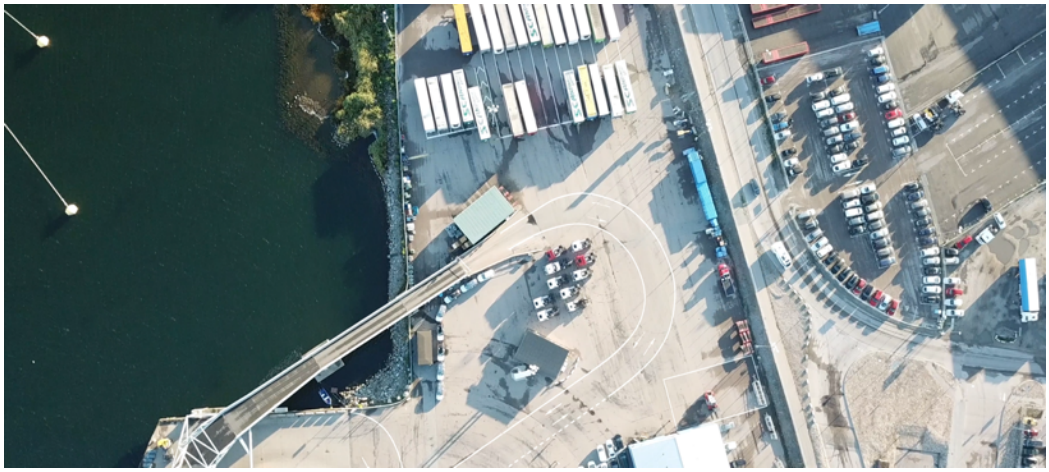
Drone and Synthetic Aperture Radar (SAR) Satellite Measurements

Trans-European Transport Network - TEN-T

A TENTacle Pilot Study within the INTERREG program



Blekinge Institute of Technology, BTH, SE-371 79 Karlskrona, Sweden, +46 455 38 50 00

Table of contents

Abstract

From the urgent need for new objective metrics on European transportation networks, the idea of using an Earth observation satellite equipped with a high-resolution imaging synthetic aperture radar (SAR) emerged. This became the starting point for a pilot study within the framework of the INTERREG Program 2014-2020 and the transnational cooperation project called TENTacle. This project aims to improve the mobility, inter-modality, and interoperability of the major transport axes across Europe, and provide suitable recommendations for transport policy decision making in the Baltic Sea Region.

The TENTacle project consists of activities including work packages, tasks, and pilot studies. The goal of the pilot study was to develop a new concept for analyzing and detecting changes in goods transportation flows and finding bottlenecks along the Trans-European Transport Network (TEN-T) Core Network Corridors (CNC). The study also aimed to propose a tool for monitoring the potential of remote geographical areas to become new extensions of CNC in the Baltic Sea Region (connecting to the ports in Blekinge, Sweden).

The first part of the pilot study consisted of developing tools and models for analyses using satellite synthetic-aperture radar (SAR). In the latter part of the project, the technology's potential and the newly developed concept were both verified through practical demonstrations. Some measurements, performed within the framework of the pilot study, were carried out simultaneously with the satellite SAR system TerraSAR-X, and a camera-equipped drone (UAV).

The TENTacle project has also established an innovative environment in analyses of traffic flows and intramodality in ports and terminals using satellite SAR and drones. This report should therefore be seen as part of the increased trend toward technologically advanced surveillance and analysis. It presents some illustrative examples from the pilot study, some developed recommendations for this type of analysis, and a guide for how the pilot could be easily scaled up for a new, larger joint-EU project or joint study (such as a SAR-Satellite survey including the Baltic and Adriatic corridor).

Background

Over the last few decades, there has been significant advancement in the area of space borne synthetic aperture radar (SAR) systems, including satellites equipped with high-resolution SAR systems. These radar systems are mainly made for military surveillance and for measuring geophysical properties. However, over the last few years, several systems have been used for civilian projects, including measuring human activities like transportation. There seems to be a rapid increase in the number of systems that will become available over the next ten years, which in turn will enable much more comprehensive surveillance coverage over both space and time.

The aim of the pilot study was to use satellite SAR to measure transport chains across large areas of the EU. This new measurement method is very promising, exemplifying how to select measurement areas that can provide valuable information about transportation flows from different perspectives. Examples of such measurement areas are intermodal terminals, harbors, roads along corridors, and railway tracks.

The TENTacle project aims to produce satellite measurements of various parts of the European sea-transport corridors. For this purpose, the satellite system TerraSAR-X has been considered to exemplify how central parts of a transportation network can be measured and analyzed from different and novel perspectives. A satellite system equipped with SAR was chosen for its cost efficiency and ability to measure goods and traffic with consistency across the EU. In addition, a SAR-equipped satellite can capture measurements throughout the year, regardless of weather conditions.

The purpose of this kind of measurement is to provide information to end users and decision makers whose purpose is to evaluate and develop the Trans-European Transport Network (TEN-T).

This report presents the pilot results with a high-level approach, and will be followed by research reports and new publications after the project is complete (accessible via www.diva-portal.se). A follow-up report will be prepared to cover the more research-oriented aspects of measurements included in the pilot TENTacle project. In this context, there are more theoretical discussions concerning the accuracy of average traffic estimates, which movements and comparisons from a satellite perspective should be considered, and how the process of capturing measurements and processing statistical data can become optimally effective.

The research group implementing this part of TENTacle anticipates future participation in new and exciting collaborative projects within the EU framework. For example, the

measurements collected through the TENTacle pilot project could easily be scaled up to collect new and interesting measurements across previously unstudied parts of the EU in collaboration with new partners.

Satellite and Drone Measurement and Analysis

The pilot study aimed to develop new concepts to analyze changes in transportation chains and to identify new tools for finding the bottlenecks along the TEN-T Core Network Corridors (CNC). Such phenomena can originate from many different factors, both endogenous[1] and exogenous[2]. It is therefore particularly challenging to isolate specific key factors within the TEN-T and its envisaged enlargement areas that for add even greater importance to the EU transportation network and strengthening socioeconomic growth.

One way to deal with this complexity is to focus on the gathering of satellite data covering several domains in the transport network, instead of trying to isolate individual transport modes. Therefore, in the pilot study, we have chosen to analyze several key figures in different domains. This will provide good examples of what is possible (and what is not possible) in terms of data accessibility. The availability of data between EU member states can be a problem, but this does not exist in a satellite measurement context. A large number of measurements of parked trucks in ports, ongoing goods transport in the network covering roads/sea, and activities in terminals were made. From these kinds of measurements, several different types of key figures can be identified to provide a comprehensive picture of the effects of investment in CNC.

Because there is no comprehensive European database that regularly monitors goods transports, we proposed a stratified approach for collecting SAR-satellite data. The purpose of this approach was to generate new knowledge about the effects of potential development opportunities, as well as the expansion of land and sea transportation networks.

Transportation of goods in Europe looks different in different parts of the continent, depending on the geographical location, the price of the product in relation to transportation cost, and the product's destination. In different parts of the EU, new transport scenarios have arisen that do not have any alternative means of transport. These corridors therefore play a central role for the regions and sub-regions (neighboring regions) included in the CNC.

[1] Endogenous are those factors that originate from within a system.

[2] Exogenous refers to a factor or object that comes from outside a system.

Within the framework of the TENTacle project, the aim of this study was to demonstrate new possible positive effects of the expansion of the TEN-T. Critically, expansion should be based on well-founded objective measures and measurement figures, formed into an optimally accurate model of the system. When studying aspects such as traffic flows, traffic density, goods flow in terminals, and free capacity in a port, it is important to use systems that can deliver a clear picture across the EU to ensure a fair comparison. This means that large-scale measurements of exactly the same measurement system are highly desirable and important to ensuring the quality of analysis.

Methodology and Key Figures of Efficient Transportation Chains

The purpose of the pilot study was to demonstrate good examples, such as designing a method for analyzing the transport networks for goods handling. From a broader perspective, this could be used as a basis for consistency when considering the efficiency of expansions and investments in the CNC. The underlying idea of the pilot study was to highlight and build knowledge to facilitate future expansion. The methodology also provides different options, such as before and after evaluation (the possibility of conducting ex-ante and ex-post effect evaluations).

The aims were to produce examples of different measurement methods where the SAR satellite and drone measurements would contribute to before-after evaluation of an investment or extension of the TEN-T implementation. Satellite measurements are well suited to storage, both in the form of results and raw data in a database, in order to support follow-up studies in ex-post analysis. In terms of conducting ex-ante and ex-post studies, it is necessary to carry out satellite measurements and collect data before as well as after the implementation of new routes or extensions of corridors. Accordingly, a stratified random selection in well-selected corridors was considered a fruitful technique for collecting data on traffic flows and goods allocation along the TEN-T corridors. This is because such data in existing databases is very limited and does not cover the entire EU. However, it is important to point out that the new methodology does not contrast with current existing approaches. Rather, the new, co-optics using SAR satellite technology should be seen as a valuable new contribution and a powerful companion to existing measurements that can lead to calibration, support trade-offs, and improve the quality of the existing data.

For new planned expansions of the TEN-T into neighboring regions, our recommendation is to start the satellite measurements over the new regions several years before the implementation. In this way, the analysis will address the true improvement and its value in the upcoming ex-post study.

Measuring activity, flows and efficiency in freight terminals

The purpose of the pilot study within TENTacle was to develop useful satellite-based assessments for studying positive effects in different regions from an EU perspective. The assessments, such as freight flows and activities, should be based on well-founded objective measurements and measurement figures in order to optimize the accuracy of the EU's global insight. When studying aspects of a transportation system such as port activities, traffic flows, traffic densities, and goods allocation in harbors, it is important to use systems that can deliver a clear picture to ensure a fair comparison of regions. A fair comparison can be more important than measurement accuracy. This means that large-scale measurements conducted simultaneously of exactly the same kind are highly desirable and important for ensuring the quality of future evaluations, comparisons, and decision-making at EU-wide level.

In this pilot study, we outline recommendations based on the satellite measurements carried out in the frame of the study. We recommend that future analyses begin with data collection over the corridor to register the current situation. Based on these measurements, researchers can further investigate and describe when, how often, and over which geographical areas of TEN-T the measurements should be made. It is considered that the new satellite measurement technology leads into a new pixel-to-people era in which it will be possible to produce new interesting measurement figures with an EU transportation focus. The aim here is to show that the system can measure changes and traffic over larger areas and that it is an extremely powerful tool for highlighting new details. The pilot study shows examples of large-scale satellite measurements, for example covering an entire port, the seaway including the main shipping channel, and the road/rail network around the harbor. Typical performance of satellite-borne SAR measurement systems, such as the system used in this study, can cover all traffic and activities over a 900-square kilometer area in one deployment. Thus, we argue that the concept of traffic and freight flows in this context should be seen from a wider perspective, as in addition to mapping goods or traffic flows, we can now analyze a transportation system with more granularity, measuring, for instance, the percentage of stationary vehicles in a harbor or along nearby corridors. Detection of free capacity in terminals and quay areas is, of course, another aspect of particular interest for the EU, the Baltic Sea Region, and all stakeholders in the development of the motorways of the sea (MoS).

An important aspect of this pilot study is the vision of how a future large-scale data collection of Europe's road network should be conducted. One data collection chain that has

been verified through this pilot study is as follows: selecting strategic and important parts or links within a corridor, ordering the measurements from a satellite operator, downloading the high-resolution radar images, adapting the radar images for the analysis system, statistically analyzing the images, and detecting changes (for example that occurred in connection with the extension or improvement of TEN-T) (see Figure 1). In the pilot project context, this chain has been verified through practical demonstrations with measurements over an area in northern Europe, more precisely in Blekinge, in the Baltic Sea Region close to the Adriatic corridor, where the satellite system TerraSAR-X was used in tandem with its twin satellite, TanDEM-X.

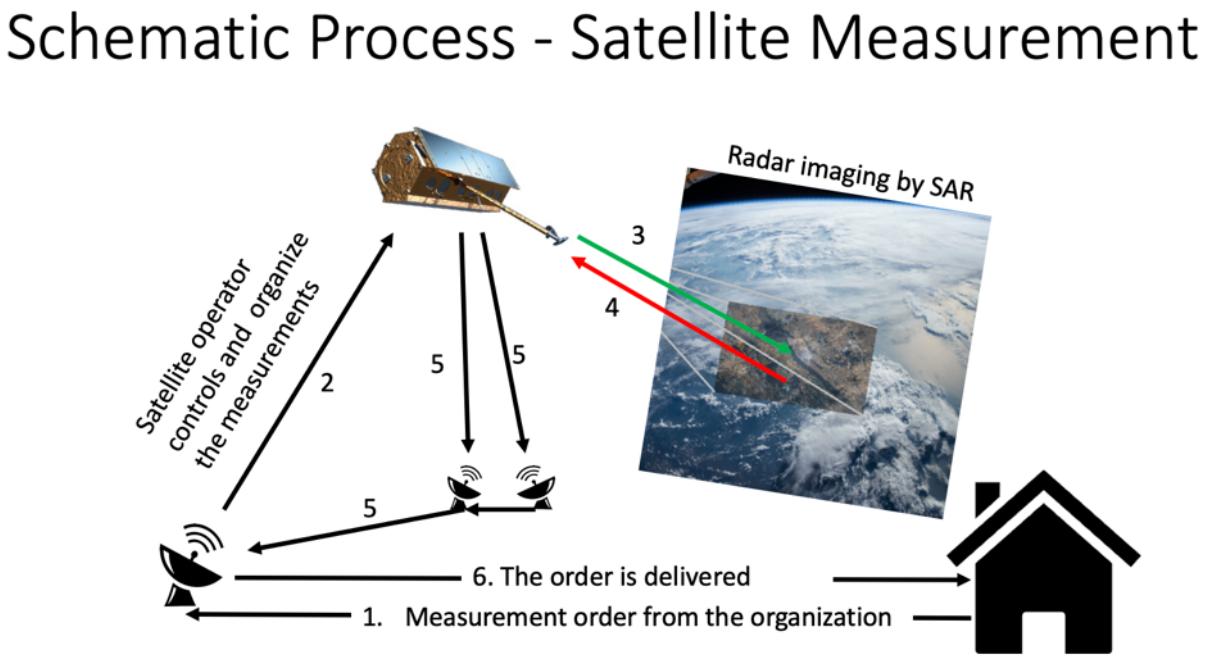


Figure 1: Schematic description of a SAR satellite measurement. The client (customer/organization) wants to measure and cover a large geographical area (e.g. part of the TEN-T, like a harbor or an intermodal terminal). The client places an order for the actual area to the service provider (the satellite operator). 2. The satellite measurement system is directed towards the geographical area. 3. Radar pulses are sent out when a satellite passage takes place over the area. 4. The satellite records and stores radar reflections from vehicles, containers, trailers (radar echoes from a large area). 5. When the satellite passes reference stations on the earth, the gathered data is transferred to the satellite operator. 6. The operator delivers high-resolution radar "images" back to the client. The client then extensively processes these "images" using a computer, and uses the information they contain to create a large area traffic measurement and change detection analysis.

TENTacle node Experiment

In the node experiment, we concentrated on the activity in one TEN-T node, or in a TENTacle node associated with a TEN-T node. In Blekinge there are two such nodes—Verkö harbor and Stilleryd harbor close to the city of Karlskrona and Karlshamn, respectively. In the TENTacle Blekinge pilot case 3.1, the measurements of the truck traffic/parking situation around these two harbors were of interest. In Verkö harbor, the measurements were performed with a satellite-based SAR and a drone-based optical camera.

Short background and purpose of the Blekinge case

Karlskrona and Karlshamn are two port cities in the county of Blekinge in the southern part of Sweden. They form part of the arterial shipping routes across the Baltic Sea to Gdynia and Klaipeda, which connect Sweden to continental Europe. The ports and traffic to and from the ports partially demonstrate how the economy in these areas has developed, not only in Blekinge but also in the northern and western areas in Sweden. In the future, these ports will receive more investment and be expanded, necessitating extensive changes in land use in and around the port areas. For example, access roads and various types of communication due to the rapid development of transport will be opened. Non-compliant, unplanned, and unsustainable development of port areas, for example, can lead to problems for the development of corridors and communications within the EU. Studies that support the planners and decision makers are therefore crucial. This study evaluates the usefulness of remote sensing with satellites and drones in providing remote sensing data for analyses. The satellite measurements are performed with SAR, while the drone measurements are achieved with an optical camera. The idea of satellite measurements of this kind is that the measurements can both provide a direct radar image and multi-temporal satellite data. A change analysis of the terminals can be performed using the multi-temporal SAR satellite data. In this test, study areas allocated by goods and vehicles could also be observed. An overall understanding of these types of changes is critical for enabling planners to optimize development.

Satellite image over harbors

Measurements from space borne SAR systems (SAR systems mounted on satellites) were supplied through an agreement between the Blekinge Institute of Technology, Airbus Defense and Space and German Aerospace Centre (DLR). The measurements were captured at approximately at 06:15 (Karlshamn), 07:15 (Karlskrona), 17:45 (Karlshamn) on each of the sample days. Highlighted satellite images over a part of Karlskrona and the Verkö area are shown in Figure 2 and Figure 3, respectively. The large coverage of satellite images is evident

from Figure 2. The measurement times were coinciding with the time when a ferry arrives. The ferry route between Karlskrona and Gdynia is operated by Stena Line, and the route between Karlshamn and Klaipeda is operated by DFDS Seaways, two international transport and ferry operators.

It is worth mentioning that the most efficient route between Scandinavia (via the South Baltic Sea) and the Baltic countries', Adriatic Sea or Suez Canal are via these harbors. The harbors have an optimal location in southeastern Sweden, close to other regional hubs. Because of advantages such as shorter transport routes, more environmentally friendly transport methods, and more cost-effective shipping, Karlskrona and Karlshamn municipality, the EU, and several strong operators in the transport and shipping industry work together to develop these harbors, -this may lead to local studies about sea traffic in the future.

For example the main facilities provided by the harbor in Karlskrona include parking lots, a taxi station, a bus station, and a storage area, as shown in Figure 2. Because of the ferry route operation, a large number of vehicles, trucks, trailers, containers, and other goods are present in the harbor during certain periods of each day. Changes in the harbor caused by the vehicles are continuous and significant. Detecting and analyzing changes is also important for planning future projects. The data revealed that the number of trucks in the harbor is usually high, but on some days it is significantly lower.

In the Verkö harbor, the measurements were carried out using drone video of the harbor area. Figure 4 presents one drone-generated image depicting the Verkö harbor just at the time the ferry arrives. Drone measurement is valuable for on-site harbor investigation, while satellite measurements support long-term evaluation of large harbors or several harbors in Europe at the same time. In the future, both technologies will be subject to further development, and satellite-based technologies will provide greater availability to make evaluation measurements of transport chains over large areas of the EU. Based on these measurements, Figure 4 reflects a typical situation from one of the days that the port's cargo traffic surfaces are heavily loaded. The large number of trucks and trailers take up almost all available surfaces while waiting for the next departure.

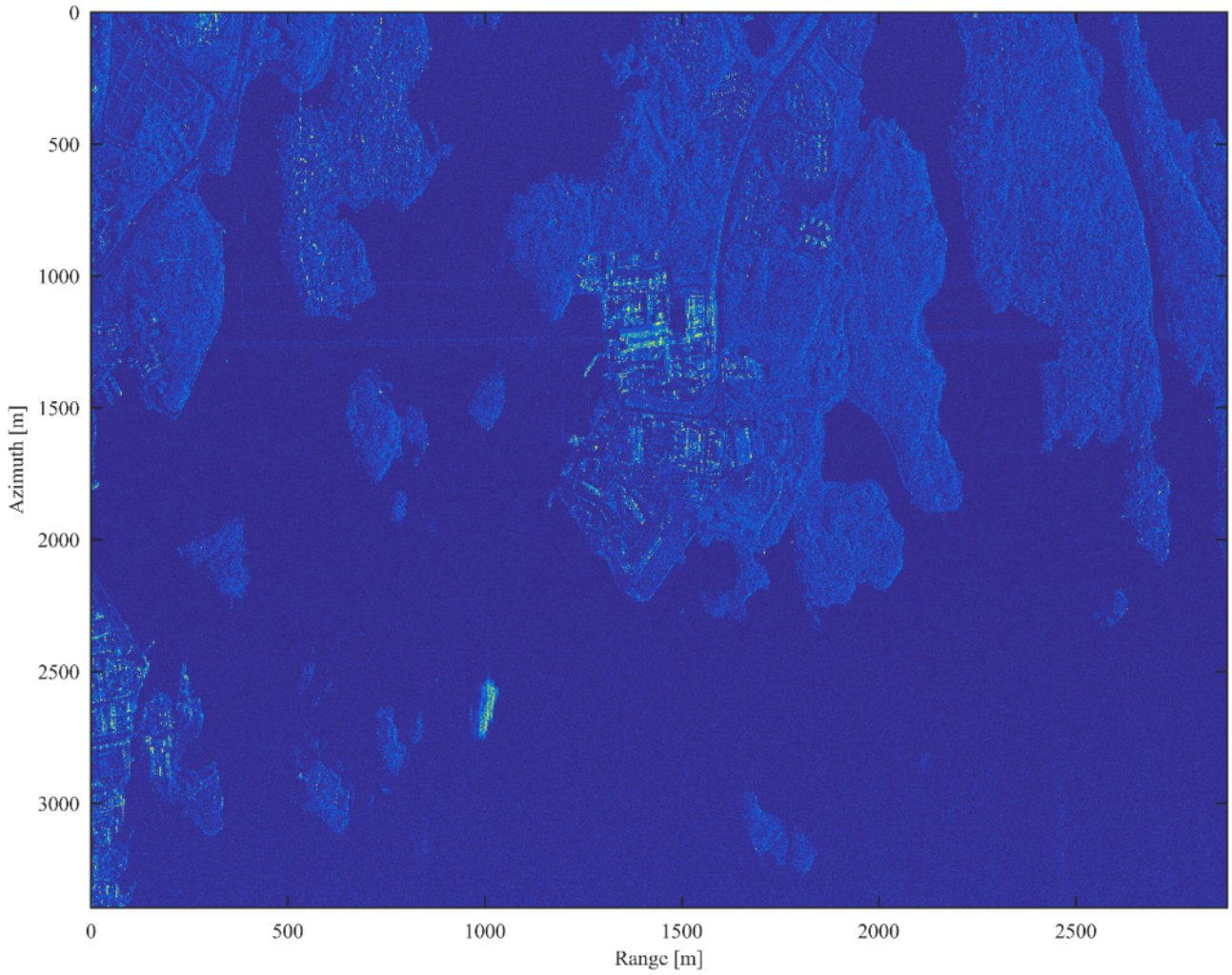


Figure 2: Satellite image over a part of Karlskrona

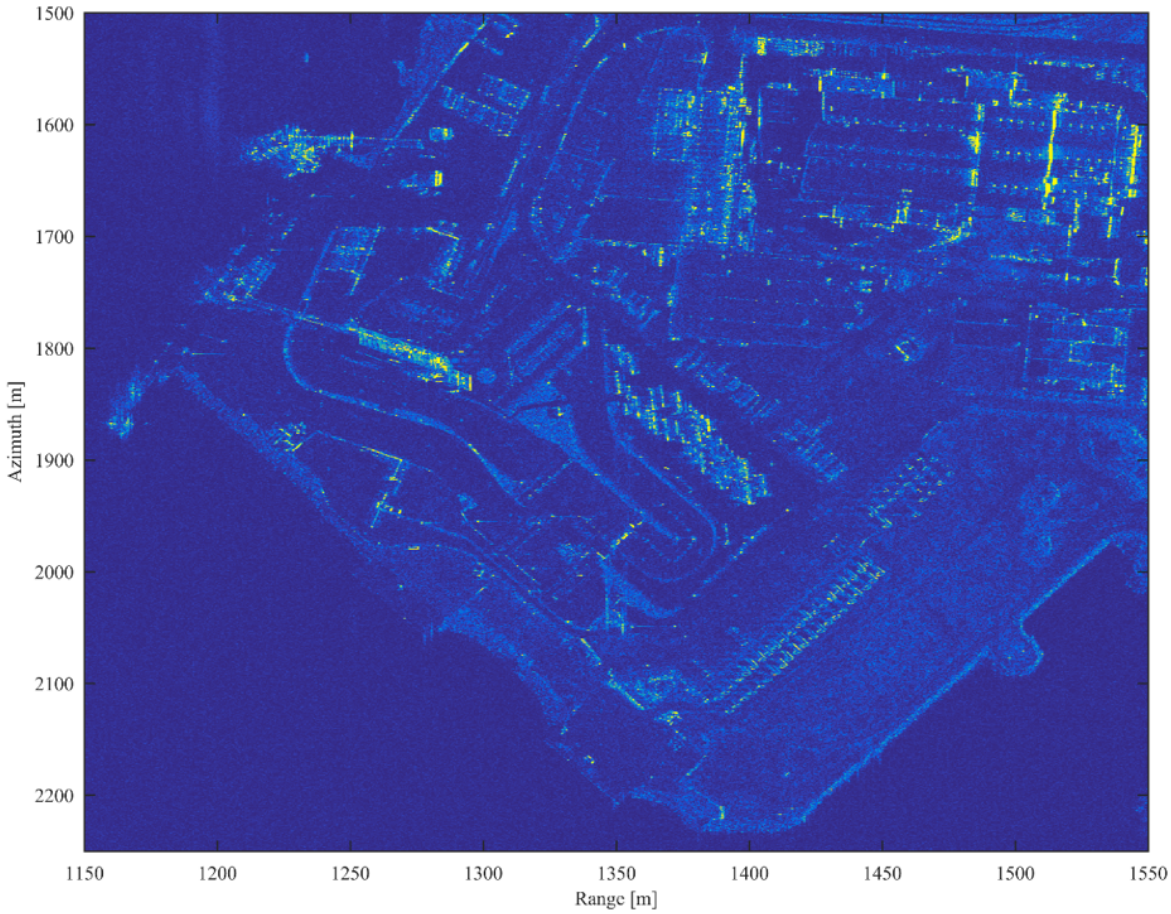


Figure 3: Satellite image over Verkö harbor

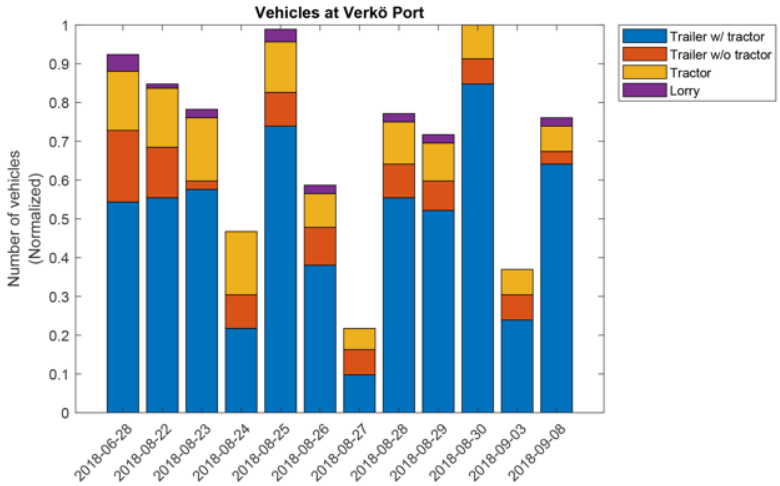
Figure 4: Verköhamnen in Karlskrona, Sweden (2018)

Within the framework of the TENTacle project, a test measurement campaign was conducted with TerraSAR-X and a camera-equipped drone. The campaign (carried out over 10 days in August through September 2018) reinforced the picture that a significant amount of the port's goods transport moves along the Karlskrona–Gdynia MOS road. The information provided in Fel! Hittar inte referenskälla. and the infographic in Figure 5 (notwithstanding the limitations of the study) demonstrate the usefulness of satellite surveillance and complementary drone measurements for collecting and clarifying critical data to support the development of ports and transportation corridors.

The results of the satellite and drone measurements further emphasize the shortcomings and needs highlighted in this report. Hence, the report points out the importance of establishing Blekinge's connection to TEN-T.

A further more comprehensive and important result is the methodology of regularly using an SAR-equipped satellite and drones to evaluate transport chains across large areas of the EU. Although this new measurement method is very promising, the selection of test site in this pilot study is also very important. Well-selected measurement areas, such as intermodal terminals, harbors, roads, and railway tracks, can provide optimally calibrated information about the actual transportation flows within the EU, from an evaluation and development perspective.

Table 1: Normalized load in the Verkö harbor. A short-term analysis based on measurements with a SAR-equipped satellite and a drone.



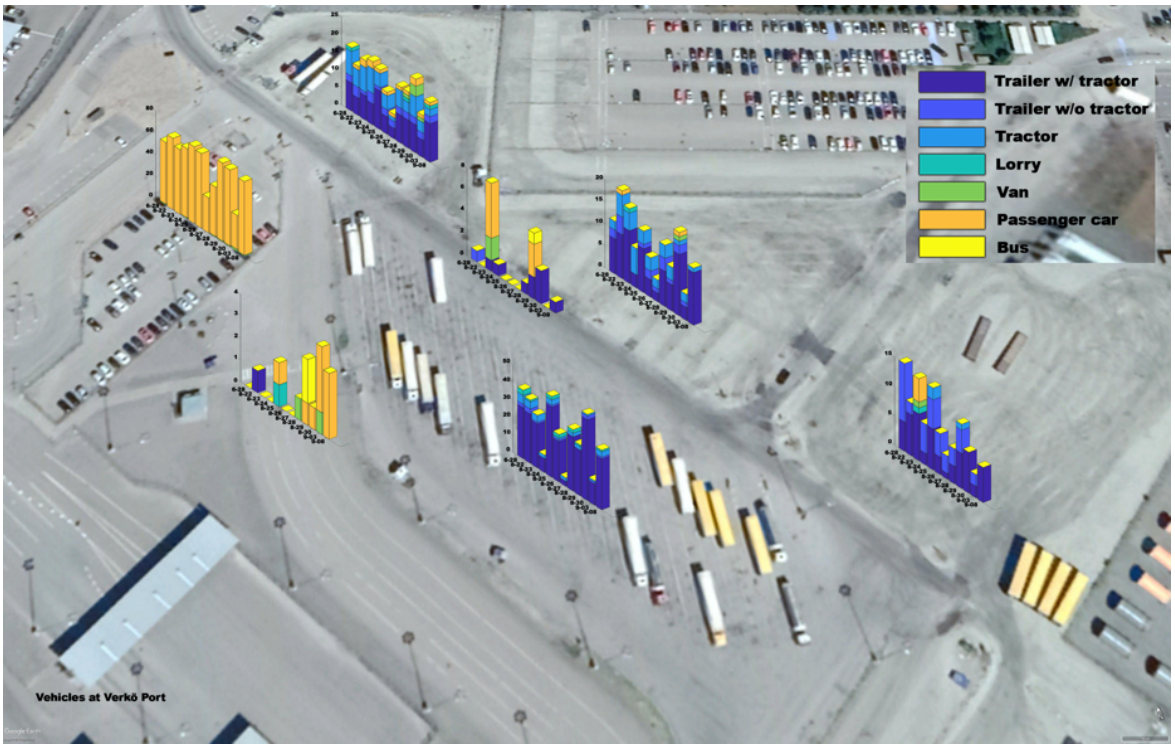


Figure 5: Infographic showing the allocation of surface areas. This illustrates the significance of TENTacle, as well as the development of measurement methodologies like SAR-equipped satellites and drones.

Discussion and Outcomes

Karlskrona and Karlshamn are two port cities in the county of Blekinge in the southern part of Sweden, connecting Scandinavia to important shipping routes across the Baltic Sea and to Gdynia and Klaipeda. The ports and traffic to and from the ports represent a major economic development, not only in Blekinge, but also for the northern and western parts of Sweden. In the future, these ports will be developed and will become even more important freight and transport hubs. Extensive changes in land use can be predicted in and around the ports, including access roads and various types of communication, due to the rapid development of transportation. Noncompliant, unplanned, and unsustainable development of the areas around the ports can lead to problems for the development of corridors and communications within the EU. This study evaluates the usefulness of remote sensing using SAR-equipped satellites and camera-equipped drones in analyses of traffic flows and intramodality in ports and terminals. Some measurements with SAR-equipped satellites and camera-equipped drones have been conducted. Satellite measurements can provide radar images and multi-temporal radar data. This multi-temporal data is useful for conducting

change analyses of terminals. In this test study, the areas allocated by goods and vehicles could be observed. An overall understanding of this type of change enables planners to optimize their development plans.

Finally, it is evident that the Pixel-to-People era has come to stay.