. Open comments related to road transport issues implement that main risks are icy roads, whirling snow, and insufficient road maintenance.

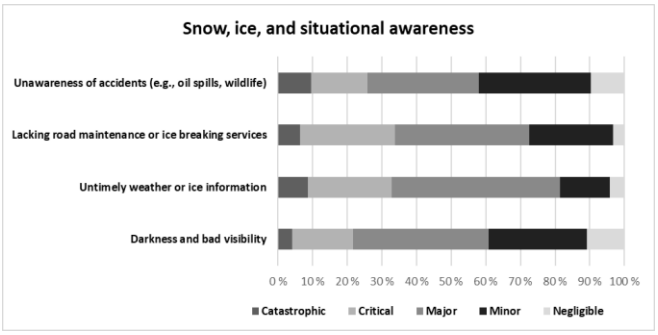

Fig.3. Significance of snow, ice, and situational awareness related issues.

All participants from rail segment reported that untimely weather or ice information as well as unawareness of accidents have at least *major* effects. Currently, the weather and climate conditions are biggest factors causing productive losses in rail transport. regarding the future scenarios of autonomous traffic, also on rails, these factors may contribute to more severe challenges.

Similarly, weather information is very important for aviation, especially in the case of low level (0-3000m) flights, such as helicopters and helicopter emergency medical services (HEMS). One weather information service provider commented that they produce weather information for road transport 120 000 times per year and the system updates once per every hour. While the emphasis is on rapid changes, the inadequate accuracy of the location references on maps cause challenges.

2) Telecommunications

All telecommunication issues were considered to be comparably severe as over 60% of participants classified these matters as *catastrophic*, *critical*, or *major*, as seen from the Fig. 4.

Regarding telecommunication consequences from the aviation segments' viewpoint, lacking coverage was seen to have most severe effects: 15.4% said it would be *catastrophic*, 15.4% answered *critical*, and 30.8% expected *major* consequences. In comparison, lacking coverage of telecommunications was classified to be *major*, *critical* or *catastrophic* by all rail segment participants.

According to the open comments, sheer lack of communications and bandwidth limitations were a significant operational hurdle, adding cost and complexity to all operations. One respondent implied, that the biggest challenge with terrestrial networks is related to the disparities of different networks and the reliability of data transfer between operators.

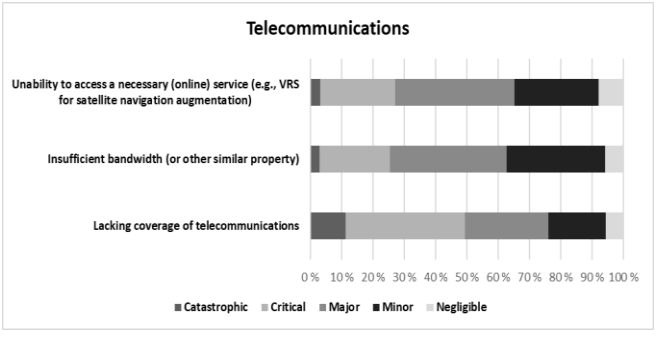

Fig. 4. Significance of telecommunications related issues.

Disclosing the fact that connections in Northwest and West-North Passages are poor or nonexistent, the prospects of utilizing alternative Northern sea routes require also improvements in the infrastructure. The commonly shared concern of lacking virtual reference station (VRS) and other precise GNSS augmentation services was reflected in open comments.

3) Satellite-based navigation and radio navigation

As seen from Fig. 5, the *major* effect was the most common answer to every question. The amount of consequence that was experienced to be *catastrophic* or *critical* varied, dropping from the 30% to ca. 5%. The underlining trend appears to be that the more detailed and technology related the question was, the more it gained either *empty* or *no opinion* answers.

Maritime users had more often *no opinion* answers in the consequences of satellite-based navigation than other groups. This may be due to the alternative techniques, for example radar navigation used near coastal and inshore, utilized for navigation at sea.

The open comments prove that the level of experienced and required positioning accuracy is highly dependable on the situation and the means of transport. For instance, one survey respondent explained that Northern railways are mainly single rails where adequate position accuracy can be reached with current technologies. In comparison, the situation on rail yards is more complex and for example, DGPS alone provides only defective accuracy. Multi GNSS with more frequencies is better than GPS L1 only to cover for ionospheric scintillation.

In addition to satellite-based navigation, we dedicated one survey question to other radio navigation methods, such as eLORAN and Distance Measuring Equipment (DME). Based on the answers, inadequate accuracy was seen to be more critical that unavailability of these services. Significantly, both inadequate accuracy and unavailability of services were mostly considered to have *major*, *minor*, or *negligible* impacts – 3% rated that inadequate accuracy is *catastrophic* and 5% said it has *critical* effects. In the case of unavailability, 3% of respondents said the effects are *catastrophic* and rest classified them to have *major*, *minor*, or *negligible* impacts. Furthermore, since half of the respondents had no opinion regarding radio navigation methods, we can conclude that these technologies are scarcely exploited.

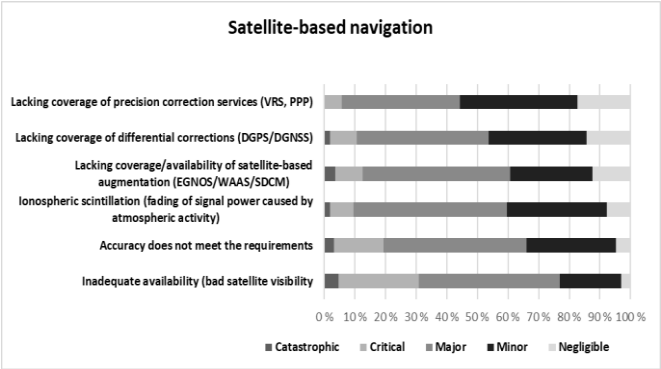

Fig. 5. Significance of lacking coverage and inadequate availability or accuracy of satellite-based navigation and correction services.

4) Maps and nautical charts

As seen from Fig. 6., the answers show clearly that the future prospects of autonomous traffic raise concerns about the adequate navigation accuracy. In current applications, we can still supplement inadequate map and nautical chart accuracy with other technologies and operations. According to maritime segment, consequences with maps and nautical charts were severe since the clear majority of participants voted for them to be major, critical or catastrophic.

Comments related to maps and nautical chart stressed the fact that both nautical charts and maps of the Arctic are outdated and entirely insufficient for modern precision navigation. Probing has been done prior to the satellite navigation era and therefore the reliability is not adequate for current norms.

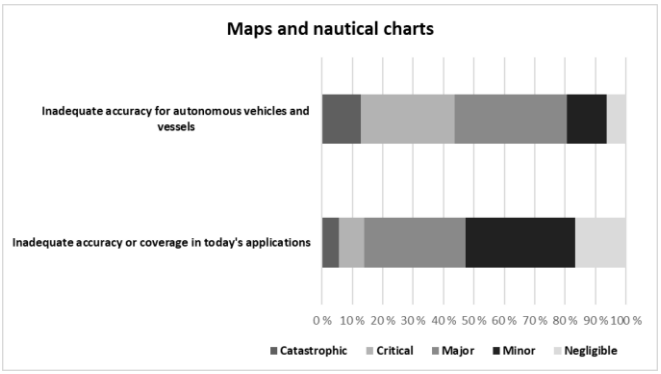

Fig.6. Significance of inadequate accuracy and coverage of maps and nautical charts.

V. Feasibility of Solutions

The last part of the survey focused on feasibility of solutions that are either recently deployed or under development and prospected to become mainstream technologies in the future. For example, the number of nanosatellites launched yearly has grown significantly during the 2010s, providing new tools for ad-hoc radar imaging. This kind of new applications have remarkable potential to improve the quality and timeliness of navigation. This section addresses respondents' experiences and opinions related to suggested solutions

When looking at the Fig. 7 and the answer rates in *definitely useful* and *indispensable* categories, it seems that the most important, or needed, solutions according to users' opinion are: telecommunications technology/services and extended assistance and augmentation services for satellite navigation. If excluding the telecommunication solutions, the differences in approximated feasibility were proportionally minor. Overall, at least 60% rated every evaluated solution to be *indispensable* or *useful*.

When comparing the feasibility of solutions by market segment, few interpretations can be made. Telecommunications technology/services were rated to be the most feasible solution while 87.8% of the maritime users admitted these would be *definitely useful* or *indispensable*.

Remote sensing was seen as the most feasible and important solution among the aviation segment: 63.6% said it would be *definitely useful* and 18.2% classified the importance *indispensable*.

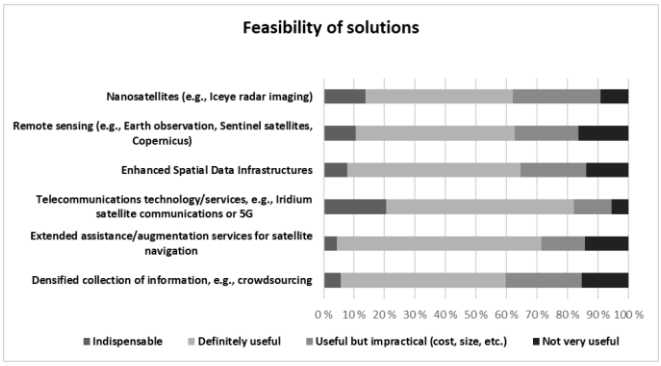

Fig. 7. Empirical evaluation of solutions shows that improvements regarding telecommunications technology and services were seen most feasible.

Other important solutions were telecommunications technology/services (38.5% *definitely useful*; 38.5% *indispensable*) and extended assistance/SBAS (61.5% *definitely useful*; 7.7% *indispensable*). Nanosatellites were seen to be either *definitely useful* or *useful but impractical*.

According to the road segment representatives, remote sensing services, such as Copernicus, were seen *definitely useful* or *indispensable* (100% of the responses were in these categories).

Among the rail sector, extended assistance/augmentation services for satellite navigation was seen as the most useful (88.9% saying it would *be definitely useful* or *indispensable*) whereas 77.8% of the rail segment participants rated the improvements of telecommunications capability to be either *definitely useful* or *indispensable*.

Participants representing the other market segments were comparably optimistic about the feasibility of solutions: only nanosatellites and remote sensing received one vote saying that these solutions are *not very useful.* Otherwise, all were classified to be at least *useful*. Extended assistance/augmentation services for satellite navigation was seen as the most competent (93.8% saying it would be *definitely useful* or *indispensable*).

Open comments related to feasibility of solutions debated that improved connectivity and communication services are only helpful if they are affordable, also for general use outside scientific research. The reliability of iridium was questioned, and one respondent reported that iridium solutions have worked poorly in when other communication equipment has malfunctioned. Furthermore, the open answers underlined the need for accuracy: especially since technology is developing rapidly, and different market segments are having different needs, the level of exactness should not be restricted.

VI. Conclusions

In this paper, we have described the challenges of Arctic navigation from the user perspective, based on real-life experiences. The main contribution is the characterization of empirically proven challenges, providing novel insights of the relations between the represented industry, encountered challenges and areas of operation. Based on the user survey, the following topics were identified as most significant challenges: telecommunications, maps and nautical charts,

GNSS augmentation and integrity, and situational awareness.

The results indicate that telecommunications insufficiency in is a widely recognized and encountered problem as nearly 90% of the participants had been affected by lacking telecommunication services or inadequate bandwidth. These issues are familiar to all but affect the navigation operations and accuracy especially in the Arctic. Otherwise, the impact of each challenge varied slightly between the market segments (aviation, maritime, rail, road, other) the survey respondents and workshop participants represented. The results also showcase the differences in navigation and location-based services between countries and public versus commercial actors. We found two major dependent variables, nationality and market segment, which were analyzed further.

The forecasted revolution of both autonomous vehicles and vessels as well as unmanned aerial vehicles (UAV) reflected in the answers. Particularly, the issues of insufficient maps and nautical charts were mentioned as a part of larger reliability challenge. From the technology perspective, the survey participants underlined that the current accuracy of any navigation application along with the insufficiency in telecommunication coverage is causing severe issues in precise positioning and close-proximity navigation.

The more detailed and technical the question was, the more it gained *empty* or *no opinion* answers. This trend can be seen especially in potential consequence questions, where satellite and radio navigation-related questions received more *empty* and *no opinion* answers than other questions. All answer options included examples of related technologies for guidance.

As 44% of the participants were from Finland (see Fig. 1), we compared the English and Finnish versions to find out if there are significant differences. Of course, this method can only give indicative results since some Finnish participants answered in English. Nevertheless, few interesting observations were made, especially when the answers from maritime segment were compared. Firstly, Finnish participants tended to select the stronger options. For example, in the series of questions evaluating the consequences, *minor* was chosen over *negligible* whereas *critical* gained more answers than *major*. Secondly, very few Finnish maritime participants selected *no opinion*, or *I don't know* options. Lastly, the questions related to remoteness and extreme weather conditions were seen to have more severe and wider consequences and confronted more often among Finnish participants than in the international group.

In other market segments, the number of *no opinion* or *I don't know* answers was typically higher in the Finnish survey than in the international group. However, generalizing the answers to reflect the experiences and opposed challenges of the whole market segment would be misleading since the sample size in other market segments varied between 2-6 participants where six participants reported to operate on road, while aviation, rail and other segments each had two participants, respectively.

Secondary contribution of this work are the observations regarding the feasibility of solutions, presented in Section 5. Telecommunications solutions, such as Iridium satellite communications and 5G, were evaluated to be most feasible. Despite the commonly agreed usefulness of the valued solutions, all confronted criticism. Either they were seen to be useful, but impractical due to high price or size, unreliable or inaccurate.

The sufficiency of precise navigation in Arctic areas was common concern among survey respondents. Especially, the requirements of autonomous traffic were mentioned several times with the concurrence of augmentation service accuracy.

Overall, the survey pointed out some problems and insufficiencies that affect very specific areas, applications, or technologies. Some of these are related to political decisions but are similarly crucial to the operators who are dealing with these matters regularly.

To sum, the user survey results provided relevant empirical insights to complement the scientific findings of the positioning performance, availability, and accuracy in the Arctic. Ensuring sufficient coverage of satellite-based navigation and augmentation services is a prerequisite for the overall development of the Arctic area. In addition to the needs, the current level of is not in line with the political promises to offer equal services for all EU member states. Providing modern standards of bandwidth to the Arctic is a crucial prerequisite for the development of other technologies and services in the area. Fortunately, initiatives to address Arctic telecommunications challenges are being planned, e.g., based on satellites in highly elliptical orbits [17]. Based on the findings of the user survey, the relevance of crowdsourced data is emphasized. Crowdsourcing could improve maps, nautical charts, or situational awareness systems.

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