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ENGLISH TRANSLATION

Socio-Economic Analysis of Satellite-Based PNT Services

An analysis of the socio-economic costs associated with the loss of satellite-based PNT services (GNSS)

REPORT

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Foreword

On behalf of the Ministry of Trade, Industry and Fisheries, Menon Economics has conducted a socio-economic analysis of satellite-based services for positioning, navigation and timing (PNT). The analysis highlights how satellite-based PNT services are used across different sectors in Norway, and the importance they have for value creation and the functioning of society. A central purpose has been to examine the socio-economic consequences that the loss or disruption of such services may entail, as well as to identify vulnerabilities and possible measures to reduce dependency.

The project at Menon was led by Magnus Utne Gulbrandsen, with Per Fredrik Johnsen as project manager. Andreas Becker Cappelen, Marius Berge Eide and Torgeir Dahl Jørgensen were project team members. Kristoffer Midttømme acted as quality assurer.

We would like to thank the Ministry of Trade, Industry and Fisheries for an engaging and interesting assignment. We also thank all interviewees for their valuable input throughout the process. Menon is responsible for all content in the report.

March 2026

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Executive Summary

Satellite-based services for positioning, navigation and timing (PNT) have today become a fundamental part of the infrastructure of the digital society. This report analyses how PNT services are used in Norway, which sectors depend on them, and the socio-economic consequences that may result from a loss of these services. Based on sector-specific analyses, the priced direct costs of a seven-day loss are estimated at approximately **NOK 3.4 billion**. This estimate does not include the defence sector.

A comprehensive assessment of the consequences cannot be limited to the sum of direct losses within individual sectors. Several of the sectors most dependent on PNT services also constitute **critical societal infrastructure** upon which other sectors depend. The greatest vulnerabilities are therefore not necessarily found where the direct costs are highest, but rather in cross-sectoral functions such as **power supply, finance and electronic communications**.

Although these sectors typically have built-in redundancy, the risk associated with the infrastructure is nonetheless increased in the event of loss or manipulation of satellite-based PNT services. Overall, the analysis shows that increasing use of satellite-based signals delivers significant efficiency gains, but may also increase societal vulnerability if robustness and alternative solutions are not developed in parallel.

Satellite-based services for positioning, navigation and timing (PNT) have become an integral part of the infrastructure of modern society. The technology is used in everything from aviation and maritime navigation to mobile networks, financial transactions and the operational systems of emergency services. At the same time, dependence on satellite-based signals is often largely invisible. Many organisations do not use the technology directly but rely on systems and infrastructure that do.

This makes it difficult to gain an overview of where dependencies lie and what consequences loss or disruption may have. This report analyses how satellite-based PNT services are used in Norwegian society and what consequences loss or disruption may entail. The analysis maps both the use of PNT services and the consequences at sector level and at the level of society as a whole.

The purpose of the analysis is to strengthen the knowledge base on society's dependence on PNT services, highlight vulnerabilities, and provide a holistic picture of the technology's importance for value creation and societal functioning.

Satellite-based PNT services rely on signals from global navigation satellite systems (GNSS). These signals are freely available, have global coverage and high precision, and have therefore become an attractive technological solution across many sectors. Usage has increased sharply over the last two decades, meaning that an increasing number of systems and processes are dependent on GNSS signals—either directly or indirectly through digital infrastructure and automated systems.

In recent years, documented disruptions to GNSS signals have occurred in Norway, including in Northern Norway. Such incidents show that the risk of loss or disruption is not merely theoretical. In a digitalised and interconnected society, failures in fundamental technological references such as position and time can have consequences far beyond the systems that directly use the technology.

1. Introduction

Modern Norwegian society is increasingly dependent on satellite-based services for precise positioning, navigation and timing (PNT). Such services are freely available, have global coverage and generally high availability. They enable efficient solutions and increased value creation across a wide range of sectors and critical societal functions, including emergency services, petroleum activities and financial markets. In everyday life, PNT services are used in mapping and navigation services on mobile phones, payment solutions, mobile networks and other digital communication systems.

PNT services are largely based on signals from global navigation satellite systems (GNSS). This entails a shared technological dependency across sectors and application areas. The use of GNSS has increased significantly over the past two decades. However, the dependency that has emerged is often not very visible, and awareness of vulnerabilities varies. The widespread use means that loss or disruption of GNSS signals can rapidly have consequences for both value creation and societal functioning.

Northern Norway is an area with documented disruptions to satellite-based GNSS signals, including as a result of jamming. This has affected aviation and maritime activities and illustrates that the risk of loss and disruption has already materialised in concrete incidents in Norway. In many cases, dependency and vulnerability are not fully understood—by either suppliers or users—because systems are closely interconnected and indirectly dependent on GNSS through underlying infrastructure.

This report highlights the use of satellite-based PNT services across sectors and societal domains. We analyse how the technology forms part of value-creating activities and societal functions, and assess the consequences of various events that may lead to disruption or loss. The analysis covers both natural and human-induced events and distinguishes between misleading positioning, incorrect timing and complete signal loss.

The analysis applies different scenarios to illustrate types of disruption in satellite-based PNT services, with variation in probability, duration and severity. The scenarios include transient loss (approximately one hour), short-term loss (one day) and more prolonged loss (one week). For consistency and comparability across sectors, the quantitative calculations focus on one main scenario: a continuous seven-day loss of satellite-based PNT services. The scenario illustrates the order of magnitude of direct, first-order consequences in a Norwegian context.

Finally, the report discusses possible measures to strengthen robustness and reduce vulnerability. Robustness of PNT services is closely linked to societal security. In light of the current security policy situation and the widespread use of GNSS, there is a need to consider measures that can reduce vulnerability to loss and manipulation. Such measures may include increased redundancy, improved protection against intentional and unintentional interference, and clearer requirements for robustness and risk management in critical societal sectors.

The report is structured as follows: Chapter 2 provides an overview of PNT services and their applications in society. Chapter 3 describes the framework, methodology and data sources. Chapter 4 discusses society's overall dependence and systemic vulnerabilities and assesses the socio-economic costs of a seven-day loss. Chapters 5–13 analyse usage and consequences across different sectors. Chapter 14 summarises the main findings and implications, while Chapter 15 discusses possible measures to strengthen robustness and reduce vulnerability.

2 GNSS and Satellite-Based PNT Services

PNT services can be delivered in various ways, and positioning, navigation and time determination were possible long before satellite-based systems such as the Global Positioning System (GPS) were adopted for widespread civilian use in the 1990s. Norway has a long history of precise determination of time and position.

As early as 1773, *Norges Grændsers Opmaaling*—the predecessor of the Norwegian Mapping Authority—was established to map strategically important areas along the border with Sweden. In 1779, scientific triangulation between mountain peaks began. From 1815, Christopher Hansteen worked at what later became the University Observatory in Oslo to determine the country's coordinates through astronomical observations. A meridian circle at the observatory that recorded passing stars, together with Norway's most precise clock, established a reference point. Pendulum clocks and chronometers were then transported throughout the country to link local observations to this reference. In this way, Hansteen established both a common time and a common position reference for the country.

Today, GNSS fulfils much of the role once performed by these tools, but with far higher precision and availability. Global Navigation Satellite Systems (GNSS) is a collective term for satellite-based systems providing positioning, navigation and timing with global coverage. The four most well-known and widely used GNSS constellations are the American GPS, the European Galileo, the Russian GLONASS and the Chinese BeiDou. All these systems are based on satellites orbiting at an altitude of approximately 20,000 kilometres above the Earth. From there, they transmit signals containing extremely precise time stamps and orbital information, enabling receivers on the ground to calculate their position, speed and time.

To determine an exact position, a GNSS receiver must use signals from at least four satellites simultaneously. In practice, receivers often combine signals from multiple GNSS constellations to achieve better availability and accuracy and to reduce vulnerability. GNSS therefore constitutes the technological foundation for satellite-based PNT services. This includes the provision of information on positioning, navigation and timing, which enables localisation, movement and a precise time reference for users, systems and technical infrastructure.

In this context, **positioning** refers to the determination of a specific geographic location of an object, expressed as map coordinates. **Navigation** refers to the ability to determine and follow a route from one position to another, including route planning, course calculation and updates on movement over time. **Timing** refers to the provision of precise and synchronised time information, which makes it possible to determine points in time and establish a common reference for when events occur.

GNSS-based services can deliver centimetre-level positioning accuracy in real time across the entire country. For example, **CPOS**, the Norwegian Mapping Authority’s nationwide correction service, uses a network of reference stations to improve signals from GNSS systems. Norway is not only a user of this technology: the Norwegian Mapping Authority’s geodetic earth observatory in Ny-Ålesund is a key station in the global network that determines Earth rotation parameters on which all satellite navigation and related services depend.

The GNSS architecture is divided into three main segments:

- the **space segment**,
- the **ground/control segment**, and
- the **user segment**.

The space segment is owned and operated by the system providers and consists, among other elements, of the satellite constellation and the satellites’ atomic clocks. The space segment transmits radionavigation signals with a defined signal structure and stores and forwards navigation messages to the control segment.

The ground or control segment manages and monitors the system and ensures that the signals remain precise and synchronised. This segment comprises extensive ground-based infrastructure, including control stations, antennas and communication systems that receive signals from the satellites and transmit updates back to them. Like the space segment, the control segment may be vulnerable to technical failures, natural events or intentional attacks.

The user segment consists of the receivers that capture signals from the satellites in order to calculate the user’s precise position, speed and time. These receivers are found in everything from mobile phones and vehicles to machinery, clocks and sensors that provide users with easy access to GNSS- and PNT-based services.

The breadth of applications, combined with high availability and global coverage—including in areas where terrestrial alternatives have limited reach—has made PNT services a fundamental input factor in many sectors and societal functions. In line with technological development and the digitalisation of the past 20–30 years, PNT services have become an important contributor to value creation and productivity growth. Nevertheless, there is considerable variation in the extent to which and the ways in which different sectors have adopted PNT services.

This report outlines the main applications of PNT services across a range of central sectors in Norway, including the petroleum industry, maritime activities, transport and the power sector. PNT services are used across multiple sectors and areas of society and function as a foundational element in both public and private systems.

In the **transport sector**, PNT services are used for navigation, fleet management and traffic management across road, maritime, aviation and rail transport. In **electronic communications**

(telecom), precise timing signals from GNSS are used to synchronise mobile networks and data communications. In **power supply**, PNT services are used for time and phase synchronisation in the transmission grid, which is crucial for stable and secure operation. In **financial systems**, PNT services are used for precise time-stamping of transactions, including to meet regulatory requirements.

Emergency and rescue services depend on PNT services for localisation, coordination and effective response, while in **agriculture**, PNT services are used for precision operations and efficient resource use. In the **seafood industry**, PNT services are used for navigation, fishing operations, positioning of gear and catch documentation. In the **petroleum sector**, PNT services form a central part of maritime and offshore operations, including navigation, dynamic positioning, time synchronisation of operational systems and subsea mapping. Within the **maritime sector**, PNT services are widely used for navigation, traffic monitoring and situational awareness, both on board vessels and in land-based systems.

Taken together, this means that PNT services function as a key input factor across many different parts of society.

As the use of PNT services has increased, society’s functional capacity has become increasingly dependent on GNSS. A loss or significant disruption can have extensive consequences, as these services now constitute a basic input factor in many sectors and systems. As a result of high availability and uptime, several sectors have moved away from alternative solutions. Over time, knowledge and experience of alternative methods have also diminished. This reduces redundancy and creates broad vulnerability to events that render PNT services unavailable or disrupted.

The availability of GNSS-based PNT services may be affected by a wide range of events. Because of their long journey from satellites in space, GNSS signals are weak when they reach the Earth’s surface, which makes them vulnerable to both natural and human-induced interference. Physical factors such as buildings and terrain can block or reflect the signals, reducing accuracy or causing outages. Natural phenomena such as space weather, including solar storms and ionospheric disturbances, can also reduce signal strength and accuracy or cause temporary outages.

Furthermore, GNSS is vulnerable to human-induced impacts, including unintentional interference and deliberate attacks such as **jamming, meaconing and spoofing**. Such events can result in loss of availability, reduced accuracy or erroneous position and time information, potentially affecting systems and societal functions that rely on PNT services.

The use of and dependence on GNSS and PNT services in Norway follows an international trend in which such services are increasingly adopted across sectors and areas of society. According to the *EUSPA EO and GNSS Market Report 2024*, the global number of GNSS-compatible devices was estimated at approximately 7 billion units in 2023, with further growth towards up to 10 billion units by 2033. The report also shows that around 2 billion GNSS-compatible devices are delivered annually, making the services available to ever larger user groups.

In Norway, responsibility for GNSS- and PNT-related matters is divided between several authorities with different roles and areas of responsibility. The Norwegian Space Agency is responsible for the management and development of Norwegian space activities, including international cooperation and national interests related to satellite-based systems such as GNSS. The Norwegian Communications Authority (Nkom) has an overarching responsibility for electronic communications, including robustness and security in electronic communications networks that largely depend on precise timing and synchronisation. The Norwegian Mapping Authority has national responsibility for geodetic infrastructure and reference systems and, among other things, manages services that enable precise positioning. The Norwegian Metrology Service (Justervesenet) is responsible for the national time scale and metrological traceability and plays a central role in ensuring correct and traceable time determination, including where GNSS is used as a source or reference.

Taken together, this means that responsibility for PNT services in Norway is distributed across sectors, and that robustness and preparedness depend on interaction between several specialised authorities.

3 Framework, Methods and Data Sources

This chapter describes the framework, calculation methods and data sources used to estimate the socio-economic costs associated with the loss of satellite-based PNT services. The purpose is to explain how the knowledge underpinning the analysis has been obtained, which methodological choices have been made, and which sources have been used in the work.

The analysis is based on a combination of existing literature, qualitative interviews with relevant stakeholders, and quantitative data from public statistical sources and sector-specific datasets. Taken together, this provides a comprehensive basis for examining both the benefits of PNT services and the consequences of service loss in a Norwegian context.

3.1 Literature Review

The socio-economic analysis is based on extensive information gathering in order to facilitate a holistic understanding of the value of PNT services, the consequences of service loss, relevant threats and possible measures to increase robustness. As a foundation for the analysis, a literature review has been conducted of previous work with substantial transferability to Norwegian conditions.

The analysis draws in particular on international studies covering valuation of GNSS/PNT services, cross-sectoral dependencies, and consequences of service loss. A key reference is *The economic impact on the UK of a disruption to GNSS* by London Economics (2023). This report is a socio-economic analysis providing quantitative estimates of the consequences of GNSS disruption. It was prepared on behalf of the UK authorities and aims to support decision-making related to robustness, preparedness and potential measures to reduce vulnerability in critical societal functions.

The London Economics analysis combines quantitative estimates with qualitative assessments, including insights from interviews and technical documentation. In the present study, this report is used as a methodological reference point, with relevant mechanisms and orders of magnitude adjusted to Norwegian conditions.

Another important reference is *Satellite-derived Time and Position: A study of Critical Dependencies* by the UK Government Office for Science (2018). This report provides a comprehensive review of dependencies, use cases and effects of satellite-based time and positioning. It was prepared as an independent review for the UK authorities, with the primary purpose of identifying critical dependencies, vulnerabilities and the need for increased robustness in key societal systems.

The report places particular emphasis on systemic and indirect dependencies, hidden vulnerabilities and the importance of precise time distribution. In the present analysis, the 2018 report is used as a conceptual framework for understanding cross-sectoral consequences and non-priced impacts of PNT service loss.

A third relevant reference is *Economic Benefits of the Global Positioning System (GPS)* by RTI International. This report presents an extensive empirical analysis of the socio-economic benefits of GPS-based PNT services in the United States. It maps the use of PNT services across a wide range of sectors, including telecommunications, financial services, energy, transport and agriculture, and estimates the value creation these services have contributed over time. The report is used to highlight the breadth of PNT applications and to identify mechanisms for value creation across sectors.

In addition to international literature, the analysis draws on relevant Norwegian publications. Norway's national PNT strategy provides an overarching framework for public authorities' work on PNT and describes society's increasing dependence on satellite-based services. Further contextual grounding is provided by the Ministry of Local Government and Regional Development's *Proposition 1 S (2020–2021)*, which offers a situational overview of satellite-based communications and navigation in a Norwegian context.

The analysis is also supported by thematic studies from the Norwegian Communications Authority (Nkom), particularly those relating to robustness in time synchronisation and the use of GNSS-based clock signals in critical infrastructure. Together, these publications provide a Norwegian strategic and institutional backdrop for the analysis.

In parallel with the preparation of this report, the Norwegian Defence Research Establishment (FFI) and the Norwegian Directorate for Civil Protection (DSB) have conducted studies on dependencies and vulnerabilities related to satellite-based PNT services. FFI (2026) maps vulnerabilities related to GNSS and dependencies in critical societal functions, with emphasis on implications for total defence. DSB (2026) analyses the consequences of manipulation of satellite-based time signals for critical societal functions.

This report complements those studies by adopting a broader socio-economic perspective, in which the consequences of PNT service loss are quantified and compared across multiple sectors.

3.2 Data Collection and Interviews

Data collection is based on a combination of document studies, statistical data sources and qualitative interviews with relevant stakeholders. The interviews supplement available statistics and literature, and provide insight into the use of PNT services, sector-specific dependencies and vulnerabilities, as well as the consequences of service loss.

Semi-structured interviews have been conducted with more than 40 stakeholders from selected sector authorities, infrastructure owners, service providers and expert environments within areas where PNT services constitute a key input factor. The interviews cover stakeholders from both the public and private sectors, including national authorities, agencies with sectoral responsibility, infrastructure owners, operators, providers of PNT-related services and technology environments.

The selection of interviewees was made strategically to ensure coverage of key sectors and application areas. A complete overview of interviewees is provided in Appendix B.

3.3 Assumptions and Delimitations for Calculations

The approach used to calculate the costs associated with loss of PNT services varies across sectors and application areas. This sub-chapter describes the overall approach, general assumptions and valuation principles underlying the sector analyses. The sector-specific calculations and assumptions are described in detail in the individual sector chapters.

The socio-economic costs of PNT service loss may take different forms. In some cases, service loss results in increased production costs, for example through increased labour input, capital use or resource consumption. In other cases, costs arise through reduced service quality, such as delays, cancellations or increased travel time in the transport sector. Overall, valuation can be grouped into three categories:

- Increased production costs, linked to higher labour input, capital use, material use or energy consumption
- Reduced quality, leading to lower willingness to pay, linked to delays, cancellations and increased travel time
- Increased risk of severe consequences, personal injury and loss of life

The sector analyses are based on a consistent, cause-neutral scenario involving a seven-day loss of satellite-based PNT services. This choice has been made to ensure comparability across sectors and to clarify consequences regardless of the underlying triggering event.

3.4 Socio-Economic Analysis

The analysis has been conducted in accordance with the overarching principles for socio-economic analysis as described in the guidelines issued by the Norwegian Agency for Public and Financial Management (DFØ). The main emphasis is on identifying and, where possible, valuing significant socio-economic costs associated with the loss of PNT services.

For certain consequences, particularly those related to preparedness and security, there is insufficient basis to carry out a precise monetary valuation. Such impacts are therefore treated qualitatively and described as non-priced effects. The calculations are subject to uncertainty, and the results should be interpreted as indicative orders of magnitude rather than precise estimates, based on conservative assumptions and available data.

Unless otherwise stated, all monetary values are expressed in 2024 NOK, which is the most recent year for which consistent and complete datasets are available across all sectors.

The calculations of socio-economic costs associated with PNT service loss are based on a seven-day outage scenario. This duration has been chosen because it is long enough to trigger noticeable operational consequences, while still short enough for the effects to be analysed primarily as direct and short-term impacts.

The analysis is delimited to identifying and, where possible, valuing **direct socio-economic effects** of satellite-based PNT service loss. Direct effects are understood as consequences that occur within organisations that use PNT services as an input factor, such as increased production costs, reduced efficiency, delays or temporary loss of production and services. The calculations cover economic effects occurring during the outage period itself.

Indirect effects or cascade effects between sectors are largely excluded from the quantitative calculations. This means that the analysis does not quantify how reduced activity in one sector affects production, deliveries or value creation in other sectors through value chains and market linkages. Non-priced effects, including security-related impacts and systemic effects, are assessed qualitatively.

The absence of quantified secondary effects does not imply that such effects are insignificant, but rather that they are methodologically demanding to isolate and quantify within the scope of this analysis. These effects are therefore included in the overall qualitative assessment of socio-economic consequences.

3.5 Scenarios and Delimitations

The analysis considers a set of scenarios that collectively capture variation in duration, likelihood and severity. These include three main categories of events:

- Short, transient outages of approximately one hour, which have the highest probability of occurrence
- Short-term outages lasting one day
- More prolonged outages lasting one week, which have the lowest probability of occurrence

The first two scenarios may be relevant for operational challenges in individual sectors. However, the duration is often too short to trigger measurable socio-economic losses beyond what is proportionate to a seven-day scenario. The quantitative analysis therefore focuses on a **seven-day outage**.

In the case of longer outages (weeks or months), mitigating measures are likely to be implemented, and alternatives to GNSS would be adopted where available. Under such circumstances, the structure of PNT-dependent systems may change, and the nature of the consequences becomes more difficult to predict. For this reason, the quantitative calculations are concentrated on **one main scenario: a continuous seven-day loss of satellite-based PNT services**.

At the same time, the consequences of disturbances may vary significantly depending on the type of event. Analytically, the report distinguishes between:

- **Outage** (signal unavailable)

- **Disruption** (reduced quality or coverage)
- **Manipulation** (erroneous but apparently valid signal)

While outages will in many cases trigger fallback solutions and gradually escalating operational challenges, manipulation can be more severe in certain systems because errors may remain undetected and influence decision-making and time-stamping.

To supplement the main outage scenario, the analysis therefore also considers **manipulation of time signals** where this is particularly relevant. This applies especially to sectors and functions with a strong dependence on precise, synchronised time, including finance, power supply and electronic communications. In these sector chapters, manipulation of time is discussed as a supplementary perspective, as this type of event may entail different consequences and risk exposure than a pure outage.

4 Society's Dependence and Systemic Vulnerability

Before presenting the sector-by-sector analyses, this chapter sets out a number of overarching findings concerning society's dependence on satellite-based PNT services. The chapter highlights direct costs, cross-sectoral vulnerabilities and development trends that frame the subsequent sector analyses.

We distinguish between:

1. **Direct socio-economic costs** associated with a delimited outage scenario,
2. **Systemic vulnerabilities**, particularly related to precise time and cross-sectoral functions, and
3. **Development trends** that influence future dependence.

Satellite-based services for positioning, navigation and timing (PNT) are integrated into a wide range of societal functions in Norway. Their use spans from direct operational application in transport and construction activities to more indirect use as an underlying reference for time distribution, synchronisation and coordination in digital systems.

The review reveals a broad dependence on satellite-based PNT services, unevenly distributed across sectors. The largest direct costs arise in industries with high value creation and strong operational dependence on precise positioning. In some sectors—particularly transport and construction—an outage may cause immediate and direct operational consequences. In other sectors, alternative solutions and redundancy exist, meaning that short-term outages result in limited service disruption.

The most **system-critical dependencies**, however, relate to **precise time** in sectors that deliver fundamental infrastructure to the rest of society. Even where direct consequences appear limited, PNT services are embedded in technical systems and infrastructures that are tightly integrated and mutually dependent. The dependence may therefore be less visible, yet structurally significant.

Moreover, developments indicate increasing digitalisation, automation and real-time control, which collectively are likely to increase the importance of PNT services going forward.

4.1 Dependence on Precise Time

The analysis distinguishes between sectors in which loss of PNT services primarily leads to **direct economic costs**, and sectors where the consequences are more strongly linked to their role as providers of fundamental infrastructure. Power supply, finance and electronic communications (ekom) fall into the latter category.

The importance of these sectors cannot be assessed solely on the basis of the direct costs incurred within the sectors themselves.

A shared characteristic of these sectors is a strong dependence on **precise and synchronised time**. Time functions as a critical input factor:

- in the power system for frequency control and synchronisation,
- in the financial sector for correct time-stamping and regulatory compliance, and
- in electronic communications for coordinated operation of mobile and data networks.

Disruptions in these functions can rapidly propagate to other sectors.

All three sectors use GNSS as a central—though not necessarily exclusive—source of precise time. At the same time, they have, to varying degrees, established redundancy through measures such as atomic clocks, internal oscillators (holdover), multiple time sources (NTP, PTP and fibre-based distribution), and sector-specific contingency procedures.

Based on the information gathered, a pure seven-day GNSS outage would not necessarily result in immediate system failure in these sectors. Internal clocks can, in many cases, maintain sufficient precision for a period, but accuracy will gradually deteriorate in the absence of external synchronisation. Vulnerability therefore increases over time.

In addition, transitions between different time sources—both during an outage and when returning to the primary source—may represent an **operational risk**.

Even though these sectors often have redundancy and alternative time sources in place, this does not imply that the risk associated with loss of satellite-based PNT services is negligible. Redundancy may sustain operations for a limited period, but robustness varies across systems and actors, and precision will deteriorate over time.

Furthermore, these sectors provide essential infrastructure to large parts of society. Even minor disturbances in time synchronisation can therefore have consequences beyond the sectors themselves—especially if multiple systems are affected simultaneously or if errors arise during transitions between time sources. As a result, the practical risk associated with loss or manipulation of time sources may be higher than what isolated sector-specific robustness measures would suggest.

Interviewees emphasise that **manipulation of time signals (spoofing)** may represent a greater and more severe risk than outright outage. Small time deviations, on the order of microseconds, may be sufficient to trigger errors in power systems, financial transactions or network synchronisation in electronic communications.

Such manipulation may be difficult to detect quickly, and incorrect time may propagate through networks and across systems. Particularly in finance and power, small and gradual deviations can have significant consequences without being immediately identified as a GNSS-related problem.

If systems gradually drift out of synchronisation unnoticed, uncertainty may arise regarding transaction order, reconciliation and legal validity. Such situations may compel operators to halt systems preventively, even if the infrastructure is technically operational. This aligns with assessments from the Norwegian Directorate for Civil Protection's analysis of satellite-based time as a strategic vulnerability.

4.2 System Assessments – From Sectors to Society

Sector-specific analyses provide an essential understanding of how satellite-based PNT services are used within individual sectors and what direct consequences an outage would entail. However, sectors are tightly interconnected through digital interfaces, shared inputs and mutual dependencies. Failures in one sector may therefore rapidly propagate to others, particularly where fundamental infrastructure is affected.

Consequently, the impacts of disruptions to satellite-based PNT services cannot be assessed on a purely sectoral basis.

As shown in the previous section, precise time is a critical input factor in power supply, finance and electronic communications—sectors that deliver services upon which the wider economy depends. Disruptions in these sectors can generate indirect consequences that far exceed the direct costs associated with a delimited outage scenario.

Such effects do not arise solely as direct losses in other sectors, but also through disruption of inter-sectoral coordination and weakening of functional linkages within the economy.

This reveals an important **asymmetry**. Sectors with high direct costs from a seven-day outage are not necessarily the most system-critical. The petroleum and maritime sectors experience substantial direct losses, largely related to production and operational efficiency. In contrast, even minor disturbances in power, finance and electronic communications may have broader societal effects due to their role as foundational enablers of other functions.

Increasing digitalisation amplifies this interconnection. Systems that were previously more isolated now operate in real time and are integrated through networks and automated interfaces. While this reduces manual buffers and increases efficiency, it also heightens sensitivity to deviations.

System complexity increases, making it challenging to maintain full oversight of how failures in one component affect the whole. This is highlighted in the Norwegian National Security Authority's report *Risk 2025*, which notes that organisations in fields such as digital systems, meteorology, navigation, logistics and financial transactions often lack sufficient awareness of their indirect dependence on satellite-based services through third parties.

A further challenge concerns **visibility and traceability**. Dependencies on PNT services are often indirect and embedded within underlying systems and supply chains. Organisations may depend on precise time or positioning without fully realising the extent of the dependency. As a result, systemic vulnerability may be greater than what sector-specific assessments alone indicate.

There are also **geographical and functional differences** in vulnerability. Areas with high concentrations of financial and administrative functions may be particularly sensitive to time synchronisation disturbances, while offshore and coastal areas have strong operational dependence on precise positioning.

It is important to underline that vulnerability is not limited to complete outages. Experience from, among other things, GNSS jamming tests at Andøya and from the pilotage service suggests that gradually increasing disturbances may pose risks equal to or greater than full outages.

Signal manipulation—where systems receive apparently valid but falsified information—can be more dangerous than signal loss, as operators make decisions based on incorrect data without realising it. Systems that lose signal entirely normally trigger alarms and contingency procedures; systems receiving false signals may not.

This asymmetry affects several of the measures discussed in this chapter: measures that address outages alone are insufficient unless combined with the ability to detect and manage manipulation.

PNT services do not operate in isolation. GNSS-dependent systems also rely on functioning power and telecommunications networks, which themselves depend on GNSS-based time synchronisation. A PNT outage may therefore coincide with, or be followed by, disruptions to communications or, in prolonged scenarios, even power supply. Measures that assume other infrastructure remains fully functional may therefore provide a false sense of security.

Robustness requires accounting for the possibility that multiple systems may fail simultaneously.

Taken together, these factors indicate that a comprehensive assessment of socio-economic consequences from a widespread and prolonged PNT outage cannot be limited to the sum of direct sectoral losses. The total risk is determined by the interaction between sectors, the level of digital integration, and dependence on shared inputs. Fully analysing such dynamics would require a dedicated macro-economic modelling framework, which has not been feasible within the scope of this study.

4.3 Direct Socio-Economic Costs of a Seven-Day Outage

The analysis is based on a seven-day outage scenario. The scenario is not intended as a probability estimate, but as an analytical tool to illustrate consequences conditional on an outage.

The estimated direct socio-economic costs of a continuous seven-day loss of satellite-based PNT services amount to approximately **NOK 3.4 billion**. The costs are unevenly distributed across sectors and are particularly concentrated in a limited number of sectors.

The largest share of costs arises in the petroleum sector, reflecting both high daily production value and strong dependence on precise positioning in offshore operations, including dynamic positioning of vessels and rigs, logistics operations and helicopter transport.

The maritime sector constitutes the second-largest cost component. PNT services are deeply integrated into navigation, traffic management, port operations and fleet management, and an outage would cause reduced efficiency and increased risk. Together, these two sectors account for more than **70 per cent** of total estimated costs.

Other sectors, such as seafood, aviation, road transport and emergency services, display lower estimated direct costs for a seven-day outage. In some cases, alternative solutions or operational adaptations reduce short-term impacts.

In finance and power supply, the analysis indicates that a seven-day GNSS outage alone is unlikely to result in direct costs due to existing redundancy and holdover capacity. However, **manipulation of time signals** represents a potentially greater challenge, as small deviations may affect system operation and synchronisation without immediate detection.

It is important to stress that the estimates primarily capture **direct, quantifiable effects** under a delimited scenario. Secondary effects, supply-chain disruptions and behavioural responses involve significant uncertainty. In longer-lasting or more complex events, total socio-economic consequences may exceed the direct cost estimates.

4.4 Increasing Dependence and Development Trends

The use of satellite-based PNT services has increased substantially over time, both in scale and in depth of dependence. What was previously mainly a navigation aid has evolved into an integrated—and often prerequisite—component of digital, automated and interconnected systems.

To date, growth in use has primarily been driven by digitalisation and efficiency gains. Looking ahead, further increases are expected in connection with autonomous systems, real-time control and tighter digital integration.

The transition to GNSS has been so successful that older methods have largely been abandoned, along with the equipment and expertise required to use them—an observation confirmed by interviewees. The vulnerability lies in the fact that a single system now underpins functions previously supported by multiple technologies and methods.

In several cases, actors have found that systems assumed to be independent of GNSS were, upon closer inspection, indirectly dependent on GNSS in ways they had not previously identified. Actual dependence is therefore greater than what many organisations have mapped or documented.

Historical growth in use is closely linked to digitalisation, automation and system integration. Digital communications networks, financial systems, power supply and logistics systems operate in real time and require a shared and stable reference. Precise time has become a fundamental input factor.

Automation has reduced manual buffers. In transport, fleet management and real-time tracking are standard. In maritime and offshore activities, dynamic positioning and digital monitoring have increased precision requirements. In agriculture, precision technology is widespread, and in railways, digital signalling and advanced traffic management are being introduced.

Finally, systems have become increasingly interconnected across sectors. Dependencies are often indirect, embedded within underlying systems and supply chains, making them less visible but no less real.

Several trends suggest further growth in dependence. These include autonomous transport systems, further deployment of ERTMS in rail, increasing demands for precise time in 5G and future 6G networks, increasing electrification of the power system and automation of financial processes.

As more systems operate in real time and in close coordination, tolerance for deviations in position and time is reduced. Even small errors may propagate rapidly and generate consequences more quickly than in earlier technological environments.

This overview demonstrates that satellite-based PNT services operate within a complex ecosystem of technologies and redundant systems. However, understanding the socio-economic consequences of service loss requires closer examination of how dependence manifests in specific sectors.

Accordingly, the following chapters analyse each sector in turn, examining:

1. how PNT services are used,
2. the consequences of a delimited outage scenario, and
3. estimated socio-economic costs of a seven-day outage.

5 Maritime-Based Industries

Maritime-based industries represent a central component of Norwegian value creation. In this chapter, we examine how these industries—specifically **maritime transport**, the **petroleum industry**, and the **seafood industry**—depend on satellite-based PNT services, and how a loss of such services would affect them. A common feature across these industries is that they operate in maritime areas, where **precise positioning** is essential for safe navigation and operational activities.

PNT services are used both to ensure safe navigation along the coast and on the open sea, and for coordination through systems such as the **Automatic Identification System (AIS)**, which contributes to efficient traffic flow and reduced risk of grounding and collisions. The services are also critical for coordinating logistics in ports, including planning of port calls, queue management, and optimisation of arrival and departure times.

In the petroleum industry, PNT services are particularly critical for **dynamic positioning** of rigs and vessels, seismic operations, and construction activities offshore. In the seafood industry, precise positioning is important for navigation, placement of fishing gear and catch reporting.

Taken together, the socio-economic costs associated with a **seven-day loss of GNSS within maritime-based industries** are estimated at **NOK 2.53 billion**.

5.1 Maritime Transport

Maritime transport is a sector with a **high level of dependence** on satellite-based services for positioning, navigation and timing (PNT). PNT services are used throughout the transport chain, from deep-sea voyages in open waters to manoeuvring in narrow fairways and port areas, as well as for monitoring and coordination of vessel traffic. The technology is largely integrated into ships' navigation systems and into land-based systems for traffic management and preparedness.

For Norway as a coastal and maritime nation—with a long coastline, dispersed settlement patterns and extensive offshore activity—the maritime transport sector is particularly important.

In this analysis, maritime transport is defined as sea-based transport of goods and passengers, including both international and domestic shipping. The definition encompasses deep-sea shipping companies engaged in international freight transport between continents, including segments such as bulk, LNG, chemicals, containers, general cargo and vehicle transport. It also includes short-sea shipping companies operating similar vessel types along the Norwegian coast and in European waters, as well as passenger ferries and vessels associated with aquaculture operations.

Maritime activity generated by aquaculture—such as well boats, service vessels, feed vessels and slaughter vessels—is included in this chapter, while fishing activity and the fishing fleet as a whole are addressed separately in the chapter on the seafood industry. Offshore shipping is not included under maritime transport here, as those activities are covered in the chapter on the petroleum industry.

5.1.1 Use of Satellite-Based PNT Services

PNT services constitute a fundamental input factor in modern maritime transport. Satellite-based positioning, navigation and timing are now used across a wide range of core functions in the maritime sector, both aboard vessels and in land-based support systems.

The main areas of application include:

- **Navigation and electronic chart systems**
  - Safe navigation on the open sea
  - Avoidance of grounding, collision and contact damage
  - Optimisation of route choice, speed and propulsion
  - Coordination of port operations
- **Automatic Identification System (AIS)**
  - Collision prevention
  - Traffic monitoring and regulatory oversight
  - Establishment of a situational picture for vessel traffic services (VTS), preparedness and rescue services

Navigation and Electronic Chart Systems

Electronic chart systems are now the primary navigation tool on most larger vessels and are closely integrated with satellite-based PNT services. These systems combine official electronic nautical charts with real-time information on the vessel's position, course and speed, allowing the vessel's movements to be continuously plotted automatically on the chart display.

Position data is obtained from onboard GNSS receivers, often using multiple satellite constellations (GPS, Galileo, GLONASS and BeiDou), and distributed to navigation systems via the vessel's internal networks. This provides navigators with a precise and up-to-date situational picture, both in open waters and in confined coastal and port areas.

Automatic positioning reduces the need for manual plotting, improves control, and facilitates keeping the vessel within designated shipping lanes and safety margins. Interviews with shipping companies indicate that GNSS is, in practice, essential for safe navigation on the open sea, where visual references or terrestrial navigation aids are absent. Without satellite-based positioning, navigation would have to revert to traditional methods such as sextant use, which is rarely practised today and is significantly less efficient.

GNSS also enhances safety by providing precise positional data used in navigation and monitoring systems, including electronic chart systems and AIS. This makes it possible to maintain safe distances from shore, shoals and installations, and reduces the risk of collisions, groundings and contact damage.

At the same time, electronic charts combined with satellite-based position and time information provide a crucial foundation for planning and continuous optimisation of routes, speed and progress. This enables more predictable voyages and better adaptation to traffic conditions, navigational constraints and planned arrival times.

Precise position data is used to calculate **Estimated Time of Arrival (ETA)**, allowing vessels to adjust speed to meet port windows and minimise waiting time at quay. According to interviewees, dependence on electronic navigation and positioning systems is increasing, particularly as new generations of navigators are trained primarily using digital tools. Knowledge of alternative, manual navigation methods is consequently declining due to reduced practical use.

Automatic Identification System (AIS)

The Automatic Identification System (AIS) is a standardised maritime reporting and tracking system that enables vessels to automatically exchange navigation and identity information via VHF radio communication. The purpose of AIS is to enhance safety at sea and facilitate efficient traffic monitoring through a shared situational picture among vessels and shore-based actors.

At any given time, approximately **5,000 AIS-equipped vessels** operate in Norwegian waters. Each vessel updates its AIS position roughly every ten seconds. Although AIS is fundamentally a radio-based data exchange system rather than a display system, the transmitted information—such as vessel identity, position, course, speed and status—is visualised in electronic chart systems onboard vessels and in traffic monitoring systems at vessel traffic service (VTS) centres.

AIS is mandatory for most larger vessels, including all passenger ships and cargo ships over 300 gross tonnes engaged in international voyages, as well as a large share of fishing and other commercial vessels.

AIS is dependent on satellite-based PNT services. In the event of GNSS loss, AIS would lose valid position information, preventing correct plotting of vessel movements in chart-based monitoring systems. This would weaken the maritime situational picture used for traffic monitoring, safe navigation and emergency preparedness.

AIS data is used operationally to prevent collisions by providing vessels with real-time information about surrounding traffic, including beyond radar range and visual line of sight. For shore-based authorities, AIS is a core input for traffic monitoring, vessel guidance and incident management. The Joint Rescue Coordination Centres use AIS to establish situational awareness during accidents and emergencies, such as identifying nearby vessels capable of providing assistance.

AIS data is also used to analyse vessel movements over time and link observations—such as oil spills at sea—to potential sources.

5.1.2 Consequences of Service Loss

Loss of satellite-based PNT services would cause key automated functions in maritime transport either to fail entirely or to operate with significantly reduced quality. This includes automatic positioning in electronic chart systems, AIS-based sharing of real-time position, calculation of ETA, and establishment of shared traffic and situational pictures among vessels and authorities.

Key consequences include:

- **Reduced navigational safety**
  Increased risk of grounding and collision, particularly in poor weather, dense traffic and confined waters, as well as greater uncertainty regarding position and course in open waters.
- **Longer response times and reduced efficiency in emergency preparedness and rescue**
  Delays and reduced effectiveness in search-and-rescue operations, increasing the risk of loss of life, health and material assets.
- **Weakened traffic monitoring and regulatory oversight**
  Reduced ability to monitor traffic, identify high-risk vessels and detect deviations, as well as delayed or less targeted preventative measures.
- **Reduced efficiency, predictability and increased costs**
  Higher fuel consumption, delays and reduced regularity, leading to increased costs for shipping companies and knock-on effects in supply chains.

Navigational safety would be reduced as vessels lose access to automatic positioning in electronic chart systems and must rely more heavily on radar, visual observations, landmarks and alternative sensors such as gyrocompass and logs. While coastal vessels operating in well-marked fairways may manage this transition, navigation on the open sea—particularly for offshore supply vessels operating far from shore—would be significantly more challenging.

Overall, interviewees emphasise that loss of automatic positioning increases operational risk and reduces efficiency compared with normal operations, particularly in demanding conditions.

5.1.3 Socio-Economic Costs of a Seven-Day Outage

For maritime transport, the socio-economic cost of a seven-day loss of PNT services is estimated at approximately **NOK 590 million**.

The largest cost component relates to **reduced value creation** (GDP contribution) due to lower efficiency and activity levels, estimated at around **NOK 520 million**. In addition, approximately

NOK 70 million is associated with increased accident risk, including loss of life and health, material damage and time costs resulting from operational disruptions following accidents.

These estimates are based on conservative assumptions drawn from interviews with maritime stakeholders and accident statistics. They reflect increased fuel consumption, delays, reduced regularity and higher accident risk under reduced navigational precision.

5.2 Petroleum Industry

The petroleum industry is a sector with a **very high dependence** on satellite-based PNT services. PNT services are used across multiple phases of activity, from exploration and mapping to drilling, production, transport and emergency preparedness. Applications include both maritime and aviation operations, as well as numerous onshore and offshore data systems where precise time and synchronisation are critical for safe and efficient operation.

For Norway as one of the world's leading offshore petroleum producers, this dependence is especially pronounced. Activities are largely conducted far offshore under demanding weather and safety conditions, involving complex operations with mobile installations, supply vessels and helicopter transport.

Stable access to reliable PNT services is therefore a fundamental prerequisite for safe operation, effective resource utilisation and regulatory compliance in the petroleum sector.

5.2 Petroleum Industry

The petroleum industry is a sector with **very high dependence** on satellite-based services for positioning, navigation and timing (PNT). PNT services are used across multiple phases of activity, from exploration and mapping to drilling, production, transport and emergency preparedness. Use includes maritime and aviation operations, as well as a wide range of offshore and onshore data systems where precise time and synchronisation are critical for safe and efficient operations.

For Norway, as one of the world's leading offshore petroleum producers, this dependence is especially pronounced. Activities are largely conducted far offshore, under demanding weather and safety conditions, and involve complex operations with mobile installations, supply vessels and helicopter transport.

5.2.1 Use of Satellite-Based PNT Services

PNT services are applied wherever operations require precise positioning, continuous navigation, coordination of mobile resources or accurate time-stamping of data and processes.

Key PNT-dependent operations include:

- **Offshore navigation and logistics operations**, including transport of personnel, equipment and supplies
- **Operations requiring dynamic positioning (DP)**, particularly near platforms and rigs
- **Seismic survey operations**, where precise positioning is essential for data quality
- **Installation and drilling operations**, which require accurate placement and stability
- **Air transport to and from offshore installations**
- **Time determination and synchronisation of offshore data systems**
- **Monitoring and emergency preparedness**

Offshore navigation and logistics

Petroleum installations are located far offshore—typically 30–260 km from the coastline. Safe transport relies on GNSS as the primary source of absolute position. Load and offload operations near installations require **dynamic positioning**, which uses GNSS as a core reference input to maintain stable vessel position against wind, waves and current.

Seismic survey operations

Seismic vessels tow long sensor arrays behind them. Continuous GNSS positioning of both the vessel and sensor arrays is a prerequisite for meaningful seismic data. Loss of GNSS invalidates data collection and may require costly re-surveying.

Installation and drilling

Installation and drilling operations require extremely high positional accuracy. GNSS-supported DP systems enable vessels and rigs to maintain stable positions during subsea construction and drilling. Loss of GNSS forces operations to stop or revert to less precise, more resource-intensive methods.

Air transport

Helicopter operations to offshore installations rely heavily on GNSS for navigation over open sea, route planning and safe approach to platforms, particularly under low visibility and adverse weather conditions.

Time synchronisation

Offshore systems require a common, precise time reference to ensure correct sequencing of operational data, event logging and fault diagnosis. Fibre connections are usually the primary time source, with GNSS serving as a critical backup. Loss of GNSS alone does not normally halt operations, but prolonged loss increases drift and operational risk.

5.2.2 Consequences of Service Loss

Consequences may be summarised as follows:

- Offshore supply operations halt or experience sharply reduced efficiency
- Seismic surveys stop immediately
- Installation and drilling activities stop
- Helicopter transport operates with reduced efficiency and capacity
- Monitoring and emergency preparedness are weakened

Short-term outages result in immediate standstill of many offshore activities. Longer outages require adoption of alternative methods, which are less precise, slower, more costly and entail higher operational risk.

5.2.3 Socio-Economic Costs of a Seven-Day Outage

The socio-economic cost for the petroleum industry is estimated at **NOK 1.83 billion** for a seven-day GNSS outage.

This reflects near-complete loss of productivity in PNT-dependent offshore operations. The analysis assumes an average **90 % efficiency loss** across offshore shipping, seismic surveys, construction/installation and mobile drilling operations.

Activity	Cost (NOK million)
Offshore vessels	740
Seismic operations	120
Construction & installation	300
Mobile drilling	670
Total	1,830

5.3 Seafood Industry

The seafood industry is one of Norway's most important industries, both in terms of value creation, employment and exports, and as a foundation for national food supply. It comprises both capture fisheries and aquaculture. Satellite-based PNT services play a central role in ensuring safe navigation, efficient harvest operations and compliance with regulatory requirements.

5.3.1 Use of Satellite-Based PNT Services

Key applications include:

- GNSS-based navigation and AIS
- Positioning and retrieval of fishing gear
- Mapping of fishing grounds and seabed topography
- Digital documentation of catch location and time
- Traffic monitoring near aquaculture installations

GNSS is particularly critical for operations far offshore, where alternative navigation references are limited.

5.3.2 Consequences of Service Loss

- **Gillnets and pots:** Offshore operations largely halt; coastal fishing continues with reduced efficiency
- **Trawling:** Continues with lower efficiency, higher fuel consumption and greater gear damage risk
- **Pelagic fishing:** Reduced coordination and lower catch efficiency
- **Coastal fleet:** More manual and labour-intensive navigation
- **Aquaculture:** Limited direct impact on production, but maritime support activities are affected

Longer outages would require major operational adjustments, as traditional navigation methods are no longer routinely practised.

5.3.3 Socio-Economic Costs of a Seven-Day Outage

Total estimated socio-economic cost: **NOK 107 million**

Method	Cost (NOK million)
Gillnets	13
Pots	6
Trawling	78
Purse seine	10
Total	107

Losses are driven primarily by reduced efficiency rather than complete cessation of activity. Impacts would be greater if outages occurred during peak fishing seasons.

Chapter 5 Summary

Sector	Cost (NOK million)
Maritime transport	590
Petroleum industry	1,830
Seafood industry	107
Total maritime-based industries	2,530

6 Transport

The transport sector makes extensive use of satellite-based PNT services, particularly within **road transport** and **aviation**. PNT services support route planning, traffic flow, logistics and capacity utilisation. A loss of these services would rapidly lead to noticeable efficiency losses through increased travel time, delays and reduced productivity in both traffic operations and infrastructure development.

Aviation would primarily be affected through increased delays and cancellations, while **rail** is to a lesser extent dependent on GNSS in safety-critical functions, but may experience moderate consequences in supporting systems such as passenger information, energy metering and maintenance.

Dependence on satellite-based PNT services is expected to increase over time in line with further digitalisation and the continued rollout of ERTMS.

The total socio-economic cost of a **seven-day GNSS outage in the transport sector** is estimated at **NOK 378 million**.

Sector	Socio-economic cost (NOK million)
Road transport	230
Aviation	143
Rail	5
Transport total	378

6.1 Road Transport

PNT services are widely used across the road transport sector, providing positioning, navigation and timing for private motorists, commercial operators, infrastructure developers and public authorities. Private vehicle users rely heavily on satellite navigation to identify optimal routes, while logistics and transport companies such as postal services, bus operators and distribution firms use real-time positioning and routing systems to manage fleets efficiently.

Public authorities and contractors use PNT services for road construction, maintenance and asset management. As a result, the road sector is now **heavily dependent** on satellite-based PNT services for planning, operations and optimisation.

Road transport represents the dominant component of Norwegian transport activity, accounting for approximately **85 % of domestic passenger transport** measured in passenger-kilometres. This dominant role means that disruptions to navigation and traffic flow have broad societal implications.

6.1.1 Use of Satellite-Based PNT Services

PNT services are used in road transport for three principal purposes:

Navigation for road users

Satellite-based navigation has become an integrated part of everyday travel. Most drivers use GNSS-based navigation through mobile applications or built-in vehicle systems. GNSS receivers typically provide positional accuracy of 3–5 metres, which is combined with digital maps and real-time traffic information to calculate optimal routes.

These systems deliver socio-economic benefits through reduced travel time, lower fuel consumption and improved traffic distribution. Real-time guidance reduces wrong turns, detours and unnecessary driving, contributes to smoother traffic flow and reduces congestion-related external costs.

Fleet management and logistics

Commercial transport operators use GNSS-based systems for route optimisation, delivery sequencing, vehicle tracking and operational monitoring. Advanced fleet management allows higher vehicle utilisation, reduced empty driving, better maintenance planning and lower operating costs.

Loss of these services leads to less efficient routing, increased travel distances, higher fuel consumption and greater operational uncertainty.

Construction and infrastructure development

Road construction and maintenance rely heavily on GNSS for surveying, staking-out, machine control and documentation. Excavators, graders and pavers are commonly equipped with GNSS-based machine guidance systems that enable precise and efficient execution of works.

GNSS also underpins the creation of digital terrain models and “digital twins” used to monitor progress and quality. Loss of PNT services forces a reversion to manual surveying methods such as total stations, which are considerably more labour-intensive and time-consuming.

6.1.2 Consequences of Service Loss

Loss of PNT services would rapidly lead to:

- Increased travel times and reduced traffic efficiency
- Higher fuel consumption and operating costs
- Greater congestion, particularly in urban areas
- Reduced efficiency in logistics and public transport operations
- Significant productivity loss in road construction and maintenance

For private motorists, the initial impact would vary depending on familiarity with routes, but increased wrong turns and reduced access to real-time traffic information would gradually increase congestion. Logistics operators would experience immediate loss of real-time fleet visibility and route optimisation, raising the risk of delays and cascading delivery disruptions.

In construction, machine guidance, automated documentation and quality control would cease, causing immediate productivity losses and requiring a shift to manual methods.

6.1.3 Socio-Economic Costs of a Seven-Day Outage

The total socio-economic cost for road transport is estimated at **NOK 229.9 million**, comprising:

- Increased travel time for road users
- Increased distance-related vehicle costs (fuel, wear, maintenance)
- Increased congestion in major urban areas
- Reduced productivity in road construction and maintenance

Approximately half of the total cost relates to increased travel time for drivers, with the remainder split between increased vehicle costs, congestion effects and construction-sector productivity losses.

6.2 Aviation

Satellite-based PNT services are widely used in aviation to support **route optimisation**, **approach and landing procedures**, and **air traffic management**. GNSS enables more efficient use of airspace, improved regularity and better handling of challenging weather and terrain conditions.

Norway's aviation system has progressed far in adopting satellite-based navigation, driven by international aviation standards set by ICAO, the EU and EASA. GNSS-based procedures are a key enabler of Performance-Based Navigation (PBN) and the Single European Sky initiative.

For Norway, satellite navigation is especially important because of long distances, complex topography and a large number of small, weather-exposed regional airports. Several newer airports are designed with minimal or no traditional ground-based navigation aids, increasing dependence on GNSS.

6.2.1 Use of Satellite-Based PNT Services

PNT services are central in three main aviation functions:

En-route navigation

GNSS enables precise, continuous positioning during cruise flight, allowing aircraft to follow more direct and fuel-efficient routes and enabling tighter separation standards. This increases airspace capacity and reduces delays.

Approach and landing procedures

GNSS supports advanced approach procedures, including curved and terrain-adapted approaches, reduced decision heights and improved regularity in poor weather. This is particularly important at regional airports where traditional instrument landing systems are impractical or unavailable.

Air traffic surveillance and control

Modern surveillance systems such as **ADS-B** rely on GNSS to broadcast aircraft position, height and velocity. GNSS-based time synchronisation is also essential for radar processing, data exchange and remote tower operations.

6.2.2 Consequences of Service Loss

Loss of PNT services would **not compromise flight safety**, as aviation systems include alternative navigation and surveillance methods. However, capacity and efficiency would be significantly reduced.

Consequences include:

- Larger separation distances between aircraft
- Longer flight routes and holding patterns
- Increased workload for pilots and controllers
- More delays and cancellations, particularly at GNSS-dependent airports

Poor weather conditions would amplify these effects, potentially forcing temporary airport closures and diversions, especially at smaller regional airports.

6.2.3 Socio-Economic Costs of a Seven-Day Outage

The socio-economic cost for aviation is estimated at **NOK 142.9 million**, driven primarily by:

- Passenger time losses from delays and cancellations
- Airline operational costs associated with ground delays and disruptions

The analysis assumes a modest increase in cancellations at major airports but substantially higher cancellation rates at smaller, GNSS-dependent regional airports.

6.3 Rail

The Norwegian rail sector is **largely independent of GNSS** for safety-critical functions such as train detection, signalling and control, which rely on closed and ground-based systems. GNSS is mainly used in **support functions**, including fleet management, passenger information, energy accounting and maintenance.

6.3.1 Use of Satellite-Based PNT Services

GNSS is used to:

- Improve real-time train position reporting for passenger information
- Support energy metering by linking consumption to correct geographical pricing zones
- Assist maintenance planning and infrastructure condition monitoring

These systems supplement, but do not replace, core safety systems.

6.3.2 Consequences of Service Loss

Loss of GNSS would not halt train operations but would lead to:

- Less precise real-time passenger information
- Increased manual correction of energy accounting
- Reduced efficiency in maintenance planning
- Slightly increased delays and limited additional cancellations

Dependence on PNT services in rail is expected to increase as digital systems and ERTMS are further deployed.

6.3.3 Socio-Economic Costs of a Seven-Day Outage

The total socio-economic cost for rail is estimated at **NOK 5.4 million**, driven mainly by increased delays and a small rise in cancellations due to reduced operational efficiency in supporting systems.

7 Emergency Services and Preparedness

Emergency services and preparedness actors are increasingly dependent on satellite-based PNT services in their core operational functions, particularly for **locating callers**, **dispatching and navigating emergency resources**, and **time synchronisation of critical communications and ICT systems**. PNT services contribute to reduced response times, better resource utilisation and more precise coordination during emergency incidents, which generates significant socio-economic benefits through reduced harm to life, health and material assets.

Loss of PNT services would not immediately incapacitate emergency services, but would lead to **longer response times**, **less precise resource deployment**, and a **gradual degradation of digital support functions**, including the emergency communications network and time-stamping systems.

The most serious consequences are associated with impaired caller localisation and reduced efficiency during response and mobilisation, which may increase the severity of outcomes in time-critical incidents. The socio-economic costs associated with a seven-day loss of PNT services in the emergency sector are estimated at **NOK 92 million**.

7.1 Use of Satellite-Based PNT Services

Emergency services and preparedness actors use satellite-based PNT services across a wide range of emergency situations, response operations and major incidents. In this analysis, the emergency and preparedness sector includes actors within Norway’s emergency and rescue system, i.e. those responsible for managing acute incidents where life, health, the environment or critical societal functions are threatened.

This includes:

- Police services
- Fire and rescue services
- Health and ambulance services
- Air ambulance services
- Joint Rescue Coordination Centres

It also includes voluntary rescue organisations that frequently participate in search-and-rescue operations, as well as technical and organisational support functions such as the national emergency communications network (Nødnett), operations centres and other relevant ICT and communications systems.

Emergency services rely on satellite-based PNT services across multiple operational functions. Necessary technology is integrated into a large share of vehicles, equipment and ICT systems. PNT services are used extensively for time-critical processes and have, in many cases, replaced or significantly improved earlier manual methods.

Tasks that previously required manual map reading, verbal coordination and confirmation between units are now performed automatically using technological solutions. These improvements generate substantial societal benefits through reduced response times and more effective handling of acute incidents, thereby reducing harm to life, health and material assets.

For analytical purposes, the primary functions of emergency services in incident handling can be divided into three main phases:

1. **Receipt of emergency calls and alerts**
   Emergency services receive notifications of accidents, fires, medical emergencies and other dangerous situations through dedicated, continuously staffed emergency call centres. These centres must rapidly determine what has occurred and **where the incident has taken place**.
2. **Dispatch and coordination of response resources**
   Available resources are allocated and coordinated so that the nearest and most appropriate units are dispatched. Continuous navigation, position sharing and situational updates are critical to minimising response time.
3. **Operational response and incident management**
   The response phase involves mitigating the consequences of the incident, as well as further coordination between agencies and supporting resources.

Across emergency services and functions, the analysis shows that use of and dependence on PNT services arises in largely similar areas, despite differences in operational mandates and working methods. Five overarching application areas have therefore been identified:

- Caller and incident localisation
- Navigation and route optimisation for emergency vehicles
- Transport and logistics of equipment and hazardous materials
- Emergency communications network and time synchronisation of critical ICT systems
- Alarm and alert systems

These application areas together form the core of how PNT services enable rapid, coordinated and effective emergency response.

Automatic localisation of caller position

When individuals call emergency numbers (110, 112 or 113) from mobile phones, the caller's position is automatically calculated and transmitted to emergency call centres. Modern smartphones use satellite-based positioning via **Advanced Mobile Location (AML)**, which combines several data sources—including GNSS—to determine the most accurate possible location.

When an emergency call is initiated, the phone automatically activates relevant sensors and calculates the caller's position, selecting the source providing the highest accuracy under the circumstances. In most cases, this involves GNSS-based AML with typical location accuracy of **5–50 metres**.

AML has been implemented in smartphones from major manufacturers since 2018, and since December 2020 AML support has been mandatory for mobile operators and devices in Europe.

AML significantly reduces the time emergency services must spend determining the caller's location, reducing the need for manual questioning and enabling faster dispatch of response units. In high-pressure situations with multiple simultaneous callers—such as major fires or large accidents—PNT services also enable prioritisation of calls from different geographic locations, reducing the risk that unrelated emergencies are delayed.

Positioning, tracking and navigation of emergency vehicles

All emergency response vehicles are equipped with positioning units that continuously update and transmit their location to operations centres. This function—often referred to as **Automatic Vehicle Location and Status (AVLS)**—is dependent on GNSS.

AVLS provides emergency services with a real-time overview of the location and availability of response units, enabling operators to dispatch the closest and most suitable resource, whether vehicles are at stations or already deployed in the field. This increases dispatch efficiency and reduces response time compared with systems based on verbal reporting or estimated positions.

GNSS also underpins navigation systems used during response. Most emergency vehicles are equipped with navigation solutions integrated with AVLS systems, using GNSS, digital maps and live traffic information to calculate the fastest and safest route. These systems continuously update routing in response to congestion, road closures or other incidents and provide updated estimates of arrival times.

Transport and logistics of medical equipment, hazardous materials and personnel

Emergency services also manage a range of logistical and transport tasks that are not always as time-critical as emergency calls but are essential for effective preparedness and operations. These include transport of medical equipment, pharmaceuticals, biological samples and personnel in the health services, as well as transport of equipment, detainees and specialised units within police and fire services.

Such tasks require precise planning, coordination and real-time overview of available resources, making them dependent on PNT services. Efficient transport can enable faster initiation of treatment, improved diagnostic processes and better utilisation of scarce resources, thereby generating significant socio-economic benefits.

Emergency communications network and time synchronisation of critical ICT systems

The national emergency communications network, **Nødnett**, provides secure and robust communications for emergency services nationwide. Nødnett is based on the TETRA standard and relies on GNSS-based time signals for synchronisation of base stations.

Loss of GNSS-based time signals would not cause immediate failure of Nødnett, as the system can rely on internal clocks with limited holdover capacity. However, prolonged outages would gradually degrade synchronisation, resulting in deteriorating voice quality and increased interference, particularly in high-traffic areas.

Beyond voice communication, emergency services depend on accurate time-stamping for incident logs, dispatch records, arrival times and event reconstruction. GNSS is widely used as a time reference for these systems. Loss of GNSS time requires reliance on internal clocks, which gradually drift and lead to inconsistent time-stamps. Precise and synchronised time is critical for documentation, chain-of-evidence integrity, inter-agency coordination and digital security functions such as authentication and encryption.

Alarm and alert systems

Emergency services also rely on a range of alarm systems that use GNSS for positioning and time-stamping. These include personal safety alarms, fire alarms, search-and-rescue beacons and other automated alert systems.

GNSS enables these systems to transmit accurate location and timing information without manual input from the user. Loss of GNSS would not necessarily prevent alarm transmission, but would reduce accuracy or require manual follow-up by operators, increasing response time and uncertainty.

7.2 Consequences of Service Loss

Loss of GNSS and PNT services would lead to a series of consequences that increase emergency response times and reduce operational efficiency. This would, in turn, increase the severity of outcomes in emergency incidents.

Loss of AML would result in less precise caller location data. Backup methods based on Wi-Fi or mobile network triangulation provide significantly lower accuracy. In some cases, callers may be unable to communicate their location effectively due to injury, illness, panic or dangerous circumstances.

For emergency vehicle dispatch and navigation, loss of GNSS would require reliance on manual coordination and navigation, leading to longer response times and increased operational uncertainty. While non-time-critical transport tasks could still be managed with alternative methods, overall efficiency would be reduced.

For Nødnett, short-term loss of GNSS would have limited immediate impact due to internal clock holdover, but prolonged outages would gradually degrade network performance. Similar degradation would affect log systems, encryption systems and other GNSS-dependent ICT components.

7.3 Socio-Economic Costs of a Seven-Day Outage

The socio-economic cost of a seven-day PNT outage affecting emergency services is estimated at **NOK 92 million**.

This reflects the increased consequences of emergency incidents resulting from longer response times and less efficient resource deployment. The estimate includes impacts on ambulance services, police and fire services.

The analysis assumes:

- An average **1-minute increase** in response time per critical emergency call due to loss of AML

- An additional **2–2.5 minutes** increase in response time due to reduced efficiency in vehicle navigation and dispatch

Time delays are valued using established estimates of the socio-economic cost of delayed emergency response, recognising that even small time increases can significantly affect outcomes in critical incidents.

8 Electronic Communications (Ecom)

Satellite-based PNT services are used in the electronic communications (ecom) sector primarily as a source of **precise, traceable time** for the synchronisation of networks, particularly **mobile networks (including 5G)**. Precise time is a prerequisite for coordinated radio transmission and efficient capacity utilisation, and contributes to the stable delivery of telephony and data services without interference or outages.

In the event of a loss of GNSS, electronic communications networks will generally not fail immediately, as operators can rely on **holdover capacity** in local clocks and internal time-distribution solutions. Over time, however, timing deviations will gradually accumulate, which can result in reduced network capacity, degraded service quality and—in the worst case—service outages.

The societal consequences associated with PNT loss in the ecom sector therefore relate less to **direct costs within the sector itself**, and more to the **indirect ripple effects** for other sectors that depend on functioning electronic communications for operations, coordination and emergency preparedness.

8.1 Use of Satellite-Based PNT Services

Electronic communications constitute a fundamental prerequisite for a modern, technology-driven society. Ecom networks enable coordination and information exchange across sectors, geographic areas and societal functions. The infrastructure includes fixed networks, mobile networks and broadcasting networks, all based on different technologies, and underpins everything from daily communication among individuals and businesses to the operation of critical societal services.

Electronic communications are defined as **critical infrastructure** and form a core element of societal security and preparedness. The infrastructure comprises:

- physical assets such as fibre cables, base stations, nodes and network equipment, and

- logical network layers for synchronisation, routing, traffic control, prioritisation, authentication and security.

Precise time is a prerequisite for synchronisation and control within ecom networks, including ensuring that large numbers of users can access services simultaneously without interference. These dependencies are largely invisible to end-users.

Within the ecom sector, satellite-based PNT services are used mainly for two purposes:

1. **Synchronisation of electronic communications networks** through precise time and frequency from GNSS
2. **Establishment and operation of physical network infrastructure**, including planning, deployment and maintenance

Synchronisation of Ecom Networks

Ecom networks use GNSS as a source of highly precise, traceable time. GNSS systems distribute their own system time scales, which are continuously corrected and can be related to UTC with extremely high precision. In practice, GNSS functions as a distribution mechanism for **UTC-traceable time** in electronic communications networks.

Operators deploy GNSS receivers at selected network locations, such as base stations, technical facilities or core network nodes. In network architectures where central **master clocks** are used, GNSS-derived time is first received at these central nodes and then distributed further within the network to other nodes and base stations, ensuring that the entire infrastructure operates on a common, synchronised time reference.

Precise time synchronisation is particularly critical in **5G networks**, which largely rely on **time division duplexing (TDD)**. Here, uplink and downlink transmissions share the same frequency but occur in precisely defined time slots. If time offsets between base stations exceed tolerance thresholds, radio signals may overlap and interfere.

In practice, ecom networks are transitioning from architectures where each base station has its own GNSS receiver, to architectures in which a limited number of central master clocks are disciplined by GNSS and distribute time internally within the network. This reduces local dependence on GNSS reception but retains **centralised GNSS dependence**.

Such master clocks can maintain sufficiently precise time for a limited period after GNSS loss, through high-quality oscillators. Time precision gradually degrades during holdover, increasing vulnerability as outages persist.

In several countries, alternative national time-distribution services are used as complements or substitutes for GNSS. These services demonstrate that **GNSS-independent time distribution** can provide high accuracy over extended periods, though such solutions require dedicated infrastructure and governance.

Requirements for time precision vary between network types:

- **Mobile networks**, particularly 5G, require synchronisation within ±1.5 microseconds
- **Future 6G networks** are expected to require nanosecond-level synchronisation
- **Fixed networks and data centres** tolerate larger deviations, but still rely on stable time for logging, operations and coordination

Mobile networks are especially sensitive because many base stations must operate in tight coordination within shared spectrum environments. Time deviations at one site may therefore cause interference affecting other operators' networks, introducing **systemic risk**.

Broadcasting networks also depend on precise time, particularly for digitally multiplexed signals that rely on orthogonal frequency techniques. Timing errors can lead to interference and reduced signal quality.

Establishment and Operation of Physical Network Infrastructure

Satellite-based PNT services are also used in the establishment and operation of physical ecom infrastructure. GNSS-based positioning supports:

- network planning and expansion,
- field maintenance and fault rectification, and
- documentation and asset management.

These uses are particularly relevant in geographically dispersed networks. While important, loss of positioning services in these contexts generally has **less severe consequences** than loss of time synchronisation.

8.2 Consequences of Service Loss

When GNSS signals are lost, ecom infrastructure loses access to satellite-based time and positioning signals that serve as reference inputs for parts of the network. GNSS receivers at key sites stop receiving updated time signals and therefore cease disciplining the local oscillators that serve as time references.

Initially, networks continue operating using internal clocks and stored time information. Over time, however, small timing deviations accumulate. When such deviations become large enough, different parts of the network may no longer operate in synchrony, affecting interoperability and technical stability.

In mobile networks, accumulating time errors may lead to **radio interference**, reduced coverage and degraded service quality. In severe cases, traffic may be shifted from 5G to 4G networks, reducing overall capacity—particularly problematic in high-density areas.

Ecom networks are not wholly dependent on continuous GNSS availability. Operators have implemented various mitigation measures, including:

- high-quality oscillators with significant holdover capacity,
- filtering mechanisms to reject erroneous time signals, and
- internal time-distribution architectures.

Interviews indicate that some operators can maintain acceptable synchronisation for **weeks or even months** in the absence of GNSS, depending on equipment quality and network design. Nonetheless, holdover capacity is finite, and prolonged or widespread GNSS outages increase the risk of service degradation and eventual failure.

Loss of GNSS due to **jamming** or **spoofing** presents additional risk. In the case of spoofing, receivers may accept seemingly valid but incorrect time signals. If such signals are not detected and rejected, erroneous time may propagate through the network. Robustness therefore depends not only on holdover capacity but also on the ability to **detect and manage corrupted reference signals**.

8.3 Socio-Economic Costs of a Seven-Day Outage

The socio-economic cost assessment is based on the assumption that a seven-day GNSS outage **does not lead to immediate, widespread loss of electronic communications services**, due to existing redundancy and holdover capacity in network clocks.

Direct costs within the ecom sector are therefore limited and primarily relate to:

- increased operational workload,
- additional monitoring and manual intervention, and
- precautionary measures to maintain service integrity.

The most significant consequences of GNSS loss in the ecom sector are **indirect**, arising in other sectors that depend on reliable electronic communications for:

- emergency response,
- transport and logistics,
- financial transactions,
- energy system operation, and
- public administration.

These indirect impacts are valued in the respective sectoral chapters where the losses materialise, rather than being counted as a separate cost category in this chapter.

Electronic communications also play a critical role in societal preparedness and crisis management by enabling coordination among emergency services, authorities and infrastructure operators. This enabling function is indirect and therefore not valued as a distinct cost item in the ecom chapter, but is implicitly reflected in the consequences assessed for other sectors.

9 Power Supply and Energy

The power supply system is a core component of society's critical infrastructure. Stable and secure access to electricity is a fundamental prerequisite for the functioning of households, industry, public services and digital infrastructure. Satellite-based PNT services play an important role in the **operation, monitoring and control of power systems**, primarily through the provision of **precise and synchronised time**.

In contrast to sectors where loss of positioning services has immediate operational consequences, the power sector's dependence on PNT services is primarily related to **time synchronisation and frequency control**. The consequences of loss of satellite-based PNT services in the power sector therefore differ from those observed in sectors such as transport or petroleum activities.

9.1 Use of Satellite-Based PNT Services

In modern power systems, precise and synchronised time is a critical input factor. Power system operation requires tight coordination between production, transmission and consumption in order to maintain **system frequency, stability and power quality**.

Satellite-based PNT services—primarily GNSS-derived time—are used for several key purposes in the power supply system:

- **Time and phase synchronisation** in the transmission and distribution networks
- **Monitoring and control** of power flows and system states

- **Fault detection, analysis and event reconstruction**
- **Market settlement and documentation**

Time and phase synchronisation

The electricity transmission grid operates as a synchronous system, where generators and consumers must remain aligned in frequency and phase. Precise time synchronisation is therefore necessary to ensure that measurements from different parts of the grid can be compared and interpreted correctly.

Phasor Measurement Units (PMUs), protection relays and monitoring systems rely on time-stamped measurements to identify deviations, oscillations and faults in the grid. GNSS is commonly used as a time source for these systems due to its high accuracy and widespread availability.

Accurate time synchronisation enables operators to gain real-time situational awareness of the grid, detect instabilities early, and initiate corrective actions before faults propagate or escalate.

Monitoring, protection and control systems

Satellite-based time is used in supervisory control and data acquisition (SCADA) systems, wide-area monitoring systems and digital protection equipment. These systems depend on accurate sequencing of events to function correctly.

Time-stamped data allows operators to:

- identify the location and cause of faults,
- coordinate automated protection mechanisms, and
- analyse incidents retrospectively to improve system robustness.

Market operations and settlement

Precise time also plays a role in electricity market operations, including logging of production and consumption, settlement of imbalances and documentation for regulatory compliance. While market settlement systems are generally more tolerant of timing deviations than operational control systems, consistent and traceable time references remain important.

9.2 Consequences of Service Loss

Loss of satellite-based PNT services does **not** generally result in immediate outages or direct disruptions to electricity supply. This is because power system operators have implemented **significant redundancy and backup solutions** for time synchronisation.

Short-term consequences

In the short term, loss of GNSS signals is mitigated through:

- local clocks with holdover capacity,
- fibre-based time distribution, and
- alternative time sources embedded in operational systems.

These solutions allow continued operation without immediate degradation of system performance. As a result, a **seven-day GNSS outage** is unlikely to cause direct service interruptions or measurable production losses in the power sector.

Degradation over time

However, local clocks will gradually drift in the absence of external synchronisation. Over time, this may lead to:

- reduced accuracy in time-stamped measurements,
- decreased visibility of system conditions, and
- increased uncertainty in fault analysis and diagnostics.

The risk increases with the duration of the outage and the quality of holdover solutions deployed by different actors. Variations in robustness across grid operators and installations may introduce **heterogeneous risk exposure**.

Risk of manipulation and hidden failures

Interviewees and previous analyses emphasise that **manipulation of time signals** (e.g. GNSS spoofing) may pose a more serious risk than complete signal loss.

Small timing errors—on the order of microseconds—can be sufficient to:

- distort phasor measurements,
- trigger false alarms or mask real incidents, and
- impair automated protection mechanisms.

Such errors may remain undetected for extended periods, especially if systems continue to receive what appear to be valid time signals. This can create latent vulnerabilities that only become visible once multiple systems exhibit inconsistencies.

In extreme cases, undetected timing errors could lead operators to halt parts of the power system preventively to avoid cascading failures, even if physical infrastructure remains intact.

9.3 Socio-Economic Costs of a Seven-Day Outage

Based on the sector analysis, a seven-day loss of satellite-based PNT services is **not expected to result in direct, quantifiable socio-economic costs in the power supply and energy sector**.

This assessment is based on:

- substantial existing redundancy,
- the ability of local clocks and fibre-based solutions to maintain sufficient accuracy over a limited period, and
- the absence of immediate impacts on electricity production or delivery.

As a result, **direct costs are estimated at zero** for the seven-day outage scenario examined in this report.

Systemic importance and residual risk

The absence of direct costs does not imply that the power sector is unaffected or that risk is negligible. The power supply system forms a **foundational dependency for nearly all other sectors** analysed in this report.

Even limited degradation in situational awareness, fault-handling capability or protection system reliability increases the potential for **system-wide consequences** if combined with other adverse events.

Longer or more complex incidents—including concurrent outages, cyber incidents or extreme weather—could exacerbate the consequences of impaired time synchronisation. These risks are therefore treated as **systemic vulnerabilities** rather than direct, priced costs.

The analysis highlights that robust time distribution and the ability to detect and manage erroneous time signals are critical to maintaining resilience in the power sector, particularly as systems become more digitalised and interconnected.

10 Finance

The financial sector is a critical component of the modern economy and depends on stable, secure and well-functioning infrastructure. Satellite-based PNT services play an important role in the financial sector, primarily through the provision of **precise and traceable time** for transaction processing, trading systems and regulatory compliance.

Unlike sectors where loss of positioning services leads to immediate operational disruption, the financial sector's dependence on satellite-based PNT services is largely related to **time-stamping, sequencing and synchronisation** of digital transactions and data flows. As a result, the consequences of loss of PNT services in finance differ from those observed in transport or maritime sectors.

10.1 Use of Satellite-Based PNT Services

Precise and synchronised time is a fundamental input factor in modern financial systems. Financial infrastructure consists of tightly integrated digital systems that process, validate and record transactions at very high speeds, often across multiple institutions and jurisdictions.

Satellite-based PNT services—primarily GNSS-derived time—are used in the financial sector for several key purposes:

- **Time-stamping of financial transactions**
- **Sequencing and reconciliation of trades and payments**
- **Operation of trading and settlement systems**
- **Regulatory compliance and auditability**

Transaction time-stamping

Banks, payment service providers, stock exchanges and trading venues rely on precise time-stamps to record when transactions occur. Time-stamping is essential for determining the correct order of transactions, price formation, settlement priority and legal validity.

European financial regulation, including MiFID II, places explicit requirements on the accuracy and traceability of transaction time-stamps. Financial institutions must therefore ensure that their systems are synchronised to a recognised time reference, commonly Coordinated Universal Time (UTC). GNSS is widely used as a primary or reference source for this purpose.

Trading, clearing and settlement systems

High-frequency trading, algorithmic trading and automated settlement systems rely on precise time synchronisation to function correctly. Even small timing discrepancies can affect:

- market integrity,
- fairness between market participants, and
- the ability to reconstruct trading events retrospectively.

PNT-derived time is also used in post-trade processes, such as clearing and settlement, where accurate sequencing of transactions is required to manage counterparty risk and ensure financial stability.

Infrastructure for payments and critical financial functions

Payment systems, including interbank settlement systems and retail payment platforms, depend on accurate time references for logging, monitoring and reconciliation. Time synchronisation supports fraud detection, dispute resolution and operational continuity.

Financial institutions typically use a combination of time sources, including GNSS, local atomic clocks, network-based protocols (such as NTP and PTP) and fibre-distributed time. GNSS often serves as a primary reference or as a calibration source for internal clocks.

10.2 Consequences of Service Loss

Short-term consequences

Loss of satellite-based PNT services does not normally result in immediate disruption of financial services. Most critical financial institutions have implemented **significant redundancy and holdover capacity** in their time-synchronisation infrastructure.

Local clocks and internal time-distribution systems can typically maintain sufficient accuracy for a limited period without external GNSS synchronisation. As a result, a **seven-day GNSS outage** is unlikely to cause immediate failures in trading, payment processing or settlement.

Degradation over time

Over time, however, local clocks will gradually drift without external synchronisation. This may lead to:

- increasing discrepancies in time-stamps between systems,

- reduced precision in sequencing of transactions, and
- greater difficulty in reconciling records across institutions.

The impact of such drift depends on the quality of local clocks, the duration of the outage and the robustness of internal monitoring and correction mechanisms. Smaller institutions or peripheral systems may have lower holdover capacity than systemically important financial institutions.

Risk of manipulation and hidden vulnerabilities

As in the power and electronic communications sectors, **manipulation of time signals** represents a potentially greater risk than complete signal loss. GNSS spoofing that introduces small but consistent timing errors may remain undetected for extended periods.

Even minor timing deviations—within regulatory tolerance limits—can accumulate across systems and institutions, creating inconsistencies in transaction records and sequencing. In extreme cases, uncertainty regarding transaction order or timestamp validity may force institutions to suspend trading or settlement activity as a precautionary measure.

Such preventive shutdowns could have wider market impacts, even if no physical infrastructure is damaged and core systems remain operational.

10.3 Socio-Economic Costs of a Seven-Day Outage

Based on the analysis, a seven-day loss of satellite-based PNT services is **not expected to result in direct, quantifiable socio-economic costs in the financial sector**.

This assessment reflects:

- extensive redundancy and backup solutions,
- the ability of internal clocks to maintain regulatory-compliant accuracy over a limited period, and
- the absence of immediate disruption to transaction processing under the analysed scenario.

Accordingly, **direct costs are estimated at zero** for the seven-day outage scenario.

Systemic importance and residual risk

The absence of direct, priced costs does not imply that the financial sector is unaffected by loss of PNT services. Finance is a **system-critical sector** that underpins economic activity across all other sectors.

Reduced confidence in the integrity of time-stamping, sequencing or settlement systems—even if temporary—may undermine trust in financial markets. In combination with other stress factors, such as cyber incidents or operational failures, impaired time synchronisation could amplify systemic risk.

As financial markets become more digitalised, automated and interconnected, the sector's sensitivity to time errors may increase. Ensuring robust, diverse and tamper-resistant time sources is therefore essential to maintaining financial stability and resilience.

11 Agriculture

Agriculture has increasingly taken advantage of satellite-based PNT services to improve efficiency, resource utilisation and productivity. The introduction of precision agriculture technologies has enabled more targeted use of inputs such as seed, fertiliser and plant protection products, and has contributed to improved yields and reduced environmental impact.

The agricultural sector's dependence on satellite-based PNT services is primarily linked to **positioning and navigation**, rather than time synchronisation. As a result, the consequences of loss of PNT services in agriculture differ from those observed in sectors where precise time is a critical input factor.

11.1 Use of Satellite-Based PNT Services

Satellite-based PNT services are used extensively in modern agriculture, particularly in connection with **precision farming** and mechanised field operations. GNSS-based positioning enables accurate guidance and control of agricultural machinery and equipment, allowing operations to be performed with high spatial precision.

Key applications include:

- **GNSS-based guidance and auto-steering of agricultural machinery**
- **Precision planting, fertilisation and crop spraying**
- **Field mapping, yield mapping and documentation**
- **Efficient operation planning and reduced overlap**

Machine guidance and auto-steering

The majority of modern tractors, harvesters and other agricultural machines are equipped with GNSS-based navigation and auto-steering systems. These systems guide machinery along predetermined paths with high accuracy, often down to the sub-meter or centimetre level when correction services are used.

Auto-steering reduces operator workload, enables higher operating speeds, improves working conditions and ensures consistent coverage of fields. Accurate guidance reduces overlap and missed areas, which in turn lowers fuel consumption and input use.

Precision application of inputs

GNSS-based positioning is central to precision agriculture technologies that allow site-specific application of fertiliser, pesticides and seed. Position-referenced prescription maps are used to vary application rates across a field based on soil conditions, crop needs and yield potential.

This targeted approach improves productivity and resource efficiency while reducing environmental impacts and operational costs.

Field mapping and documentation

PNT services are also used for field mapping, yield mapping and digital documentation of agricultural activities. Harvesters equipped with GNSS record yield data that can be analysed to optimise future operations.

Digital documentation supports compliance with regulatory requirements and provides farmers with better decision-support tools for long-term farm planning.

11.2 Consequences of Service Loss

Loss of satellite-based PNT services would primarily affect **operational efficiency** in agriculture, rather than bringing operations to a complete halt.

Short-term consequences

In the event of GNSS loss:

- Auto-steering systems would become unavailable
- Machinery would need to be operated manually
- Precision input application would revert to uniform application or be postponed

Farmers would still be able to carry out field work using manual steering and visual guidance, but operations would become more labour-intensive and less precise. Reduced precision would increase overlap, fuel consumption and time use.

Impact on productivity and resource use

Loss of PNT services would lead to:

- Increased fuel consumption
- Higher use of fertiliser and pesticides due to overlap
- Reduced operational capacity per working hour
- Increased operator fatigue

The impact would be particularly pronounced during time-sensitive operations such as planting and harvesting, where delays may reduce yield potential.

Seasonal sensitivity

The consequences of PNT service loss depend strongly on **timing within the agricultural season**. Loss during peak periods—such as spring planting or autumn harvest—would have greater impacts than loss during less intensive periods.

Longer outages would reduce the benefits of precision agriculture but would not generally prevent agricultural production from continuing.

11.3 Socio-Economic Costs of a Seven-Day Outage

The socio-economic cost of a seven-day loss of satellite-based PNT services in agriculture is estimated at approximately **NOK 11 million**.

This estimate reflects:

- reduced productivity due to lower operational efficiency,
- increased input and fuel costs, and
- additional labour requirements.

The calculation assumes that agricultural activities continue, but with **reduced efficiency** rather than full cessation. The cost estimate is therefore relatively low compared with sectors where loss of PNT services results in standstill of core operations.

Limitations and uncertainty

As in other sectors, behavioural adaptations and farm-specific conditions introduce uncertainty. Farmers may choose to postpone certain operations during short outages, while others may continue with reduced precision. The aggregated estimate represents an average effect across the sector.

12 Construction and Civil Engineering

The construction and civil engineering sector has, over time, become increasingly dependent on satellite-based PNT services, particularly through the widespread adoption of **digital surveying, machine control and positioning technologies**. These services are used throughout the value chain, from planning and design to execution, quality assurance and documentation.

The sector's dependence is primarily linked to **precise positioning**, rather than time synchronisation. As a result, loss of PNT services affects **productivity, precision and efficiency**, rather than causing immediate safety-critical failures or complete standstills.

12.1 Use of Satellite-Based PNT Services

Satellite-based PNT services are used extensively in construction and civil engineering projects, particularly in earthworks, infrastructure construction and large-scale projects involving complex geometry and strict tolerance requirements.

Key applications include:

- **Surveying, staking-out and measurement**
- **GNSS-based machine control**
- **Digital terrain models and project planning**
- **Quality assurance and documentation**

Surveying and staking-out

GNSS is widely used for surveying and staking-out construction sites. Positioning services enable rapid and accurate placement of reference points, alignments and elevations based on digital design models.

Compared with traditional optical surveying methods, GNSS-based techniques allow faster deployment, lower labour requirements and improved flexibility—particularly in large or complex project areas.

Machine control and automation

Modern construction machinery, such as excavators, bulldozers, graders and asphalt pavers, is frequently equipped with GNSS-based machine control systems. These systems use satellite positioning to guide machinery according to digital design models, enabling highly precise execution of earthworks and surface construction.

Machine control reduces the need for manual staking-out, minimises rework, improves material efficiency and allows continuous quality control during operations. The technology also reduces the dependency on skilled survey staff being physically present in the field during active construction phases.

Digital models and project coordination

PNT services support the creation and use of **digital terrain models and digital twins**, which are increasingly used to plan, monitor and document construction projects. Accurate positioning enables seamless integration of design data, machine operation data and as-built documentation.

12.2 Consequences of Service Loss

Loss of satellite-based PNT services would have **immediate and noticeable impacts on productivity and efficiency**, but would not bring construction activity to a complete halt.

Operational impacts

In the event of loss of PNT services:

- GNSS-based surveying and staking-out would become unavailable
- Machine control systems would cease functioning
- Construction processes would need to revert to manual methods

Manual surveying using total stations and physical markers would still be possible but would require additional personnel, time and coordination. Construction machinery would need to be operated using visual judgement, fixed references and manual checks, resulting in lower precision and slower execution.

Productivity and cost implications

Loss of PNT services would lead to:

- Reduced productivity in earthworks and infrastructure construction
- Increased labour requirements
- Higher risk of errors and rework
- Increased material use due to reduced precision

The impact would be particularly significant in **large-scale projects**, linear infrastructure (roads, railways, pipelines), and projects with tight tolerances or complex geometric requirements.

Project delays

Reduced efficiency and increased rework would increase the risk of project delays. Time-critical projects or those operating with limited weather or seasonal windows would be especially affected.

12.3 Socio-Economic Costs of a Seven-Day Outage

The socio-economic cost of a seven-day loss of satellite-based PNT services in the construction and civil engineering sector is estimated at approximately **NOK 351 million**.

The estimate reflects:

- productivity losses resulting from reduced efficiency,
- increased labour and equipment costs, and
- higher material use and rework.

The calculation assumes that construction activities continue during the outage, but with **substantially reduced efficiency** rather than full cessation.

Assumptions and uncertainty

The estimate is based on:

- aggregate annual value creation in construction and civil engineering, and
- expert assessments of productivity reduction associated with loss of GNSS-based machine control and surveying.

Actual impacts would vary depending on project type, scale and phase. Projects in early planning stages would be less affected than those in active execution phases. Similarly, smaller projects may adapt more easily than large, highly automated infrastructure projects.

13 Consumer Products and Services

Consumer products and services encompass a broad range of goods and services used directly by households and individuals in their daily lives. Many of these products and services rely—often implicitly—on satellite-based PNT services, particularly for **positioning and navigation**, and increasingly for **location-based digital functionality**.

In contrast to sectors where PNT services underpin critical infrastructure or safety-critical operations, dependence in consumer products and services primarily affects **convenience, efficiency and service quality**, rather than basic functionality or safety.

13.1 Use of Satellite-Based PNT Services

Satellite-based PNT services are integrated into a wide variety of consumer-oriented products and services, often as an enabling technology embedded in smartphones, vehicles and digital platforms.

Key applications include:

- **Navigation and mapping services**
- **Location-based digital services and applications**
- **Mobility and delivery services**
- **Recreational, leisure and outdoor applications**

Navigation and mapping services

GNSS-based navigation is one of the most widespread consumer applications of satellite-based PNT services. Navigation systems embedded in smartphones, vehicles and dedicated devices provide turn-by-turn guidance, route optimisation, travel time estimates and congestion avoidance.

These services are used extensively by private motorists, cyclists, pedestrians and public transport users. They reduce travel time, improve route reliability and lower cognitive effort for users.

Location-based digital services

A wide range of digital services depend on accurate positioning, including:

- ride-hailing services,
- shared mobility platforms,

- location-based advertising,
- social media applications with geotagging functionality, and
- retail and service discovery platforms.

GNSS-based positioning allows services to be tailored to users' locations, enabling more relevant information, efficient matching of supply and demand, and improved user experience.

Delivery, logistics and on-demand services

Consumer delivery services—such as food delivery, parcel distribution and on-demand retail—rely on PNT services to track drivers, optimise routes and provide accurate delivery estimates. Precise positioning improves coordination between consumers, service providers and logistics platforms.

Loss of GNSS would reduce transparency and efficiency, but would not render these services inoperable.

Recreation and leisure activities

PNT services are widely used in recreational activities, including hiking, skiing, boating and other outdoor pursuits. GPS-enabled devices and applications provide navigation, tracking, safety features and performance analysis.

Positioning is also used in consumer electronics, such as fitness trackers and smartwatches, to record movement and activity patterns.

13.2 Consequences of Service Loss

Loss of satellite-based PNT services would have **limited societal consequences** in the consumer products and services sector, but would noticeably reduce convenience, efficiency and service quality.

Short-term impacts

In the event of PNT service loss:

- Navigation applications would become unavailable or significantly degraded
- Location-based services would lose precision or functionality
- Delivery services would face increased inefficiency and delays
- Consumers would need to rely on alternative methods, such as manual navigation or fixed addresses

Most consumer services would continue operating, but with reduced accuracy, longer response times and lower user satisfaction.

Adaptation and user behaviour

Consumers are generally able to adapt quickly by:

- using familiar routes,
- relying on local knowledge, or
- postponing discretionary activities.

As a result, behavioural adaptation limits the socio-economic consequences of PNT outages in this sector.

Distributional considerations

While overall impacts are limited, certain user groups—such as tourists, individuals with limited local knowledge, or users with reduced mobility—may be more affected than others.

13.3 Socio-Economic Costs of a Seven-Day Outage

The socio-economic cost of a seven-day loss of satellite-based PNT services affecting consumer products and services is estimated at approximately **NOK 20 million**.

This estimate reflects:

- increased time use due to less efficient navigation,
- reduced quality of consumer services, and
- minor productivity losses in service delivery.

The cost estimate is relatively modest compared with other sectors, reflecting both:

- the non-critical nature of most consumer PNT applications, and
- the high capacity for short-term behavioural adaptation among users.

Uncertainty and limitations

The estimate is subject to uncertainty related to user behaviour, variation in service usage and the diversity of affected services. However, even under less favourable assumptions, the sector's contribution to total socio-economic costs remains limited relative to infrastructure-dependent sectors.

14 Overall Assessment and Implications

This chapter brings together the findings from the sector-specific analyses and discusses their broader implications. The purpose is to provide a holistic assessment of the socio-economic consequences of loss of satellite-based PNT services and to highlight key insights that are not fully captured by the quantitative cost estimates alone.

The chapter addresses:

1. what the sector-specific analyses show collectively,
2. which impacts are not fully reflected in the cost figures, and
3. key development trends and the growing importance of precise time.

14.1 What Do the Sector-Specific Consequences Show?

The sector analyses demonstrate that satellite-based PNT services play a materially important role across large parts of Norwegian society. The extent and nature of dependence vary significantly between sectors, both in terms of how PNT services are used and how quickly and severely a loss would affect operations.

The estimated **direct socio-economic costs of a seven-day outage**, amounting to approximately **NOK 3.4 billion**, are concentrated in a limited number of sectors. Petroleum activities, maritime transport and construction account for the largest share of quantified losses, reflecting strong operational dependence on precise positioning and navigation.

Other sectors—such as road transport, aviation, emergency services, agriculture and consumer services—also experience measurable impacts, but at lower levels. In these sectors, loss of PNT services primarily leads to **reduced efficiency, delays and higher operating costs**, rather than complete standstill of activity.

In contrast, several system-critical sectors—including **power supply, finance and electronic communications**—show **limited or zero direct costs** in the seven-day scenario. This is not because these sectors are unimportant or unaffected by PNT loss, but because:

- they primarily depend on **precise time rather than position**, and
- they typically have **redundancy and holdover capacity** sufficient to maintain operations over a limited period.

A key conclusion from the sector analyses is therefore that **high direct economic costs are not synonymous with high systemic importance**. Some sectors with relatively modest direct losses play a crucial enabling role for the rest of the economy and society.

14.2 What Is Not Fully Captured by the Cost Figures – and What Are the Implications?

The quantified cost estimates in this report deliberately focus on **direct, first-order effects** occurring within a defined seven-day outage period. Several important types of consequences are therefore **not fully reflected** in the figures.

Systemic and cascading effects

Many of the most critical PNT dependencies are **systemic and cross-sectoral**. Power supply, electronic communications and financial services provide foundational infrastructure for nearly all other sectors. Disturbances in these functions may propagate through society in ways that far exceed the initial disruption.

Because such cascading effects depend on complex interactions between systems and on behavioural responses, they are methodologically difficult to quantify in a sector-based, partial-equilibrium analysis. Their exclusion from the cost figures does not mean they are insignificant—on the contrary, they may represent some of the most severe potential consequences of large-scale or prolonged PNT disruption.

Impacts of manipulation versus outage

The cost estimates largely consider **loss of availability** of PNT services. However, experience and interviews indicate that **manipulation of signals**—particularly time spoofing—may pose equal or greater risk.

Manipulated signals can remain undetected, leading to gradually accumulating errors in systems that otherwise appear to function normally. In sectors such as power, finance and telecommunications, very small timing deviations can have disproportionate consequences. Such scenarios may force operators to shut down systems preventively to maintain safety or integrity.

These risks are difficult to price but have significant implications for societal resilience.

Preparedness, confidence and trust

Some impacts relate not to immediate economic losses, but to **confidence, trust and preparedness**. Loss of reliable time and position references can undermine trust in digital systems, transaction records, monitoring data and situational awareness.

In crisis situations, diminished trust in system outputs may lead to more conservative decision-making, reduced automation and greater reliance on manual processes, with broader efficiency and welfare consequences.

Distributional and equity effects

Aggregate cost estimates mask differences in how impacts are distributed:

- geographically,
- between sectors, and
- across population groups.

Remote areas, offshore activities and regions with limited redundancy may be more exposed than urban areas with multiple alternatives. Certain user groups—such as emergency services, offshore workers or time-critical industries—bear a disproportionate share of risk relative to aggregate cost figures.

14.3 Development Trends and the Importance of Precise Time

Several long-term trends indicate that society's dependence on satellite-based PNT services—particularly **precise time**—is likely to increase further.

Digitalisation and automation

Digitalisation has transformed infrastructure systems, industrial processes and public services. Real-time operation, automation and data integration have reduced manual buffers and increased efficiency, but also increased sensitivity to errors in underlying reference signals.

As more systems operate automatically and interact at machine speed, tolerance for deviations in time and position is reduced.

Increasing importance of synchronised time

Across multiple sectors, **precise and synchronised time** is emerging as a shared critical dependency:

- in power systems for stability and fault handling,
- in electronic communications for network synchronisation and capacity,
- in finance for transaction integrity and compliance, and
- in emergency systems for coordination and documentation.

This form of dependence is often less visible than positional dependence, but potentially more consequential because it operates across sectors simultaneously.

Reduction of alternative methods

The success and reliability of satellite-based PNT services have led many sectors to phase out alternative methods and degrade manual competencies. While this has delivered efficiency gains, it has also reduced redundancy at the system level.

In several sectors, interviewees reported that GNSS dependence was greater than previously assumed, as indirect dependencies had not been fully mapped.

Implications for resilience

Taken together, these development trends imply that:

- society’s **aggregate vulnerability** to disrupted or manipulated PNT services may increase over time, even if individual systems become more optimised, and
- resilience increasingly depends on **diversity of time and position sources**, detectability of anomalies, and coordinated cross-sectoral governance.

Overall Implications

The analysis shows that satellite-based PNT services are not merely a productivity-enhancing technology, but a **foundational component of modern societal infrastructure**.

The quantified socio-economic costs provide an important indicator of exposure, but they do not capture the full risk picture. The most critical vulnerabilities relate to:

- system-wide dependencies,
- hidden and indirect effects, and
- the risk of undetected manipulation rather than outright failure.

These findings underline the importance of viewing PNT robustness and resilience as a **cross-sectoral and strategic issue**, rather than a challenge confined to individual industries or technologies.

15 Alternative Technologies and Measures to Reduce Dependence

This chapter discusses alternative technologies and measures that can help reduce dependence on satellite-based PNT services and improve societal robustness in the event of outages, disruptions or manipulation of GNSS signals. The chapter draws on interviews with stakeholders across sectors and on relevant technical and policy documents.

The measures discussed are **not prioritised recommendations**, but examples of approaches and solutions highlighted by stakeholders themselves. No socio-economic cost-benefit analysis of specific investments or prioritisation between measures has been conducted.

The chapter covers:

1. increasing robustness in existing systems,
2. monitoring and situational awareness,
3. strengthening holdover capacity and transition solutions,
4. redundancy and alternative sources of PNT,
5. competence related to alternative methods and systems,
6. governance models and national strategy, and
7. proposed measures and input from stakeholders.

15.1 Increasing Robustness in Existing Systems

One approach to reducing vulnerability is to increase robustness within existing systems that rely on GNSS, rather than replacing satellite-based PNT services outright. This may involve technical improvements in receivers, system design and operational routines.

Examples include:

- improved receiver resilience against interference and spoofing,
- use of multi-constellation and multi-frequency GNSS receivers,
- integration of multiple PNT sources within a single system, and
- improved filtering and validation of PNT signals.

Several stakeholders pointed out that robustness gains can often be achieved at relatively low cost by:

- configuring equipment and systems more defensively, and
- using existing capabilities more effectively.

At the same time, robustness varies significantly across sectors and operators. In some cases, PNT dependence is implicit and undocumented, making targeted robustness improvements difficult without first mapping dependencies in greater detail.

15.2 Monitoring and Situational Awareness

Improved monitoring of GNSS status and PNT quality was highlighted as a key measure to strengthen situational awareness and enable faster response to disruptions.

Possible measures include:

- expanding and coordinating existing GNSS monitoring infrastructure,
- sharing real-time information on GNSS disturbances and anomalies, and
- providing operators and users with timely warnings and status information.

Stakeholders pointed to the potential to further develop existing infrastructure—such as the **CPOS network**, the **Norwegian Coastal Administration's sensors**, and **monitoring stations operated by the Norwegian Communications Authority (Nkom)**—into a more comprehensive national GNSS monitoring and alerting service.

Such a service could include:

- formalised coordination between relevant authorities,
- real-time dissemination of GNSS status to operators, and
- potentially public visualisation of GNSS conditions.

It was also suggested that interference detectors already built into many receivers could play a greater role as part of a national monitoring architecture.

15.3 Strengthening Holdover Capacity and Transition Solutions

Measures related to **precise time** were highlighted as particularly important, given the cross-sectoral nature of time dependency and its often low visibility compared with positional dependence.

Key approaches include:

- strengthening local holdover capacity through higher-quality oscillators,

- ensuring smooth transitions between primary and backup time sources, and
- improving resilience during both loss and restoration of GNSS signals.

Several stakeholders emphasised the importance of establishing a **national time service independent of GNSS**. Experience from Sweden’s **Netnod time service** was cited as an example of how a centrally coordinated, GNSS-independent service could provide long-term, high-precision time distribution.

Such solutions could reduce vulnerability to both outages and manipulation by:

- providing a trusted alternative time reference, and
- enabling cross-checking of GNSS-derived time.

15.4 Redundancy and Alternative Sources of PNT

A more system-oriented approach to reducing dependence involves introducing **redundant or alternative PNT sources** that do not rely solely on GNSS.

Potential alternatives discussed by stakeholders include:

- **Terrestrial PNT systems**, such as eLoran
- **The Galileo Public Regulated Service (PRS)**
- **Low-Earth-orbit (LEO) satellite-based solutions**
- **R-Mode (navigation based on maritime radio signals)**
- **5G-based positioning and timing solutions**

These technologies vary significantly in maturity, coverage, precision and governance requirements. Measures in this category typically involve:

- large-scale infrastructure investments, and
- broader security or industrial policy considerations.

Stakeholders noted that such solutions would require clarification of:

- the state’s role and responsibilities,
- financing models, and
- cross-sectoral benefits and prioritisation.

15.5 Competence in Alternative Methods and Systems

Several interviewees highlighted the need to maintain and strengthen **competence in alternative PNT methods**, both technical and operational.

This includes:

- knowledge of non-GNSS navigation techniques,
- understanding of fallback procedures and manual operations, and
- training in recognising and handling GNSS disruptions and spoofing events.

In some sectors, alternative methods still exist but are rarely used in practice. Over time, reduced use leads to degraded competence and increased reliance on automation. Maintaining competence therefore requires:

- regular exercises and testing, and
- integration of PNT disruption scenarios into training and preparedness activities.

15.6 Governance Models and National Strategy

Many stakeholders emphasised that dependence on satellite-based PNT services is a **cross-sectoral issue** that cannot be addressed effectively through isolated, sector-specific measures alone.

Suggested governance-related measures include:

- clearer national roles and responsibilities for PNT resilience,
- improved coordination between sector authorities,
- national guidelines for robustness and redundancy, and
- development of a coherent **national PNT strategy**.

Such a strategy could help ensure that:

- measures with public-good characteristics are appropriately supported, and
- investments that benefit multiple sectors are evaluated and prioritised holistically.

Clearer governance could also support alignment between civilian resilience measures and broader security and defence considerations.

15.7 Measures and Stakeholder Input

Based on interviews and stakeholder dialogue, the following **illustrative measures and directions** were highlighted as potentially relevant for reducing vulnerability to GNSS outages, disruptions and manipulation:

- development of a coordinated national GNSS monitoring and alerting capability,
- establishment of a GNSS-independent national time service,
- development of guidelines for minimum holdover capacity in critical sectors,
- improved robustness requirements for GNSS receivers used in critical operations,
- continued practical testing and exercises related to GNSS disruption and spoofing, and
- further assessment of complementary or alternative PNT technologies.

Stakeholders emphasised that managing PNT dependence requires a combination of:

- technical measures,
- organisational arrangements, and
- improved information sharing.

Chapter 15 Summary

The analysis shows that satellite-based PNT services are deeply embedded in modern societal infrastructure, delivering substantial efficiency gains but also introducing systemic vulnerabilities.

The quantitative cost estimates illustrate the scale of direct economic impacts from outages, while sector analyses and stakeholder input reveal broader **systemic dependencies and resilience challenges**.

Reducing vulnerability therefore requires a **portfolio of measures**, combining:

- increased robustness in existing systems,
- improved situational awareness,
- enhanced time resilience,
- selective redundancy and alternative PNT sources, and
- stronger governance and cross-sectoral coordination.

Appendix A: Further Detail on the Calculation of Socio-Economic Costs Associated with Loss of PNT Services

This appendix provides a more detailed description of the calculation methods used to estimate the socio-economic costs associated with loss of satellite-based PNT services in the various sector analyses presented in Chapters 5–13.

The purpose of the appendix is to:

- clarify underlying assumptions,
- document data sources and calculation logic, and
- increase transparency and verifiability of the cost estimates.

All calculations relate to the **main scenario of a continuous seven-day loss of satellite-based PNT services** and capture **direct, first-order effects** only, in line with the methodological delimitations described in Chapter 3.

Unless otherwise stated, all monetary values are expressed in **2024 NOK**.

General Methodological Principles

Across sectors, socio-economic costs are estimated using a combination of:

- sector-specific production data and value-added statistics,
- assumptions regarding efficiency loss or activity reduction during a PNT outage,
- standard valuation methods for time use, accidents and material damage, and
- qualitative input from interviews with sector actors.

The calculations aim to represent **average effects** across each sector and are therefore subject to uncertainty. The estimates should be interpreted as **orders of magnitude**, not precise figures.

The following general principles apply:

- Only costs occurring during the seven-day outage (and short-term immediate effects) are included.
- Indirect value-chain effects and macro-economic feedbacks are excluded.
- Behavioural adaptation is taken into account where relevant, but conservatively.

- Where precise quantification is not possible, impacts are described qualitatively in the main report.

Maritime Transport

For maritime transport, costs are calculated based on:

- estimated reductions in operational efficiency,
- increased fuel consumption and delays, and
- increased accident risk due to reduced navigational precision.

Efficiency losses

Efficiency loss is estimated based on interviews with shipping companies and port authorities. A reduction in navigational precision leads to:

- more conservative sailing,
- longer routes,
- increased waiting time in ports, and
- reduced regularity.

The assumed efficiency reduction is applied to sectoral value creation to estimate lost value added over the seven-day period.

Accidents and safety-related costs

Increased accident risk is estimated using historical accident statistics for grounding, collision and contact damage. The analysis assumes an increase in the probability of such events during a PNT outage.

Socio-economic costs are calculated using standard valuation of:

- fatalities,
- personal injuries, and
- material damage.

Petroleum Industry

Costs in the petroleum sector are driven by near-complete loss of productivity in GNSS-dependent offshore operations.

The calculation distinguishes between:

- offshore supply and service vessels,
- seismic survey operations,
- construction and installation activities, and
- mobile drilling operations.

For each activity, an **average efficiency loss of approximately 90 %** during the outage period is assumed, reflecting that most operations must be suspended or operate at minimal levels without reliable positioning.

Production from fixed installations is assumed to continue largely unaffected in the short term and is therefore excluded from the cost estimate.

Value loss is calculated by applying activity-specific efficiency reductions to estimated daily value creation.

Seafood Industry

In the seafood sector, calculations are differentiated by fishing method:

- gillnets,
- pots,
- trawling, and
- purse seine.

The analysis assumes that fishing activity continues, but with **reduced efficiency** due to:

- loss of precise navigation,
- inability to accurately locate fishing gear,
- reduced ability to map fishing grounds, and
- weaker coordination between vessels.

Efficiency reductions vary between methods, with offshore and gear-intensive fisheries affected more strongly than coastal operations.

Socio-economic costs are calculated by applying estimated efficiency losses to annual value creation, scaled to a seven-day period.

Road Transport

For road transport, costs are calculated based on four components:

1. increased travel time for road users,
2. increased vehicle operating costs (fuel, wear and maintenance),
3. increased congestion in urban areas, and
4. reduced productivity in road construction and maintenance.

Travel time

The value of lost travel time is calculated using:

- total driven kilometres,
- assumed reduction in route efficiency due to loss of navigation services, and
- standard valuations of time per hour for different user groups.

Construction and maintenance

Productivity losses in construction are based on estimated reductions in efficiency when GNSS-based machine control and surveying are unavailable, requiring more manual methods.

Aviation

Aviation costs are calculated based on:

- increased delays,
- increased cancellations, and
- associated passenger and operator costs.

The analysis differentiates between:

- large airports with significant redundancy, and
- smaller, GNSS-dependent regional airports.

Passenger costs are valued using standard valuations of travel time and cancellation inconvenience. Operator costs reflect increased fuel use, crew costs and operational disruption.

Rail

Railway costs are limited and relate primarily to:

- increased delays, and
- minor increases in cancellations.

Safety-critical functions are assumed unaffected. Costs are calculated using:

- observed punctuality data,
- assumptions about increased disturbance during GNSS loss, and
- standard values for passenger travel time.

Emergency Services

For emergency services, socio-economic costs are estimated based on:

- increased response times due to loss of automatic caller location (AML), and
- reduced efficiency in vehicle navigation and dispatch.

The valuation relies on established estimates of the socio-economic cost of delayed emergency response, recognising the strong relationship between response time and outcomes for life and health.

Electronic Communications, Power Supply and Finance

For electronic communications, power supply and finance, no direct costs are quantified for the seven-day scenario.

This reflects:

- substantial redundancy and holdover capacity, and
- the ability to maintain operational continuity in the short term.

However, Appendix A reiterates that **systemic and indirect effects** remain significant and are discussed qualitatively in Chapters 4 and 14.

Agriculture

Agricultural costs are calculated based on:

- reduced operational efficiency without GNSS-based auto-steering,
- increased fuel and input use, and
- increased labour requirements.

Production is assumed to continue, but at lower efficiency. Costs are scaled to a seven-day period and averaged across the sector.

Construction and Civil Engineering

Costs in construction are driven by:

- loss of GNSS-based surveying and machine control,
- reduced execution speed,
- increased rework and material use.

Efficiency loss assumptions are applied to sectoral value creation to estimate lost productivity during the outage period.

Consumer Products and Services

Costs for consumer products and services are based on:

- reduced efficiency of navigation and location-based services,
- minor productivity losses, and
- increased time use for consumers.

The estimates are conservative and reflect rapid behavioural adaptation.

Concluding Remarks on Methodology

Appendix A demonstrates that:

- the largest quantified costs arise where PNT services are embedded directly in production, and
- sectors that appear to have low direct costs may nonetheless be system-critical through indirect dependencies.

The methodological approach provides transparency and consistency across sectors, while recognising that the most severe risks associated with PNT loss relate to **systemic, cross-sectoral effects** that are not fully captured in quantitative estimates.

Appendix B: Overview of Interviews

This appendix provides an overview of the interviews conducted as part of the information-gathering process for the socio-economic analysis of satellite-based PNT services.

The interviews supplement statistical data and literature by providing qualitative insight into:

- how PNT services are used in practice,
- sector-specific dependencies and vulnerabilities, and
- operational and organisational consequences of loss, disruption or manipulation of PNT services.

The interview material has been used as an input to the sector analyses presented in Chapters 5–13, as well as the cross-sectoral assessment in Chapters 4 and 14.

Interview Scope and Selection

Interviews were conducted with more than **40 organisations and actors**, selected to ensure broad coverage across:

- relevant sectors,
- different roles in the value chain, and
- both public and private stakeholders.

The selection was strategic rather than statistically representative and focused on actors with:

- operational responsibility,
- infrastructure ownership,
- regulatory or sectoral oversight roles, or
- technical expertise related to PNT services.

Coverage by Sector

The interviews cover actors from the following main sectors and functional areas:

- **Maritime transport and shipping**
- **Petroleum and offshore activities**
- **Seafood and fisheries**
- **Road transport and logistics**
- **Aviation**
- **Rail transport**
- **Emergency services and preparedness**
- **Electronic communications (telecom)**
- **Power supply and energy**
- **Finance**
- **Agriculture**
- **Construction and civil engineering**
- **Public authorities and regulators**
- **Technology providers and competence environments**

Within each sector, interviews typically included a mix of:

- operators and service providers,
- infrastructure owners,
- sector authorities and regulators, and
- technical or operational specialists.

Form of the Interview Overview

In the original Norwegian report, the interview overview is presented as a **tabulated list**, summarising for each interview:

- sector or functional area,
- type of organisation (e.g. authority, operator, infrastructure owner, technology provider),
- general role or responsibility.

Individual interviewees are **not named**, and statements are **not attributed** to specific organisations in the report. All interview input is treated anonymously and aggregated in the analysis.

Use of Interview Material

The interview material has been used to:

- validate assumptions used in the quantitative calculations,
- identify sector-specific operational dependencies,
- assess availability of fallback solutions and redundancy, and
- highlight system-level and cross-sectoral vulnerabilities not visible in statistics alone.

Interview insights were particularly important in assessing:

- efficiency losses during PNT outages,
- feasibility of alternative methods in short-term scenarios, and
- sensitivity to manipulation of time and position signals.

Concluding Note

Appendix B serves as documentation of the empirical basis for the analysis and demonstrates the breadth of stakeholder involvement across sectors.

The overview supports transparency but does not constitute a source of standalone findings; all analytical conclusions drawn from the interviews are presented in the main chapters of the report.