General Lighthouse Authorities

The United Kingdom and Ireland

Marine Navigation Plan 2040

Commissioners of IRISH LIGHTS | Navigation and Maritime Services

Northern Lighthouse Board

TRINITY HOUSE

Contents

Table of figures

The General Lighthouse Authorities (GLA) are responsible for aids to navigation in the United Kingdom and the Republic of Ireland. They are divided into regions as follows:

The Commissioners of Irish Lights, known as Irish Lights (IL), for all of Ireland;

The Commissioners of Northern Lighthouses, known as the Northern Lighthouse Board (NLB), for Scotland and the Isle of Man; and

The Corporation of Trinity House, known as Trinity House (TH), for England, Wales, the Channel Islands and Gibraltar.

The GLA operate a shared research and development department (GRAD) which is recognised as an international centre of excellence on Visual and Radio Navigation, as well as emerging digital AtoN services, and will play a key role in the delivery of this GLA Maritime Navigation Plan.

Photo by **Scott Tacchi**

1 Executive Summary

Through the Merchant Shipping Acts (MSA) and other legislation, the UK and Irish governments have empowered each of the GLA to meet their obligations under the Safety Of Life At Sea (SOLAS) Convention. To meet these obligations against an ever-changing maritime environment, the General Lighthouse Authorities of the UK and Ireland (GLA) undertook a detailed assessment of the likely threats and opportunities facing the GLA on the way to 2040. Making a clear commitment to meet their obligations, a strategy document was formed, *GLA Strategy 2040: Navigating the Future*.

This *GLA Marine Navigation Plan 2040* takes this further, by outlining a combined plan of action to achieve each aspect of the strategy. It closely follows the core themes explored in the strategy, addressing each aspect of the full marine aids to navigation (AtoNs) mix. It highlights key steps and the work to be done to successfully deliver against every part of the strategy.

Navigating successfully to 2040 means continuing to provide their trusted services that keep mariners safe, against a backdrop of rapid change to technology, the maritime environment, and mariners themselves. Achieving this will require careful management of legacy GLA assets and estates, whilst incorporating innovation through every element of GLA operation to be agile to these changes.

Particular key trends have been identified that will impact the operations of the GLA. **A shared and changing sea-space** will bring increased congestion in both a physical space and digital bandwidth perspective, and a shifting vessel mix will require higher performance AtoNs and supporting systems. **The future mariner** may be quite different from today, with consumer technology and greater access to data-rich situational awareness for all mariners emboldening them further offshore, and the rise of autonomy giving rise to future 'robot mariners'. The external pressures of **global politics and changing legislation** will have implications for cross-border international working, and could threaten accidental or intentional disruption to GLA technology and services. The GLA have identified how their operations must be made resilient to the threats of **climate change**, and are committed to pro-actively meet their net zero obligations and reduce the impact from their operations on the environment.

Many of the objectives will be achieved through the smart management of technological change, requiring both focused investment in beneficial technology and responsive safeguarding against technological threats. This plan addresses the full mix of GLA technology, including both visual and digital AtoNs, and presents plans for individual devices alongside the broader systems they sit within. This plan groups these into four key technology areas:

- Physical infrastructure;
- Visual signalling;
- Resilient Position, Navigation, and Time;
- Maritime digitalisation & connectivity services.

Of equal importance is strategic partnering and collaboration with national and international government and organisations, where the GLA will maintain its trusted role in providing expert advice and direction in policy creation and management. This plan outlines how the GLA will continue to foster its relationship with these partners and enhance co-working. With increasing responsibilities as data-authorities, new obligations may arise for the GLA to share data with our partners, whilst also allowing mutual benefit to come from exploiting novel big data techniques to enhance service provision.

2 Introduction

2.1 Introduction

The *GLA Strategy 2040: Navigating the Future* document outlined the vision of the General Lighthouse Authorities of the UK and Ireland to meet their commitment to provide safe passage for all mariners against the backdrop of an ever-changing landscape. The main strategy is:

Leverage trusted agent status, experience and understanding of emerging technology to provide the maritime community with thought leadership.

Influence the development of regulations and policy to support the evolving use of the maritime sea-space and the ever-growing complexity associated with the change in vessel types, operations and the introduction of autonomy.

Grow government and academic support for research into innovative e-Navigation, marine data infrastructure, physical aids, and PNT and Data resilience as part of the GRAD programme.

Hasten the GLA reduction in emissions to support a net zero carbon footprint by 2050 and the adaptation of the AtoN estate in response to the impact of climate change.

Transform AtoN services to ensure they continue to provide reliability, efficiency, cost effectiveness and relevance in an evolving, complex, sea-space.

Highlight the users of AtoN and services in emerging blue-economy roles and seek opportunities to collaborate, in pursuit of government aims and objectives.

Optimise the GLA physical infrastructure for future data-enabled support of safe navigation and maritime operations.

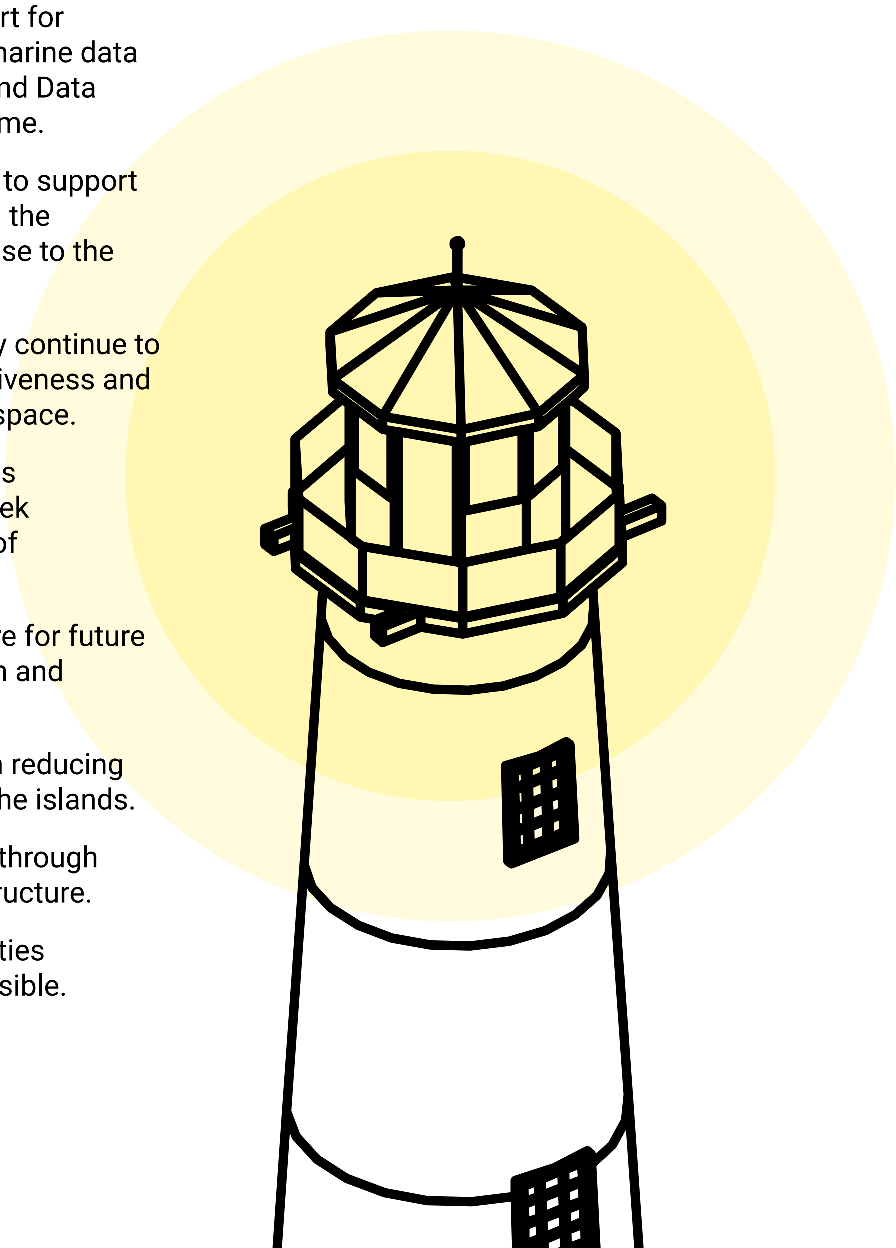
Understand the role the GLA can play in reducing the impacts of climate change across the islands.

Support mass data connectivity at sea through exploitation of the GLA physical infrastructure.

Ensure government SOLAS responsibilities continue to be met as efficiently as possible.

This *GLA Marine Navigation Plan 2040* outlines how this strategy will be achieved. To achieve these strategic aims, the GLA will continue to **improve their understanding** of the needs of all mariners, enhance knowledge and continuously innovate **new technology**, build upon **partnerships and enhance collaboration**, and use this to provide expert guidance and **thought leadership**.

Underpinning these core elements is the highly skilled workforce of the GLA. Whilst a full discussion of the workforce strategy falls outside the scope of this document, the GLA recognise that investment into the training and development of its people is pivotal to achieving the successful delivery of the ambition within this plan.



The GLA places significant importance on addressing climate change, with a clear commitment to reduce the impact of their operations on the environment

2.2 Structure of the GLA Marine Navigation Plan

The plan consists of three core elements:

Thought leadership, partnering and advisory roles

Collaboration, partnering, and knowledge sharing are critical across all aspects of the plan. The GLA will seek to reinforce its current relationships, and this section outlines the key aspects of maintaining and building upon its thought leadership roles.

Technology

Development, management, and knowledge of technology will be a core enabler and protector of GLA services, and a broad range of research and development activities will support every aspect of GLA operation.

This section outlines the key technology plans against four broad technology themes:

- Physical infrastructure;
- Visual signalling;
- Resilient Position, Navigation, and Timing;
- Maritime digitalisation & connectivity services.

Climate change

The GLA places significant importance on addressing climate change, with a clear commitment to reduce the impact of their operations on the environment, and carrying out operations in a sustainable manner including addressing climate change .

This section outlines the approach in three main areas:

- Gradual and long-term effects;
- Climate change induced events;
- Biodiversity and sea chemistry.

3 The impact of the 2040 trends on the navigational requirement

The GLA have a shared mission statement:

"To deliver a reliable, efficient, and cost effective AtoN service for the benefit and safety of all mariners."

Whilst this mission remains constant through to 2040, the changing landscape requires the GLA to adapt to continue to achieve this mission and meet its obligations. To provide reliability across services, efficiency across operations, and to support every mariner, understanding the trends and making robust plans of action will be necessary.

This section outlines the overall impact of the trends on the Navigational Requirement, and the key aspects of the trends that need to be planned for.

3.1 Navigational Requirement to 2040

The Navigational Requirement is the overall set of requirements that emerge from the GLA meeting the joint mission statement, and covers the entirety of their responsibilities. It is therefore both broad and complex, but key areas are summarised as:

Contributing to the provision of safe sea-space

The sea-space and the physical area the GLA cover; are

(a) Trinity House, England, Wales, the Channel Islands and Gibraltar;

(b) Commissioners of Northern Lighthouses, Scotland and the Isle of Man;

(c) The Commissioners of Irish Lights, Ireland and Northern Ireland.

The extent of coverage for the UK is laid out in the Merchant Shipping Act 1995 as amended by the Marine Navigation Act 2013: *"any of the areas for the time being designated under section 1(7) of the Continental Shelf Act 1964 as waters within which the jurisdiction and rights of the United Kingdom are exercisable in accordance with Part XII of that Convention for the protection and preservation of the marine environment*". This in effect is the Exclusive Economic Zone (EEZ) of the UK.

In Ireland the extent of GLA coverage is laid out in the Merchant Shipping Act 1894 as "Throughout Ireland and the adjacent seas and islands". Further, in the Merchant Shipping (Commissioners of Irish Lights) Act, 1997 it is stated that "The Commissioners shall have, and be deemed always to have had, in relation to the provision or operation of a radio navigation system or any service anywhere relating to maritime navigation, safety, distress, wreck location, pollution or related matters, power to co-operate, with the consent of the Minister, with a competent authority of another jurisdiction, an international organisation or body or another person."

In this sea-space, the GLA will:

- Provide the mix of physical AtoN and digital services required as part of a system of systems approach to navigational safety;
- Continually review and assess the volume of traffic and degree of risk within our waters;
- Assess and respond to wrecks and new dangers;
- Retain a core role in influencing the development and implementation of Position, Navigation and Timing policy;
- Provide quality assurance and statutory consent for third party AtoN services;
- Review and update the data and communication services we use and provide;
- Engage a range of stakeholders.

Assessing the needs of mariners in conducting safe and effective navigation

Ensuring the AtoN solutions we provide remain relevant to the modern mariner, including emergent autonomous vessels, the GLA will:

- Remain aware of the levels of training provided to Mariners and understand changes in trends in the application of navigation techniques, particularly as a result of the increasing digitisation of navigational services;
- Provide a universal service (for all vessels, SOLAS and non-SOLAS) of physical

AtoN to meet the volume of traffic and degree of risk obligation for all ships;

- Enhance physical AtoN for those with the appropriate equipment and digital services to receive and display digital signals (e.g. racon and AIS);
- Consider and support additional third party services such as meteorological and hydrographical visualisation service, where appropriate to do so;
- Provide superintendence services to third party AtoN providers and input into marine licencing, and to ensure hazards are placed and marked appropriately.

National and cross-border working

To provide a seamless and harmonised AtoN service internationally, the GLA will:

- Contribute to the development of legislation and policies associated with the safety of shipping;
- Remain engaged with national and international organisations concerned with shipping and navigation safety, in particular in the delivery of coastal state responsibilities for AtoN;
- Work in conjunction with neighbouring states in the delivery of AtoN provision across international borders.

Environment

To protect the environment, and mitigate and adapt to climate change, the GLA will:

- Understand the predicted impacts of climate change on GLA service provision and marine traffic;
- Deliver services and conduct operations in a sustainable and responsible manner;
- Innovate solutions for identified vulnerabilities to ensure continued AtoN service provision;
- Meet their legislative obligations and decarbonisation, biodiversity, and energy efficiency targets;
- Embrace opportunities to support third party conservation and sustainability initiatives across the GLA estate.

Technology and equipment

To ensure the GLA remain at the forefront of technological advances associated with shipping and navigation, the GLA will:

- Maintain a range of physical AtoN as part of the system of systems and will support the development of new AtoN to meet the requirements of an increasing digitised sea space;
- Monitor external technological developments and assess their impact on GLA services, and adopting these where appropriate to support the mariner. Particular focus will be given to developments in autonomy, AI, and Machine Learning that will impact on navigational techniques;
- Proactively research and develop technology to meet the needs of the GLA, maintaining its technical leadership and expertise;
- Safeguard legacy technology against emerging threats (including obsolescence management) to ensure availability targets are maintained;
- Share and collaborate on GLA technology with stakeholders where appropriate, to maximise technology harmonisation. Actively participate and offer thought leadership on relevant technology groups, committees, and panels.

3.2 Key trends to plan for

The strategy identified five key trends to be considered across the plan, and these map directly to the Navigational Requirement in Section 3.1 as follows:

1. **Contributing to the Provision of Safe Sea-space** > A shared and changing sea-space;
2. **Assessing the Needs of Mariners in conducting Safe and Effective Navigation** > The future mariner;
3. **National and Cross-border working** > Global politics and changing legislation;
4. **Environment** > Climate change;
5. **Technology and equipment** > Technology change.

The key impacts of the trends are summarised in Figure 1.

Trend: A shared and changing sea–space [Strategy section 4.1, page 12]

SUMMARY OF RISKS & RATIONALE	GLA APPROACH TO MITIGATE NAV. RISK	ASPIRATIONAL 2040 GLA REQUIREMENT
An increasing congestion of shipping space will place greater reliance on accurate, precise, and reliable position and navigational information.	This will necessitate resilient PNT technology to ensure that the mariner is aware of their position and heading, and be made aware when this information is unreliable.	GLA to provide a service to advise mariners of the operational status of PNT systems in use within UK and Ireland. > Section on Resilient Positioning, Navigation, and Timing and Situational Awareness Systems (RPNT & SA Systems)
Existing conventional AtoN remain a fundamental part of the AtoN mix due to the explicit feedback from users about their effectiveness.	The use of conventional AtoN is entirely decoupled from all forms of electronic navigation, and can be used as a reliable confirmation of position by visual means. This adds to the 'system of systems' approach to aids-to-navigation provision.	Maintain existing physical and visual aids-to-navigation. > Section on Physical Infrastructure and Visual Signalling
A significant increase in data use and size across maritime users will increase communication demand and create digital congestion.	In order to provide an effective service to the mariner, the GLA needs to further understand how mariners consume key safety information, so that critical AtoN information provided by the GLA is not lost in the noise of information.	GLA provides critical up-to-date AtoN information to the mariner using effective electronic methods of communications and portrayal. > Section on Maritime Digitalisation & Connectivity Services
A changing traffic mix will need a robust and dynamic mix of AtoNs that can cater for the needs of a wide range of mariners.	The use of conventional AtoN means that no technology is required to use these aids-to-navigation, providing democratic access to safe navigation at sea for all users. These aids-to-navigation can be enhanced with additional electronic systems for vessels of higher risk due to size, weight or cargo.	GLA to provide a mix of physical and electronic systems to provide the mariner with a comprehensive, cost-effective AtoN service. > Section on Physical Infrastructure, Visual Signalling and RPNT & SA
Collaboration and data sharing between organisations will grow in importance to provide a holistic picture of the seascape, both for strategic and operational efficiency of service delivery.	A common format of data exchange is needed to maximise the efficiency and accuracy of communication. This would be a requirement between organisations, and if necessary, between the GLAs and vessels.	GLA to utilise agreed common data exchange formats to communicate aids-to-navigation to other organisations and users. > Section on Maritime Dig. + Con. Systems

Trend: The future mariner [Strategy section 4.2, page 12]

SUMMARY OF RISKS & RATIONALE	GLA APPROACH TO MITIGATE NAV. RISK	ASPIRATIONAL 2040 GLA REQUIREMENT
The expectation of the mariner to be able to access information anywhere or at any time, will increase their expectations on GLA services	The mariner should be at the centre of technology adoption and development, acknowledging that an increasing prevalence of advanced consumer technology will increase mariner expectation of technological capability at sea	GLA to provide aids-to-navigation services that serve the users according to industry norms. > Section on RPNT & SA and Section on Maritime Digitalisation & Connectivity Services
The emergence of vessels without crews, either autonomous or remotely piloted.	New AtoN technology, or modified existing AtoN, will need to be adopted to support machine-readable AtoN. With various degrees of autonomy – from remote piloting to full autonomy, a mixed environment with all types of vessel operating will need to be safe for all mariners.	GLA will have an autonomy-aware AtoN service that meets the needs of both human and machine mariners. > Section on Visual Signalling and Maritime Digitalisation & Connectivity Services
Mariners may have a changed skillset, with more reliance on electronic information	Greater accessibility and simplicity to the user in GLA communications will ensure correct translation and understanding by all mariners	GLA will actively participate in development of Maritime Digitalisation and S100 technologies, to ensure that GLA data is available in a common format. > Section on Visual Signalling and Maritime Digitalisation & Connectivity Services
With increasing complexity of ship and navigation systems, the ability of mariners to maintain spatial and situational awareness become more difficult. There will be increased sources of information available to the mariner, which may lead to 'information overload'	Human Factors should be considered across development of new digital technologies, to enhance accessibility and usability of systems for the mariner. With large datasets and sources, information should be tailorable and focused for the mariner	GLA to contribute to the development of aids-to-navigation information systems on-board vessels to ensure that critical and relevant information is made available to the mariner in the most effective way. > Section on Maritime Digitalisation & Connectivity Services

Trend: Global politics and changing legislation [Strategy section 4.3, page 13]

SUMMARY OF RISKS & RATIONALE	GLA APPROACH TO MITIGATE NAV. RISK	ASPIRATIONAL 2040 GLA REQUIREMENT
Policy and regulation developed on national and international committees may affect GLA operations.	Membership of key national and international bodies is required, to ensure that the needs of the GLA are incorporated throughout policy.	The GLA will maintain and grow its influence on a broad range of national and international committees. > Section on Thought Leadership
Technology, services, and response may be needed cross-border, involving working with a variety of stakeholders	To provide seamless and holistic services cross-border, collaboration with stakeholders should be supported where possible . The GLA will continue to work with neighbouring states to respond to operational AtoN and new danger response matters	The GLA will work seamlessly and effectively with stakeholders and neighbouring states. > Section on Thought Leadership
Political instability will introduce new risks of communication and digital service disruption, including via jamming and spoofing	A full cyber-safeguarding approach throughout GLA systems, identifying risk points in systems, incorporating mitigations, and utilising and providing authenticated data sources	The GLA will maintain cyber secure systems and be protected against cyber and physical threats. > Section on Maritime Digitalisation & Connectivity Services

Trend: Climate change [Strategy section 4.4, pages 13-16]

SUMMARY OF RISKS & RATIONALE	GLA APPROACH TO MITIGATE NAV. RISK	ASPIRATIONAL 2040 GLA REQUIREMENT
Emissions from GLA operations and real estate contribute to climate change. Emerging legislation obliges the GLA to mitigate these and reduce carbon emissions.	The GLA are committed to reduced emissions and work towards their net zero ambitions. This requires technological change across vessels, the real estate, increase AtoN energy efficiency and reduce carbon emissions.	To reduce emissions and meet carbon reduction targets. > Section on Climate Change
Long term effects of climate change, such as sea level rise and changes to sea currents and temperature, will threaten AtoN structures and GLA operations. Sea chemistry may alter, creating variations in salinity and ph	To identify and monitor long-term changes from climate change, to assess the impact on GLA assets and operations, and to adapt or mitigate where possible	Investment in climate change research focused on GLA operations, incorporating engagement with academia and SMEs. Implement adaptations and mitigations where possible. > Section on Climate Change
Climate change induced events, such as extreme weather episodes, may cause disruption and damage to GLA assets and services, with increased frequency, intensity, and duration	Understanding and modelling the changes expected in the local climate and weather condition will allow adaption of the AtoN mix in response. Close collaboration with hydrographical and meteorological bodies will further build knowledge and understanding	Investment in climate change research focused on GLA operations, incorporating engagement with academia and SMEs. Implement adaptations and mitigations where possible. > Section on Climate Change
GLA operations may negatively impact the natural environment and biodiversity. Conversely, the GLA real estate and offshore structures may be useful for biodiversity research	Positive and proactive action will be taken across the GLA to reduce the wider impacts of its operations on the environment and nature. Where possible, the GLA will support biodiversity initiatives across its estate	To minimise the impact of GLA operations to the natural environment and support biodiversity initiatives. > Section on Climate Change

Trend: Technology change [Strategy section 4.6 & 4.7, pages 16-21]

SUMMARY OF RISKS & RATIONALE	GLA APPROACH TO MITIGATE NAV. RISK	ASPIRATIONAL 2040 GLA REQUIREMENT
New and emerging technology may bring benefits to keeping the mariner safe, or bring benefits to GLA operations. In general, technology will need to provide greater availability, cost effectiveness, efficiency, usability, and be more sustainable.	Emerging technology, developed both in-house and externally, will be assessed and integrated into GLA systems and operations where appropriate. Particular benefit may be exploited from: Artificial Intelligence (AI), big data, and machine learning algorithms; New sensor systems, lights, and communications; Improved Size, Weight, and Power of equipment; and enhanced interoperability.	To research, develop, and integrate beneficial new and emerging technology to address future challenges. > Section on Technology
New and emerging technology may bring threats to maintaining mariner safety at sea, or disrupt or negatively impact GLA operations. Legacy equipment and assets may suffer from obsolescence issues, or may be exposed to new emerging threats	Research focus will be given to protecting against key emerging technology threats of: managing big data; obsolescence, manufacturing challenges and material scarcity; and increasingly advanced technological adversaries	To research and monitor emerging technology threats, and mitigating against these where possible. Condition and availability of technology for legacy equipment will be proactively managed. > Section on Technology
The altering vessel mix and changes to the maritime environment and mariner may necessitate a different technology mix. Standards for technology may alter over time	New technology will need to consider a wide range of vessels and age and capability of on-board equipment, changes to the mariner, and the GLA must align closely with international bodies on standards to ensure services are available widely	The needs of the user and the GLA organisations will be continuously assessed and incorporated into technology requirements. The GLA will engage across various technology fora and committees. > Section on Technology. > Section on Thought Leadership > Key committees

Photo by **Iain Jamieson**

4 Plan for thought leadership, partnering and advisory roles

The GLA will continue to provide expert opinion on safety in British and Irish waters in matters of AtoN planning, risk management, technology development, and solution implementation. This includes advising on the opportunities of technology ubiquity, AtoN development, and human factors in a period of generational change in technology, operations, and decision-making.

Whilst the overall responsibility for marine spatial planning lies with other bodies, the GLA are statutory consultees in the planning process. In partnership with other organisations, the GLA will ensure that the principles of safe and efficient navigation are recognised and maintained in national and regional marine plans that will be key to managing marine complexity.

Co-operation will be key to realising enduring safety around these islands. There is strategic benefit to the GLA seeking partnership, co-operation, and collaboration, developing their reputation for fresh thinking, developing new AtoN and digital infrastructure, pro-actively utilising existing and newly built ocean infrastructure to host services, all whilst maintaining safety at sea. To achieve this, the GLA will work with UK, Irish, and international bodies, private enterprise, and support collaborative research activities with academia.

The GLA will need to keep abreast of relevant changing legislation and seek to be actively involved in policy development that impacts their operations, and the GLA will maintain and enhance its role in developing standards through participation in international committees. The GLA will further underpin their reputation as expert advisors through publication to journals, presentations at international conferences, and through ongoing engagement with the wider media. Central to this will be development of their staff, through investing in career-long education and skill development.

4.1 Key stakeholders

Key bodies and organisations

- The UK and Irish governments (including Departments of/for Transport – DoT/ DfT), Scottish government, Senedd, Isle of Man and Gibraltar governments, and Bailiwick of Guernsey;
- The European Economic Area;
- The Maritime and Coastguard Agency (MCA) and the Irish Coast Guard (IRCG);
- The International Maritime Organization (IMO);
- The International Association of Marine Aids to Navigation and Lighthouse Authorities (IALA);
- International Hydrography Organization (IHO);
- UK Hydrographic Organisation (UKHO);
- National meteorological agencies (The Met Office, Met Éireann);
- Port authorities;
- Communication authorities (OFCOM, ComReg, Commission for Communications Regulation);
- Space agencies (ESA and UK Space agency)
- UK and Irish academia, SMEs, and commercial partners;
- Environmental and heritage bodies and charities (RSPB, NPWS, EPA, Marine Scotland, English Heritage)

It should be recognised that this is a non-exhaustive list, and that other entities not listed here may become key stakeholders for the GLA in the future.

4.2 Key committees for GLA participation

The following are key committees in which the GLA are proactively involved:

International Participatory Activities

- International Association of Marine Aids-to-Navigation and Lighthouse Authorities (IALA[1])
  - Engineering and Sustainability (ENG) Committee;
  - Aids-to-Navigation Requirements and Management (ARM) Committee;
  - Digital technologies committee (DTEC);
  - Vessel Traffic Services (VTS) Committee;
  - Policy Advisory Panel (PAP);
  - Legal Advisory Panel (LAP);
  - Council;
  - General Assembly.
- International Maritime Organization (IMO)
  - Maritime Safety Committee (MSC);
  - Subcommittee of Navigation, Communications and Search and Rescue (NSCR).
- International Electrotechnical Commission (IEC)
  - Technical Committee 80, Working Group 15 on VDES and AIS international testing standards development
- International Commission on Illumination (CIE)
  - Division 2 on Physical Measurement of Light and Radiation
  - Division 4 on Transportation and Exterior Applications

National Participatory Activities

- UK Safety of Navigation Committee
- Nautical and Offshore Renewable Energy Liaison (NOREL) Group
- Offshore Wind Evidence and Change Programme
- UK Maritime Steering Committee
- UK PNT Strategy Group
- UK Centre for Seabed Mapping
- Safety of Navigation Advisory Committee

[1] The GLA will continue to support IALA activities as its status changes from a Non-Governmental Organisation (NGO) to an Inter-governmental Organisation (IGO). Its name will change to the International Organization for Marine Aids to Navigation or IALA for short. [1].

5 Plan for GLA technology

5.1 Structure of the technology plans

This section outlines categories of technology of relevance to the GLA, referencing and building upon the theme outlines in the GLA 2040 strategy, but with a focus on how those trends are directing the research & development of each technology.

The technology themes discussed are:

- Physical infrastructure;
- Visual signalling;
- Resilient Position, Navigation, and Timing systems;
- Maritime digitalisation and connectivity services.

Following an introduction to each of these themes, each is explored further with the following sub-sections.

5.1.1 Key trends

Key trends and changes for this technology theme are drawn out, specifically relating to the technology areas identified in the GLA strategy Sections 4.6 & 4.7 (pages 17-21):

Responding to emerging technology benefits

- Artificial Intelligence, big data, and cloud computing [GLA strategy section 4.6a];
- New sensor systems, lights, markers, and communications [GLA strategy section 4.6b];
- Improved Size, Weight, and Power (SWaP) [GLA strategy section 4.6c];
- Interoperability [GLA strategy section 4.6d].

Responding to emerging technology threats

- Coping with big data [GLA strategy section 4.7a];
- Manufacturing, obsolescence, and material availability [GLA strategy section 4.7b];
- More technologically advanced adversaries [GLA strategy section 4.7c].

Additionally, the context of each technology against the non-technology aspects discussed in Sections 4.1-4.3 are also discussed:

Responding to non-technology drivers

- A shared and changing sea-space [GLA strategy section 4.1];
- The future mariner [GLA strategy section 4.2];
- Global politics and changing legislation [GLA strategy section 4.3].

The climate change driver is discussed separately in Section 6: Plan for the impact of climate change for the GLA.

5.1.2 Key technologies

This section outlines the key technologies of interest in this theme to the GLA.

5.1.3 Technology Maturity

The suite of technologies handled and researched by the GLA is vast, and incorporates various maturity levels. This creates a technology pipeline, ensuring that the tri-GLA commitment is met now and in the future in an ever-changing landscape.

Each technology has been given a maturity assessment as follows:

- ‘Maintaining’ – Technology that remains relevant that must be maintained as the world changes around it;
- ‘Retiring’ – Managing technology out of service.
- ‘Evolving’ – Where existing technology is expanding or changing significantly;
- ‘Emerging’ – Completely new concepts and techniques of relevance to GLA operations.

5.1.4 Timelines

In conjunction with the technology maturity assessment, each technology has been given an indication of the approximate timeframe that it is

For each technology, an assessment of the influence the GLA has in decisions made in the development and use of that technology, versus the impact that technology has on GLA operations

expected to mature and be available to use, around three time-frames:

- 'Now' – Where technology is already (or imminently) mature and available for use;
- 'Near-term' – Where technology will mature within the next decade;
- 'Long-term' – Where technology will mature beyond the next decade, but research is active or required in the nearer-term.

5.1.5 Influence vs Impact on the GLA

For each technology, an assessment of the influence the GLA has in decisions made in the development and use of that technology, versus the impact that technology has on GLA operations.

Each technology has been mapped using the scale shown in Figure 2. Whilst several factors will determine how resources are allocated to research, thought leadership, and maintenance tasks, it provides an approximate indication of how much resource it might attract. Technologies that have a greater impact on the GLA (the x-axis) will generally attract more research effort, whilst technologies where the GLA have considerable influence (y-axis) will draw more resource to discussion, decision-making, and collaborative activities. Where there is a high impact on the GLA but little influence, additional effort may be given to building reputation and liaising in order to build influence.

5.1.6 Key aims

This section will draw out the key tasks for the GLA to perform against this theme over the lifespan of this plan, sub-divided into two areas:

Technology development

Key technology concepts that need to be researched, developed, or retired to close gaps or respond to trends and drivers.

Participation in decision-making

Activities associated with decision-making and GLA influence on these matters.

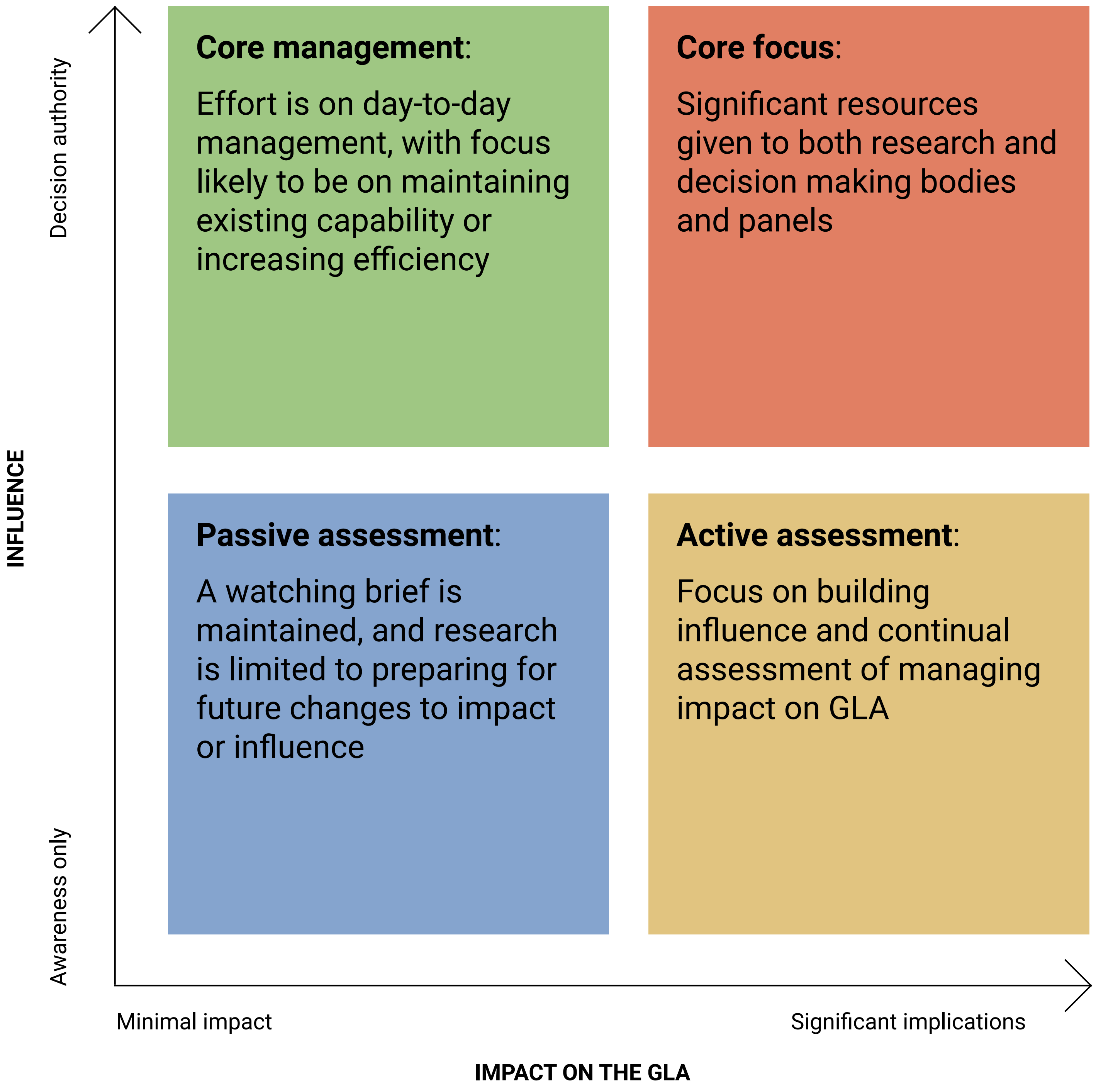


Figure 2: Influence vs. Impact on the GLA scale

5.2 Physical Infrastructure

Whilst electronic navigation is rapidly developing, with mariners able to utilise data from both satellite based and terrestrial systems. Traditional navigation methods using situational awareness gained from physical AtoN must remain at the core of seafaring, if the risk of over reliance on non-resilient data exists. This need for physical infrastructure to support general navigation around the coasts of UK and Ireland is expected to remain for the lifetime of this plan, although going forward this solution will be used in conjunction with on-board digital systems.

This section considers the wider physical construction aspects of AtoNs, for example maintaining lighthouse buildings, structures at sea, data centres, and facilities. For discussion of the visual signalling itself, see Section 5.3; for Resilient PNT technologies, see Section 5.4; and for maritime digitalisation & connectivity technology, see Section 5.5.

Floating AtoNs and Beacons

Buoys, light vessels and beacons are essential in providing the mariner with an incorruptible visual orientation, spatial awareness, waypoint, channel and hazard marking. Together, these physical AtoN provide a backbone of safe maritime navigation, and they must be designed and maintained appropriately to withstand the challenging sea environment. As well as these structures acting as a marker, various electronic equipment can be added to provide enhanced services such as the synchronisation and sequencing of lights, use as communication relays and as transmitters, and environmental data collection. Racons provide non-visual markers via the use of a vessel's radar.

Typical lifespan for floating AtoN buoys is 50+ years but this critical infrastructure is refreshed and recycled by the GLAs many times over, as paints and coatings will degrade from exposure to the elements, and physical joints, eyelets, and shackles will undergo wear and tear. Maintenance is performed by skilled technicians that clean, strip, repair, weld, and repaint them every 7-8 years. There is an ambition for buoys to stay at sea longer, ideally over ten years, before maintenance is required. Research and skill development to enhance maintenance practices and materials is needed to increase the durability to achieve this goal.

The visual appearance of the buoys must persist to an acceptable level[2] over this period. This is challenging, as over time the combined actions of sunlight, seawater, local weather, wildlife, and surface algae, lichen, and crustacean growth all degrade the paint, so that the markings are no longer conspicuous and identifiable. This necessitates improved paints, coatings, sealants, and application techniques.

Additionally, all electronic aspects must be able to survive the harsh marine environment, and maintain a high threshold of performance over the lifecycle of the buoy. Active research is exploring how this is achieved, with a particular focus on power technology that utilises solar charging in order to also meet the environmental targets.

In addition to buoys, some offshore hazards such as shoals and areas of high traffic density including traffic separation schemes, may require AtoN that are visible from a greater distance. In these instances, lightvessels and floats are currently used, but their lifespan is ending and the GLA will need to consider carefully their replacement including a detailed assessment of the required conspicuity.

Going forward, not all AtoNs may be physical, with the potential for more Virtual AtoNs to be deployed in particular to aid in situations where it is not possible or appropriate to provide a physical marker (or, in most cases, until one can be). Additionally, physical AtoN may also have digital profiles, allowing mariners to discover and interact with them and extract more information about them and their situation. Monitoring and telemetry technology will also share the condition of the AtoN, allowing early notification of faults and failures. However,

[2] As advised by IALA (applicable guidance found in linked guidance documents under Section 2 of [3])

security and authentication of these will need to be robust to emerging cyber threats.

Lighthouses and the GLA real estate

The overall real estate across the GLA is significant, with lighthouses remaining iconic centrepieces around the coasts of the UK and Ireland. Between the GLA, there are over 300 lighthouses, formed over centuries (the oldest operational lighthouse being Hook in Ireland, dating back to the 12th century) and positioned on the mainland or on isolated rocks offshore. Therefore, each station offers a unique prospect and design, but all must be maintained and kept operational against the backdrop of today's challenges.

A significant change towards the end of the last century was the change from lighthouse keepers to computer controlled operations, and thus the buildings are no longer inhabited for the majority of the year. The impact of this change on the internal condition of the buildings is currently under investigation, as respecting the heritage and importance of the buildings to local communities is recognised as important alongside their function as aids to navigation.

The advancement to the light technology used across lighthouses has also seen significant change within the lantern room, with lantern equipment greatly reducing in size and switching in most cases to LED technology. Additionally, the need to remove mercury bearings and the drive to reduce the risk of failure through moving parts while increasing efficiency, has reduced the need for rotating optics. Whilst minimum disruption is desired to reduce the risk of damage or structural change to the many listed lighthouses, as well as a perceived loss of technological heritage, it is essential to remove the mercury and its containers as this poses a health risk. A tenacious and bespoke approach is therefore needed for each lighthouse in the coming years that ensures the best service is provided for the safety of the mariner while preserving heritage as far as possible.

Lightning protection is also of continued importance to guard against damage in storms (for buildings and Light Vessels). With climate change potentially bringing more severe storm events to British and Irish coasts, it is also worthwhile to innovate ways of providing improved lightning protection for GLA assets, particularly for sites with challenging electrical arrangements or high risk maintenance processes.

Power technology

The typical peak power consumption for an AtoN demand is between watts to a few hundred watts. However, for lighthouses, the additional power needed to heat the building through colder months dwarfs this, with several kilowatts needed for this purpose.

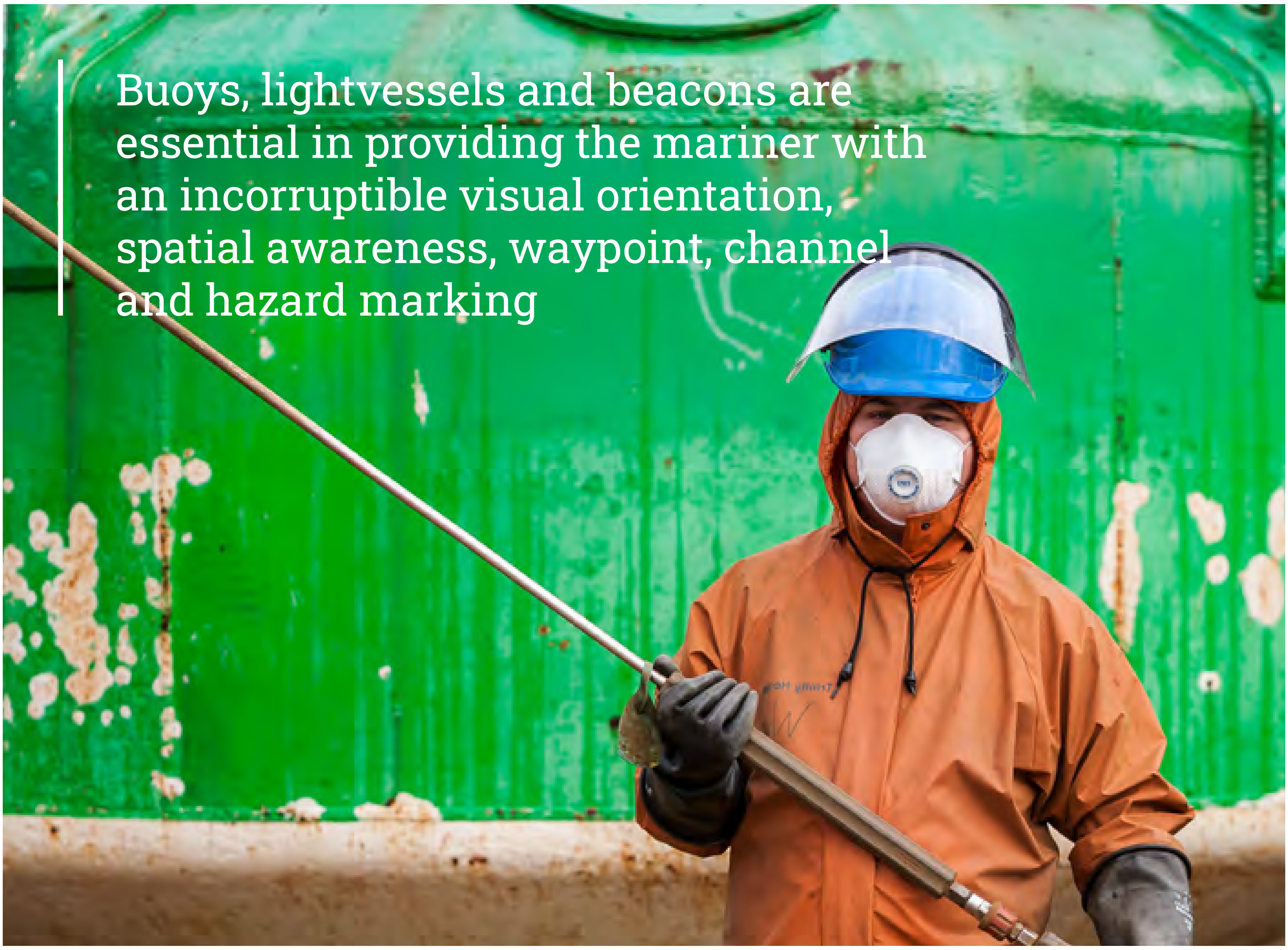
The GLA are committed to meeting their net zero emissions targets, which has led to diesel power to be removed in AtoN as widely as possible. The primary replacement system that has been established is using solar energy harvesting (Photo Voltaic technology), with research focusing on optimising efficiency, capacity, duration, and lifetime of the systems as technology advances. However, there are some instances where the use of off-the-shelf solar technology may not be suitable, for instance when there is insufficient land available for mounting the panels or there are aesthetic concerns with regards to the heritage of the site. For these instances, bespoke PV technology may be designed for the site to incorporate it onto the lighthouse in an architecturally respectful and discreet manner. Wind power has also been investigated and is in use to a lesser degree, with the focus of future research on making this robust to the harsh maritime environment.

Enhancements in battery technologies have also improved, and the full power generation and storage system should be optimised for use with solar and wind generation technologies. One alternative may be the use of fuel cell technology, which is developing rapidly due to widespread interest in using these to remove emission from vehicles and vessels. Current work is exploring their suitability for use within lighthouses.

Solar weather events present an additional risk to power supplies and electronics, as these can cause power grid outages and other hardware damage. However, this risk has been assessed as minimal to GLA assets, which generally have sufficient backup power systems in place to cover prolonged outages. However, as a greater use of satellite-based systems are used for timing and synchronisation tasks, and new cyber threats emerge that could disrupt power and electronics, this risk exposure should be regularly assessed and resilience built in to equipment.

Land-based technology assets

To support digital systems at sea, and broader navigation infrastructure, there is various monitoring and control systems in GLA operated data-centres. Additionally, research & development activities for marine AtoN require laboratory space and supporting computing and test equipment. Maintenance and management of these assets, along with investment and upgrades where needed, are an important aspect of delivering the technological changes needed going forward.



5.2.1 Key trends: Physical Infrastructure

Responding to emerging technology benefits

- New sensor systems, lights, markers, and communications:
  - › AtoNs may become more technologically capable as they become platforms for various communication, sensing, and data sharing/storage technologies.
  - › AtoNs will have a hybrid physical and digital identity and presence.
- Improved Size, Weight, and Power (SWaP):
  - › There is a drive to reduce the power consumption of AtoNs and lighthouses, and to explore and optimise energy generation and storage within them.
- Interoperability:
  - › AtoNs are evolving beyond simple visible markers, and will need to be present in both a physical and virtual sense.

Responding to emerging technology threats

- Coping with big data:
  - › As buoys become more digitally capable, they could have a greater role in data collection, distribution, and storage.
- Manufacturing, obsolescence, and material availability:
  - › Manufacturers are moving away from bespoke engineering, which may impact floating AtoNs. Although commercially available electronics and equipment may be available for use, the choice will be restricted by components that are able to cope with the harsh environment. Additionally, parts may become obsolete.
  - › The construction and maintenance of AtoN requires highly-skilled technicians, which necessitates a sustainable, well-trained workforce.
  - ›
  - › With the move away from traditional lanterns that use mercury, removal from lighthouses will be considered to enhance safety for maintenance personnel.
- More technologically advanced adversaries:
  - › Consideration of emerging cyber threats to AtoN power and control should be considered and protection built into equipment where possible (discussed further in Section 5.5).
  - › Virtual AtoNs may offer new benefits, but they are not displayable on all ECDIS, and potentially would only be visible to SOLAS vessels. Consideration must also be given to security aspects in order to prevent spoofing (discussed further in Section 5.5).

Responding to non-technology drivers

- The future mariner:
  - › Viewing 'mariners' may be human or machine, and AtoNs will need to support both in sharing the same sea-space.
- Global politics and changing legislation:
  - › The manufacture, maintenance, and material choice may be affected by changing legislation in relation to environmental and Health & Safety standards.

5.2.2 Key technologies – Physical Infrastructure

Physical AtoNs – Buoys, beacons, and Major Floating Aids (some with racon and AIS);

AtoN maintenance – Paints & Coatings, aluminium superstructure, plastic vs. metal buoys

Additional AtoN equipment – Zero emission power (inc. solar), more efficient electronics, better battery performance;

Digital AtoNs – Virtual AtoNs, Digital AtoN profiles, data exchange and security, resilience, authenticity, monitoring telemetry;

AtoNs may become more technologically capable as they become platforms for various communication, sensing, and data sharing/storage technologies

Lighthouse building & real estate – Novel zero emission power sources, building conditioning, lightning protection, mercury removal, helideck coatings;

Data centres & laboratories – Servers and network infrastructure, radio-navigation laboratory, lights laboratories, monitoring equipment and infrastructure;

Operations centres – 24hr AtoN monitoring, response services;

Novel technology – maintenance and operations using drone technology .

5.2.3 Timeline of key Maintaining, Retiring, Evolving, Emerging technologies – Physical Infrastructure

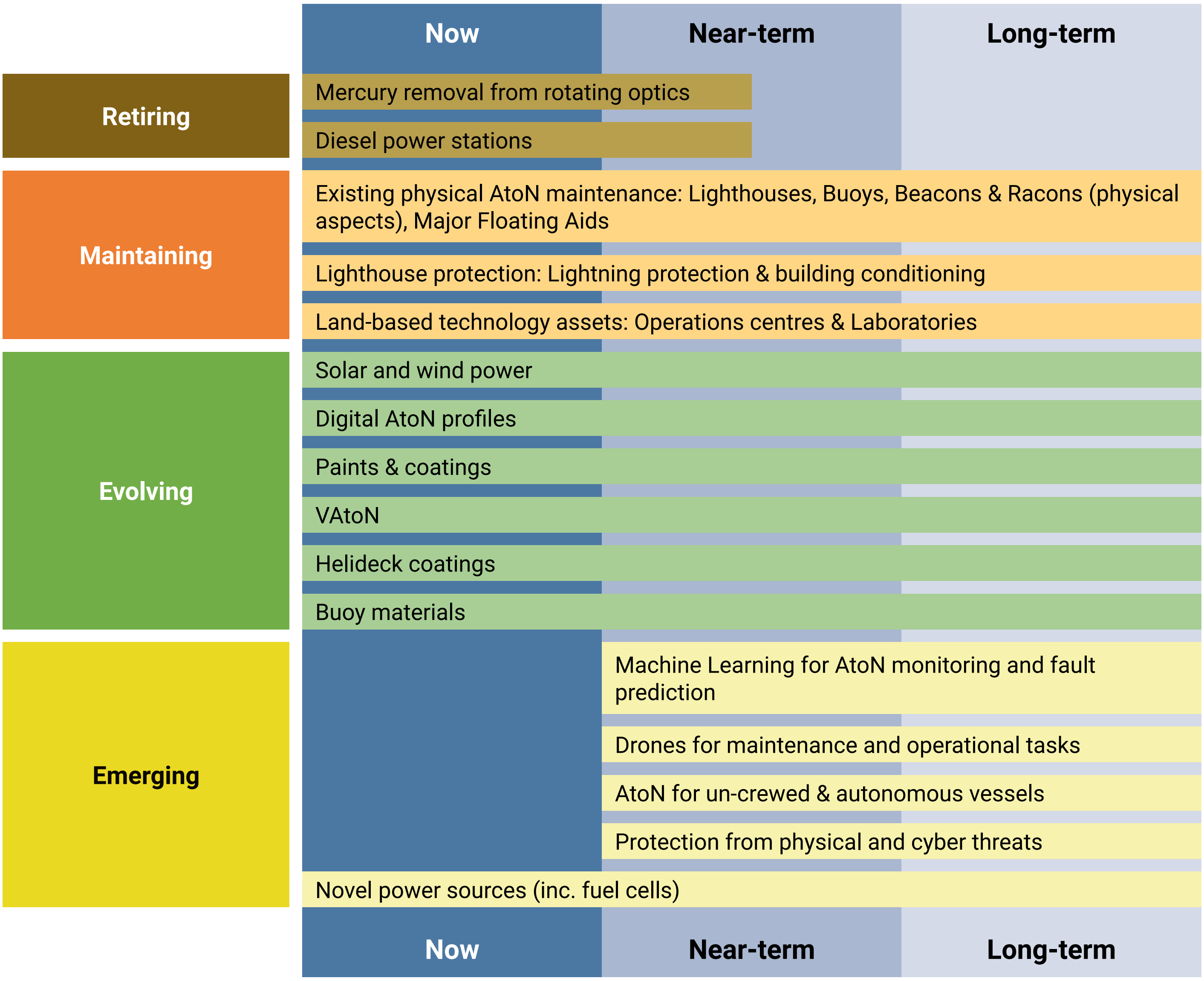
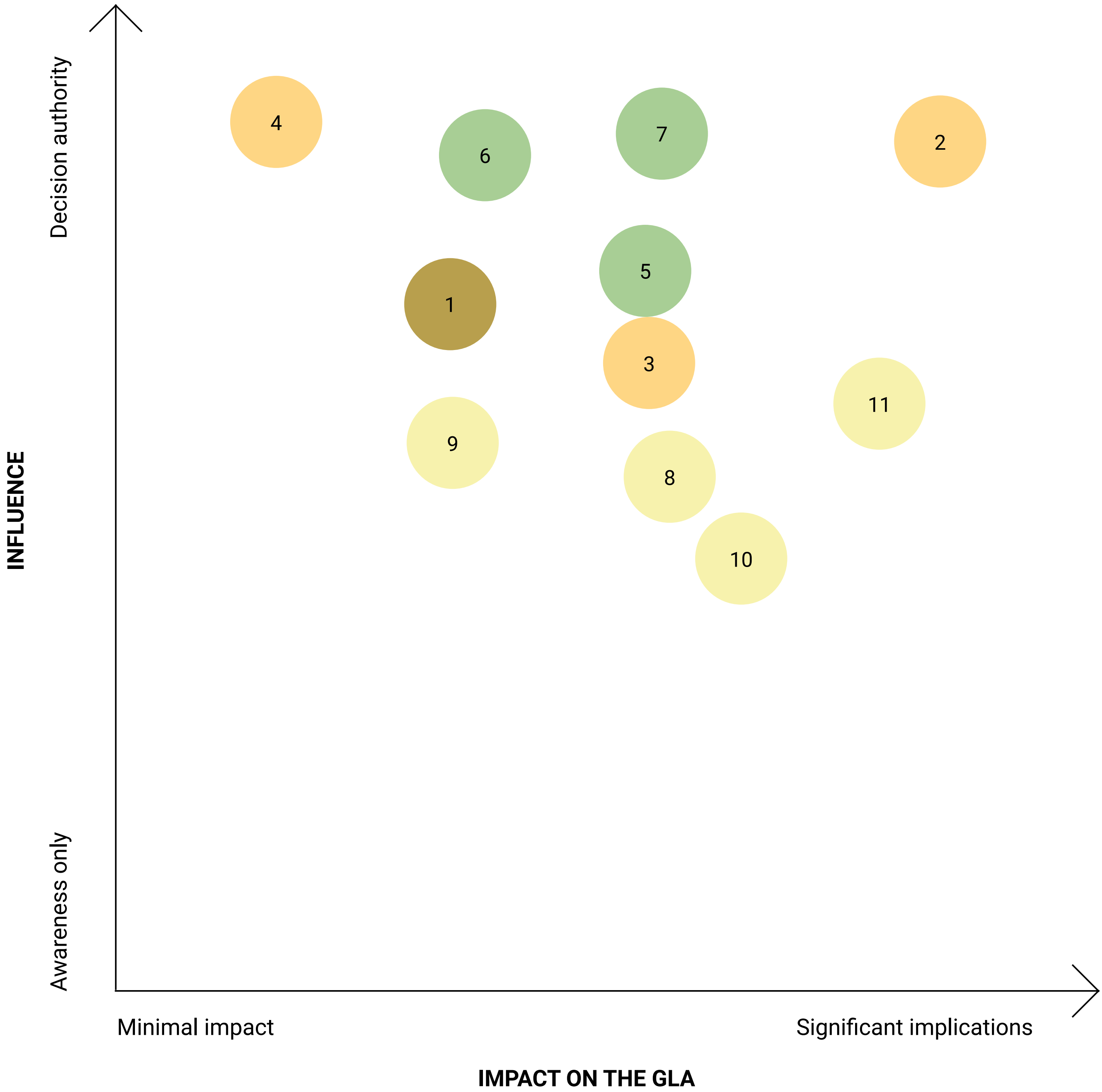


Figure 3: Timeline of physical infrastructure technologies

5.2.4 GLA Influence vs. Impact of Physical Infrastructure



- 1 Removal of diesel and mercury
- 2 Physical AtoN maintenance (fixed and floating)
- 3 Lighthouse protection
- 4 Land-based technology assets
- 5 Green and novel power
- 6 Digital AtoN profiles and VAtoN
- 7 Paints, coatings, & materials
- 8 Machine Learning for fault prediction
- 9 Drone use
- 10 AtoN for autonomy
- 11 Cyber & physical threat mitigation

Figure 4: Influence vs Impact graphic for physical infrastructure

5.2.5 Key aims: Physical Infrastructure

Technology development

- Maintain legacy physical infrastructure, enhancing and reinforcing where possible. This includes buoys, light floats, beacons, racons, lightvessels (and their replacements), and lighthouses
- Evaluating emerging technology and potential solutions to enhance performance, cost-effectiveness, and reduce emissions
- Innovating additional enhancements to physical AtoNs, potentially expanding capability with hybrid digital capabilities. Innovate new approaches to lightning protection
- Develop virtual AtoN capability and integrate with maritime digitalisation work
- Improve safety for personnel with the removal of mercury where possible from legacy equipment in lantern rooms
- Further develop modelling techniques to support design, planning, and maintenance tasks
- Improving the environmental impact of our physical AtoNs by striving for greater efficiency, bio-friendly material use, low emissions, and reduced waste
- Proactively meet our net zero obligations in lighthouses and across the real estate
- Investigate novel power systems for lighthouses and physical AtoN
- Proactively monitor physical infrastructure for obsolescence and produce a mitigation plan to prepare for retirement and replacement of services and technology
- Understand the impact of cyber, physical, and solar weather threats to power systems and build in resilience and protection across physical infrastructure

Participation in decision-making

- Lead on national and international bodies in relation to marine AtoN physical infrastructure, such as IALA, IMO, etc.
- Work in conjunction with partner organisations, such as MCA, UKHO, Irish Coast Guard, DfT, DoT, Scottish Government's Marine Directorate, Irish Maritime Area Regulatory Authority, Irish Marine Survey Office
- Proactively seek out and participate in appropriate joint innovation ventures, particularly with academia and SMEs

5.3 Visual signalling

Traditional visual signalling system such as lighthouses, buoys, and major floating aids will remain central to the GLA solution to navigation at sea. Therefore, significant focus will remain on the maintenance of existing assets and on increasing the efficiency of their use.

Novel visual signalling technology continues to emerge, with dedicated lights experts within GRAD assessing the potential of technology trends for the GLA, delivering both in-house innovation and rapid assessment of commercial technologies as they become available. Creating novel light sources has generated Intellectual Property, and invention and innovation continues to enhance light technology and improve the related services. Other emerging areas of interest include; creating 'smart' lighting and sequencing that responds to local light, weather, and traffic conditions; and monitoring the development of using light for high-bandwidth communications.

Advancements in lights and supporting technology are required to meet new legislative standards for net zero and climate change ambitions. New low-power systems, largely based on LED technology, have already been largely adopted in place of traditional lanterns across most light assets of the GLA. However, with technology advancements continuing, the need to design and introduce new light systems will continue. Each innovation must be vigorously tested to ensure it meets the same performance levels of the technology it replaces, and to ensure this is maintained over a suitable timeframe within the often-harsh maritime environment.

However, there are legacy light systems which may not be replaced with newer alternatives for some time, if at all, and so examining the reliability and resilience of existing systems will be needed to extend their lifetime. Predictive monitoring, and examination of failure rates should be considered, potentially using Machine Learning algorithms.

One particular new innovation is BinoNav. This is an innovate electronic navigation tool that encourages the mariner to look out of the window to increase their spatial awareness. Through a simple interface, BinoNav is able to mark the bearing that the mariner is viewing through the binoculars, and plot is on an electronic chart. This process, which is entirely independent from other on-board electronic positioning systems, allows the mariner to verify their location using traditional aids-to-navigation and other charted landmarks.

Ongoing research is required to enhance the conspicuity of day marks, in order to extend the range they can be seen, and ensuring correct interpretation by the mariner (especially with the desire to extend the time at sea of buoys - see Section 5.2). One emerging challenge is in understanding the AtoN conspicuity requirements of un-crewed and autonomous vessels. Whilst human observers can unconsciously interpret many visual markings that have degraded or been obscured, this becomes much more challenging for computers that must analyse imagery using rule-based algorithms. Research will be required to ensure these robot mariners are able to reliably navigate, and going forward, additional ways of marking may be needed that are tailored for these specifically.

Equally significant to the light system technology is the lights testing, which verifies the performance of light systems, ensuring that the GLA service is reliable and trusted. GRAD conducts lights testing in both purpose built light ranges, and with the unique capabilities to undertake testing directly in the field, assessing performance by examining the intensity, colour profile, and beam spread. Testing capability continues to improve due to investment in innovative new testing strategies and techniques. One particularly innovative approach under investigation is using drone technology to perform aerial lights testing.

Moving forward, this capability could be exploited by the GLA, by opening the use of these services to external organisations, providing further income and enhancing the GLA reputation as a trusted authority.

5.3.1 Key technologies: Visual signalling

Lighting technologies – Light sources (LEDs), lighting control, power;

Testing facilities – Light ranges for indoor testing of lights, field testing approaches, modelling, lights database, certification;

Novel concepts – Lights testing using drones, machine vision, BinoNav.

5.3.2 Key trends: Visual signalling

Responding to emerging technology benefits

- New sensor systems, lights, markers, and communications:
  - › Continual improvements to light technologies are occurring, producing more powerful and more efficient lighting sources.
- Improved Size, Weight, and Power (SWaP):
  - › LED technology has already delivered considerable SWaP savings, but power consumption will need to continue to reduce.

Responding to emerging technology threats

- Manufacturing, obsolescence, and material availability:
  - › Traditional lanterns have been largely replaced by LED technology, but work continues to ensure there is equivalent performance and to remove other legacy aspects of the lighting systems;
  - › Using commercial lighting components does present a risk of obsolescence.

Responding to non-technology drivers

- The future mariner:
  - › Developments in machine vision will be relevant with the rise of autonomy.
- Global politics and changing legislation:
  - › Increasingly strict environmental legislation is driving development for low-power lighting solutions.

5.3.3 Timeline of key Maintaining, Retiring, Evolving, Emerging technologies – Visual Signalling

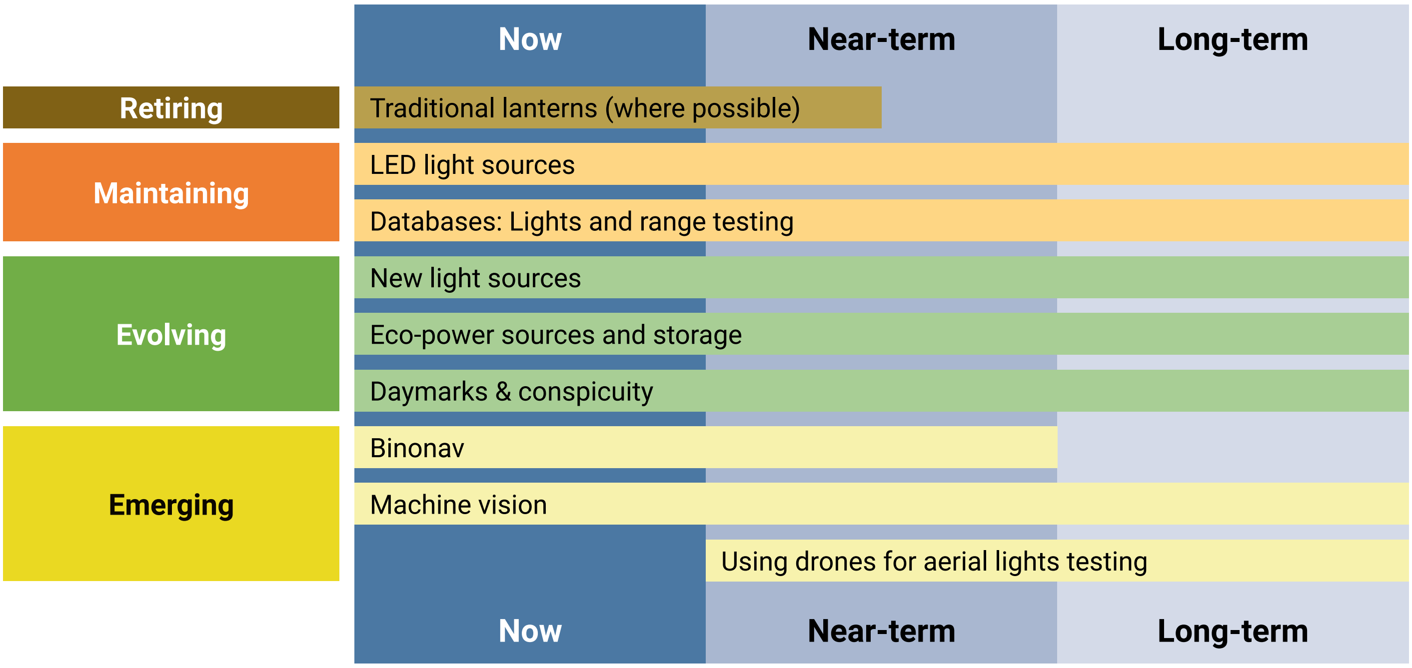
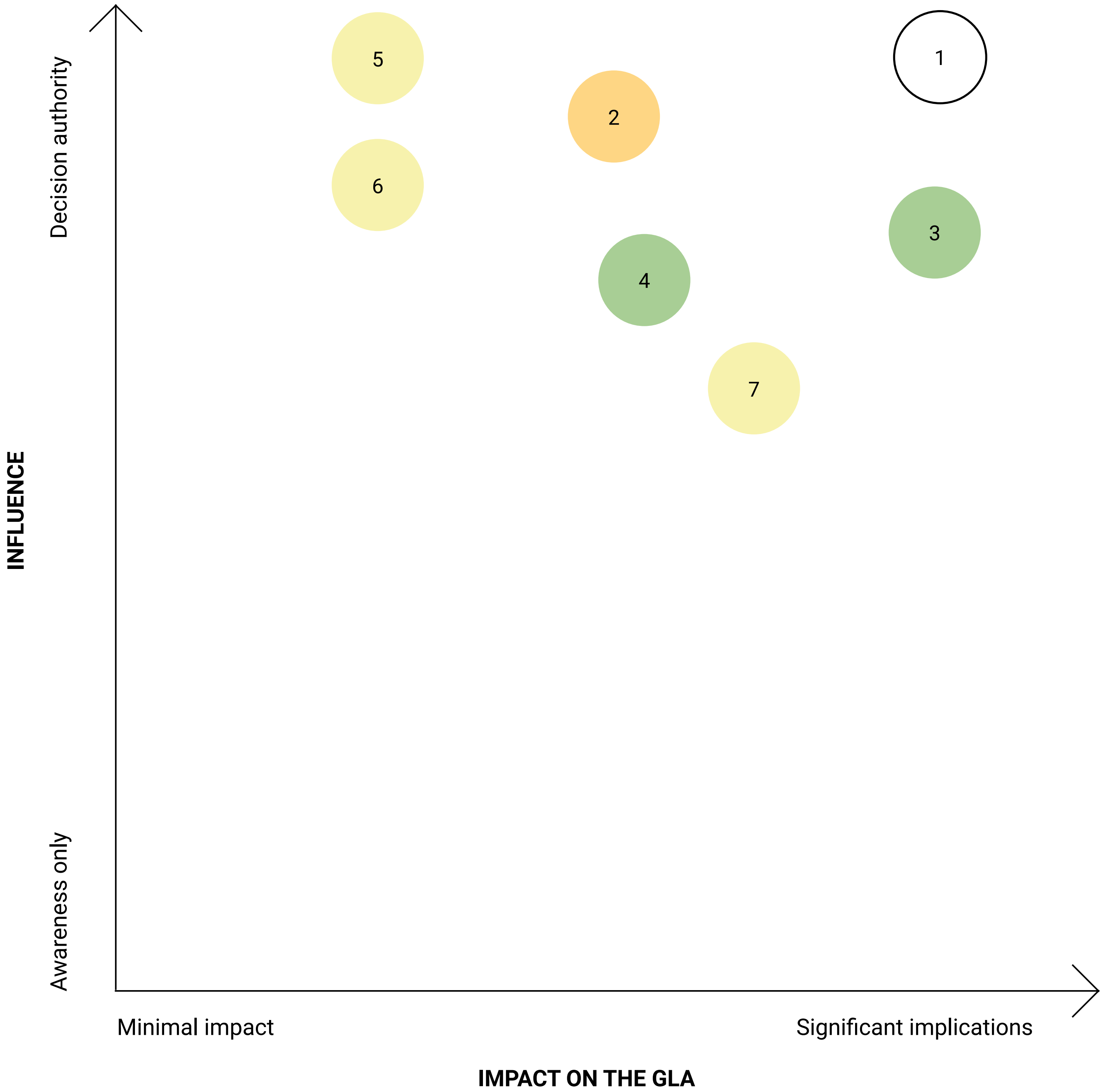


Figure 5: Timeline of Visual Signalling technologies

5.3.4 GLA Influence vs. Impact of Visual Signalling



1 Light sources

2 Databases: Lights and range testing

3 Eco-power sources and storage

4 Day marks & conspicuity

5 Binonav

6 Drone use

7 Machine vision

Figure 6: Influence vs Impact graphic for Visual Signalling

5.3.5 Key aims: Physical Infrastructure

Technology development

- Monitoring the evolving user requirements for lights, and work internationally to understand the future life and developments within the visual signalling domain
- Evaluating emerging technology and potential solutions to enhance performance, cost-effectiveness, and reduce emissions
- Innovating new light sources and technology, and exploiting GLA Intellectual Property
- Maintaining effective measurement systems, and developing innovative new testing techniques
- Further develop modelling techniques to support design, planning, and maintenance tasks
- Improving the environmental impact of our visual AtoN
- Keeping effective maintenance records to monitor life of light sources and their degradation, and make this accessible in a database of lights
- Proactively monitor light systems, and sub-components, for obsolescence and produce a mitigation plan to prepare for retirement and replacement of services and technology

Participation in decision-making

- Lead on national and international bodies in relation to visual AtoNs, such as IALA, IMO, etc.
- Work in conjunction with partner organisations, such as MCA, UKHO, Irish Coast Guard, DfT, DoT, Scottish Government's Marine Directorate, Irish Maritime Area Regulatory Authority, Irish Marine Survey Office
- Proactively seek out and participate in appropriate joint innovation ventures, particularly with academia and SMEs
- Exploit reputation of technical expertise through providing consultancy services

5.4 Resilient Position, Navigation & Timing and Situational Awareness systems

The GLA are actively involved in providing, monitoring, researching, and advising on Position, Navigation, and Timing (PNT) systems and services. The seas have limited PNT infrastructure in comparison to land, which requires mariners to need wider spatial awareness and greater expertise in charting. However, modern mariners also use satellite and terrestrial signals to achieve accurate, precise, and trusted positional information for their vessels.

Using the breadth of PNT systems together provides resilience as alternative PNT provision can be used when primary services are unavailable, and ensures safe passage in all situations.

More broadly, PNT systems and components remain an active area of research across academia and industry. However, with multiple sectors interested (including air, rail, and road transport), it is especially important to raise the voice of the mariner and to secure focused research into solving the specific issues within maritime. For example, much of the external focus for PNT research is in very-high precision position and time, miniaturisation of devices, or component and infrastructure design for 5G. Whilst these could be beneficial to maritime, without the much more extensive infrastructure seen on land, and with quick changing weather and sea-state conditions, maritime will need a greater focus on resilience to cope with fewer navigational options and harsher environments.

In addition to traditional navigation using physical AtoN positions in relation to charts, an ever-increasing reliance is given to digital navigation techniques using satellites (e.g. Global Navigation Satellite Systems – GNSS). The use of dissimilar PNT systems, such as terrestrial navigation solutions (i.e. e-Loran and R-Mode) aids resilience. Whilst these are considered independent technologies, there is a trend towards integrating data from multiple sources to improve accuracy and resilience.

Even when a position is calculated, there remains a degree of uncertainty as to how correct this is, and a mariner determines trust by appraising the integrity of the calculation.

The GLA's 2040 strategy outlined an emergent future that will need greater accuracy, integrity, and reliability from PNT systems, as it is envisaged that available navigable waters will become restricted with increasing congestion and allocation of regions for offshore wind energy generation. Without advancements in PNT technology, this congestion could lead to a greater number of collisions, especially as smaller craft and leisure users travel further offshore.

In reduced visibility visual AtoNs may be less effective, and many mariners rely on the use of racons to provide an independent means of locating marks without a reliance on GNSS. Racons are radar transponders which create a unique signal when triggered by a ship's radar. Recent research has explored enhanced-racons (e-racons) which additionally adds the capability to communicate the precise position of the racon to a solid-state radar, through encoding the position into its Morse paint (with no effect to conventional radar). Combined with advancements in radar mapping, their use could be particularly worthwhile in areas with featureless coastline.

Space weather events can cause disruption to satellite operations, with solar flares and radiation storms causing service outages across single or multiple constellations. These outages can last a number of days, so terrestrial based or vessel based inertial system alternatives are an important backup for maintaining safe navigation.

PNT information supports the day-to-day operations of GLA services, from ensuring floating AtoN are deployed and remain in the right location, through to supporting AtoN monitoring and some AtoN functions (i.e. synchronised lights).

5.4.1 Key technologies – Resilient PNT & Situational Awareness systems

External navigation system technologies – Satellite-based PNT systems (GNSS – GPS, Galileo, GLONASS, BeiDou, LEO satellites), Space-Based Augmentation System (EGNOS, UK SBAS), Terrestrial-based PNT systems (eLoran, VDES R-Mode), navigation integrity monitoring (RAIM, Maritime Integrity concept), racons and e-racons;

Ship-based navigation system technologies – Alternative PNT (absolute radar positioning, improved inertial sensors, quantum inertial sensors), Multi-system receivers (MSR);

Situational Awareness technologies – Shoal bank monitoring (from satellites), Hydrographical/meteorological data (Irish Lights), AI based navigation systems.

5.4.2 Key trends – Resilient PNT & Situational Awareness systems

Responding to emerging technology benefits

- New sensor systems, lights, markers, and communications:
    - › Monitor and respond to emerging GNSS technologies and services such as multi-frequencies, new high accuracy services, and authentication capabilities.
    - › Emergent sensing technologies, for instance improved inertial sensing and quantum timing and sensing;
    - › The GLA are actively researching alternative resilient PNT systems such as VDES R-mode and absolute radar positioning.
    - › E-racons offer added capability to existing racons by providing position information to solid-state Radars.
- Interoperability.
    - › Fusing multiple PNT sources, techniques, and solutions (for instance multi-frequency, multi-constellation GNSS);
    - › Exploiting PNT services from other domains for maritime purposes.

PNT information supports the day-to-day operations of GLA services, from ensuring floating AtoN are deployed and remain in the right location, through to supporting AtoN monitoring and some AtoN functions

Responding to emerging technology threats

- More technologically advanced adversaries.
  - Jamming and spoofing pose a growing concern for resilient PNT, as technology for doing so becomes widely available;
  - Political instability threatens state-actioned PNT bearer 'black-outs' and service denial.

Responding to non-technology drivers

- A shared and changing sea-space;
  - Greater numbers of vessels combined with reduced sea-space available for shipping increases the risk of collision, meaning that high-performance PNT becomes more necessary.
  - Offshore wind energy generation may provide some interference with Radio-Frequency based PNT.
- Global politics and changing legislation.
  - The UK is currently in a process of change due to its withdrawal from the EU, which has implications on shared PNT solutions, including satellite, terrestrial, and augmentation services.
  - There is a need to work collaboratively with international partners and stakeholders to support moving resilient PNT options from sound theory to common practice. This will involve review of existing legislation and standards to bring about change.

5.4.3 Timeline of key Maintaining, Retiring, Evolving, Emerging technologies – Visual Signalling

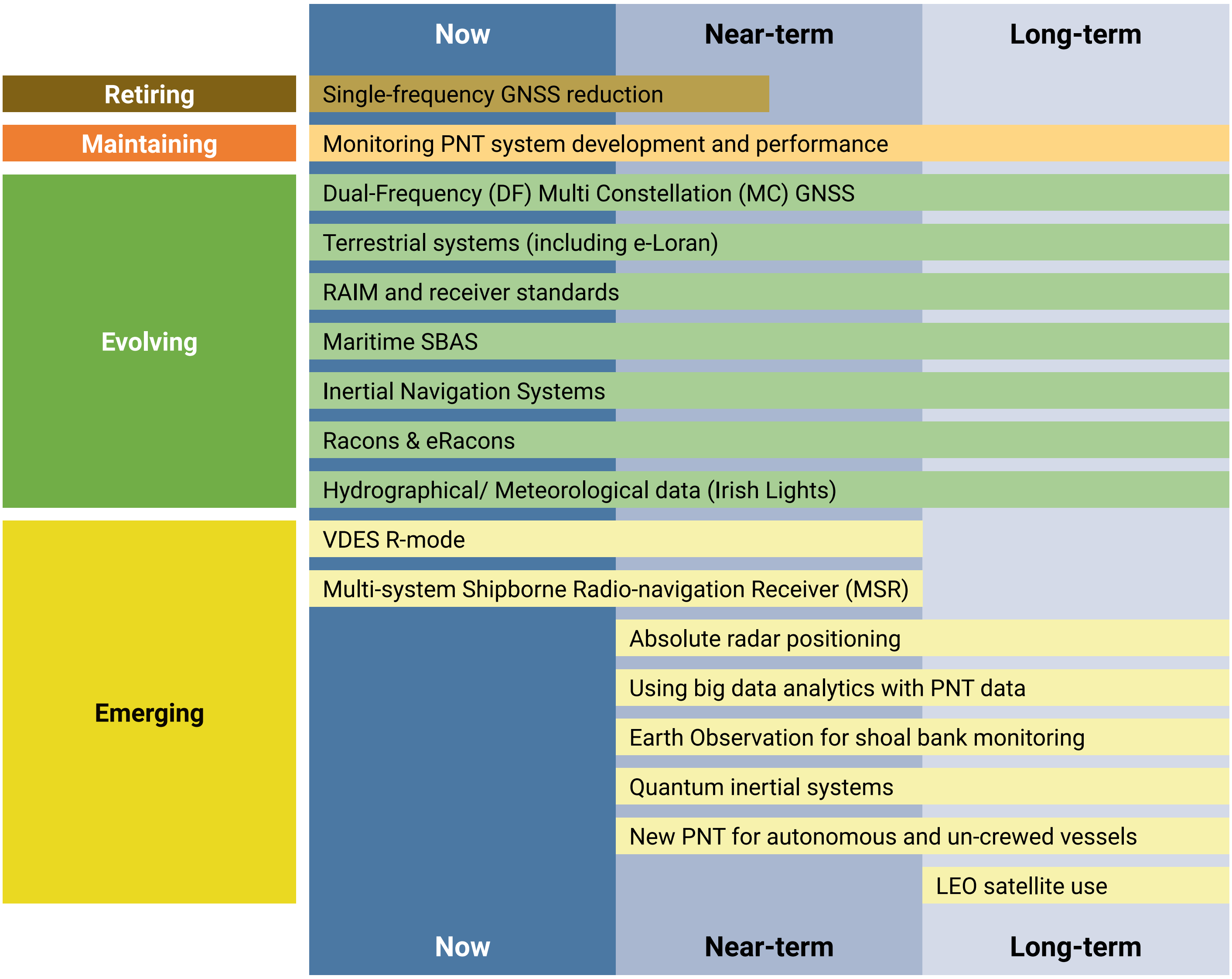
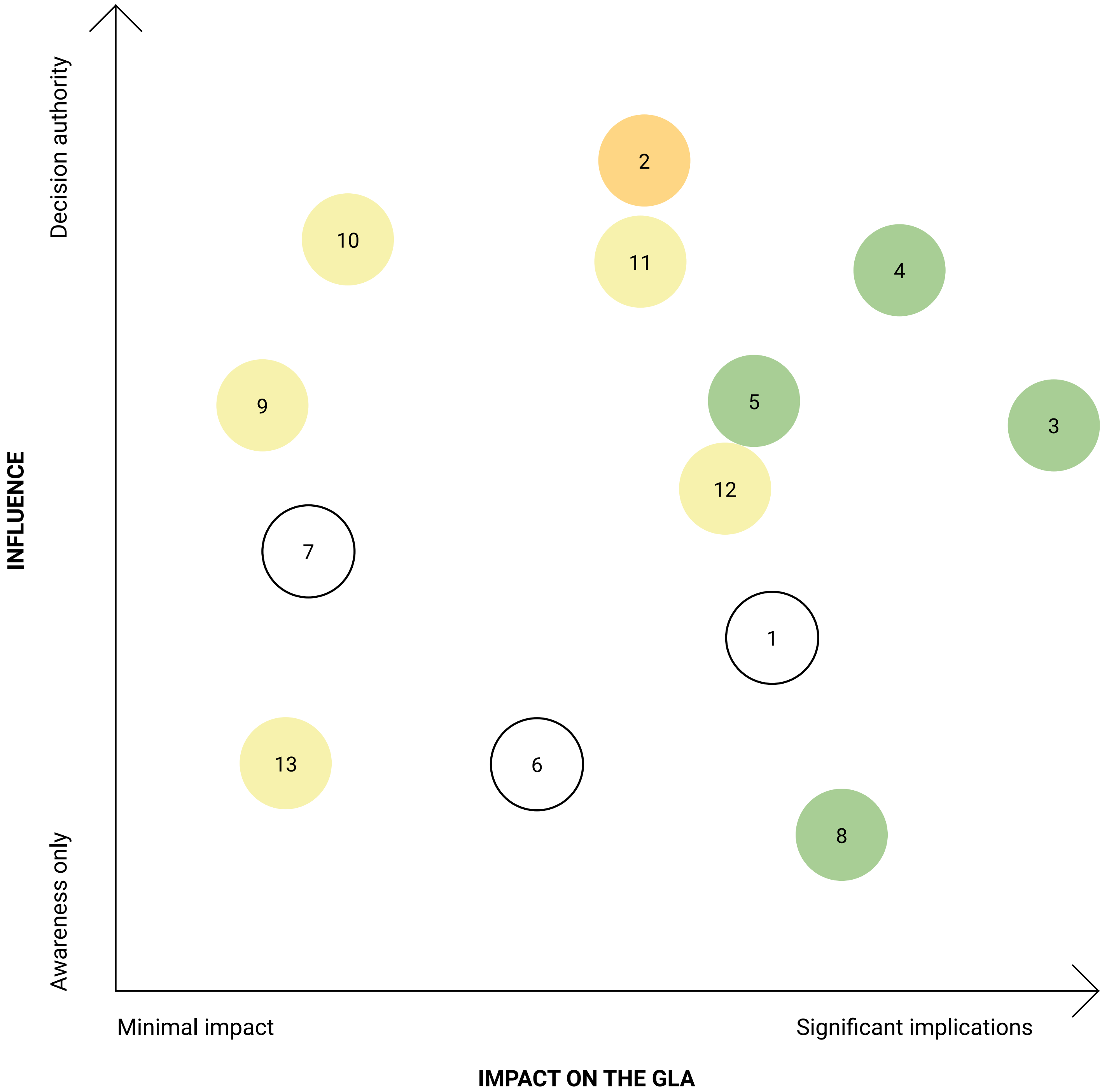


Figure 7: Timeline of resilient PNT & situational awareness technologies

5.4.4 GLA Influence vs. Impact of Resilient PNT & Situational Awareness Systems



1 GNSS Frequency change
2 Monitoring PNT
3 Terrestrial systems (including e-Loran)
4 RAIM and receiver standards
5 Maritime SBAS
6 Inertial Navigation Systems (inc. quantum)
7 Racon & Absolute radar positioning
8 Hydrographical/ Meteorological data (Irish Lights)
9 VDES R-mode
10 Multi-system Shipborne Radio-navigation Receiver
11 PNT big data
12 PNT for autonomy
13 LEO satellite use

Figure 8: Influence vs Impact of resilient PNT situational awareness technologies

5.4.5 Key aims: Resilient PNT & Situational Awareness systems

Technology development

- Monitoring the evolving user requirements for resilient PNT systems
- Evaluating emerging technology and potential solutions to enhance performance, cost-effectiveness, and impact on GLA operations
- Monitor developments in satellite-based PNT solutions (including SBAS) and innovate and collaborate on supporting technologies for maritime use of these systems
- Investigate including terrestrial based systems, such as eLoran, as part of the System-of-Systems approach
- Research and build the maturity of alternative PNT solutions such as VDES R-Mode and absolute radar positioning
- Research and validate integrity monitoring solutions, understanding any limitations and gaps in service provision and how they might be mitigated
- Consider the impacts of climate change on resilient PNT services, and strive to reduce the environmental impact of GLA owned PNT technology
- Proactively monitor systems, and components of systems, for obsolescence and produce a mitigation plan to prepare for retirement and replacement of services and technology.

Participation in decision-making

- Lead on national and international bodies in relation to resilient PNT, such as IALA, IMO.
- Work in conjunction with partner organisations, such as MCA, UKHO, Irish Coast Guard, DfT, DoT, Scottish Government's Marine Directorate, Irish Maritime Area Regulatory Authority, Irish Marine Survey Office
- Actively advocate the need for resilient PNT solutions, incorporating the Systems-of Systems approach
- Provide an expert voice on new expansions of resilient PNT infrastructure to government agencies
- Proactively seek out and participate in appropriate joint innovation ventures, particularly with academia and SMEs
- Exploit reputation of technical expertise through providing consultancy services

5.5 Maritime digitalisation & connectivity services

Every aspect of civilisation is seeing a rapid escalation of the use of online and digital services, bringing global interconnectivity that offers both new opportunities and challenges. The maritime sector and GLA are not immune from this trend, and continuing focus must be given to unlocking benefits for their operations, whilst negotiating new threats. Digital innovation is already cemented into the technology plans of the GLA, with GRAD offering specialist skills and focused research.

However, progress in bringing some of the innovation into real world use has been slower than expected, largely due to delays in agreement across organisations and the international community on the focus areas and a common approach. Going forward, equal focus must be given to coordination, cooperation, and building a consensus along with technical development.

Whilst particular focus has been given to 'e-Navigation' services, increasingly a broader set of GLA operations are incorporating digital elements. For this reason, this document discusses Maritime digitalisation, but with e-Navigation remaining a core part of the technologies. Developments in e-Navigation will see more tasks moving onto digital or cloud-based platforms, as well as new capabilities realised from enhanced situational awareness and exploitation of data to further aid the mariner.

To achieve this, all aspects of maritime data will need to be presented in a common format to avoid confusion and to enhance interoperability. This need gave rise to the creation of the S-100 framework, a universal data model which sets out the format and content of data to be shared. The immediate focus of the GLA will be undertaking its part in forming and implementing this, as it is seen increasingly as a data authority (see section 5.2 of the GLA strategy), which will require contributing and formatting a considerable amount of data (particularly for S-125/S-201). In reward, this effort will enhance communication between the GLA and outside parties, and data contributed by external bodies may also be of interest to the GLA, such as hydrographical and meteorological data.

With the quantity of data increasing significantly, there is a risk of this becoming overwhelming to the mariner. Consideration will need to be given to how this is communicated to the user, with the goal to seamlessly provide just the right data at the right time. Access for the user to GLA data could be via a self-service portal, perhaps utilising natural language searching. Enhanced presentation of the data is expected, for instance introducing a geographic information system (GIS) and using different sources of information to layer on these geospatial displays. As autonomous vessels are introduced, the 'user' may also not be human, and so this data must also be made machine readable, or even dedicated machine data created. This is already achieved through use of the S-100 framework.

Providing the future mariner with this data-rich environment means this can also be exploited through big-data techniques and the innovative use of Artificial Intelligence (AI) and Machine Learning (ML) algorithms to provide efficiency and predictive capabilities. On a broader scale, the routing of multiple vessels could be dynamically managed on a global scale, which is being explored under the Sea Traffic Management programme. This will enhance efficiency, reduce emissions, and enable 'just-in-time' shipping aspirations.

Mariners will be increasingly connected and interwoven with the shore and other vessels, swapping and sharing information, and being able to access data and resources on-demand with ease. Resilient communication and connectivity services are essential to underpin this, which will need to cope with escalating demands from multiple users and devices all wishing to seamlessly access and contribute large amounts of data. The Maritime Connectivity Platform (MCP) has developed the foundation connectivity architecture to support these aims.

The development of the supporting communication networks and technology is driven by multiple sectors, and it is essential for the GLA to support efforts to raise the voice of the mariner in decision-making. Many emerging developments are of interest to the GLA and wider maritime sector, in particular enhanced satellite and terrestrial broadband communications (including VDES), moving from analogue voice to hybrid digital voice and data channels, and emerging new bearers such as Low Earth Orbit satellites (LEOs) and High-Altitude Pseudo-Satellite (HAPS).

Whilst this interconnected digital world will provide new opportunity and capability, it also gives rise to new challenges. Mariners must also be able to trust the information they consume, and so authentication is essential to protect from rogue and malicious sources inserting or accessing data into future systems. Cyber security should be considered at every stage of the lifecycle of digital systems, and authentication processes and technology will need to be integrated to ensure that data is from a trusted source.

5.5.1 Key technologies – Maritime digitalisation & connectivity services

e-Navigation – Digital and cloud-based services that support a broad range of maritime navigation tasks, bringing these together under a common architecture (including S-100);

Sea Traffic Management – Inter-connecting data between vessels (via VTS) and between vessels and their shore-based management intelligently enhancing their route efficiency and reducing conflicts between vessels;

Secure connectivity – Resilient and secure communication systems (including AIS, VDES communications, and authentication services);

Digital futures – Big Data, Artificial Intelligence & Machine Learning algorithms.

5.5.2 Key trends – Maritime digitalisation & connectivity services

Emerging technology benefits

- Big data, cloud computing and Artificial Intelligence/Machine Learning;
  - › At the heart of this sector of technology, trends in big data, cloud computing and AI/ML should be exploited for benefit within the GLA services and wider maritime industry.
- New sensor systems, lights, markers, and communications;
  - › New communication systems, such as the innovative use of VDES comms, will allow more data-rich environments to be exploited on demand.
- Interoperability.
  - › Producing a common framework and format across services will allow far greater interoperability, making an agnostic ‘gateway; between clients (users) and services.

Responding to emerging technology threats

- Coping with big data;
  - › More powerful communication systems will allow more data to be passed seamlessly between mariners, the shore, and GLA infrastructure;
  - › Innovative machine learning techniques and the application of AI/ML will allow data to be exploited in new ways.
- More technologically advanced adversaries.
  - › Adversaries may wish to disrupt or exploit maritime connectivity and data for gain, and a greater awareness and focused investment into security will be required;
  - › Authentication research will underpin the development of digital services, building trust behind the data.
  - › Being aware of the broader cyber security threat landscape and mitigation options will become important as new communications systems emerge.

Responding to non-technology drivers

- A shared and changing sea-space;
  - › Sea Traffic Management (STM) will see maritime operations between ports ‘digitally managed’ to build efficiency, and realise ‘just-in-time’ ambitions;
  - › Current VTS services research is exploring using AI/ML in conjunction with route

exchange between vessels, to predict when vessels may cross across their journeys, and how to optimise and reduce the need to slow or stop;

    - Bandwidth congestion will need to be managed as a greater number of mariners will wish to connect, and the data exchanged increases rapidly.

- The future mariner;

    - Uncrewed and autonomous vessels will necessitate common frameworks and low-latency data exchange in order to safely share the waters with traditional vessels.

5.5.3 Timeline of key Maintaining, Retiring, Evolving, Emerging technologies – Maritime digitalisation & connectivity services

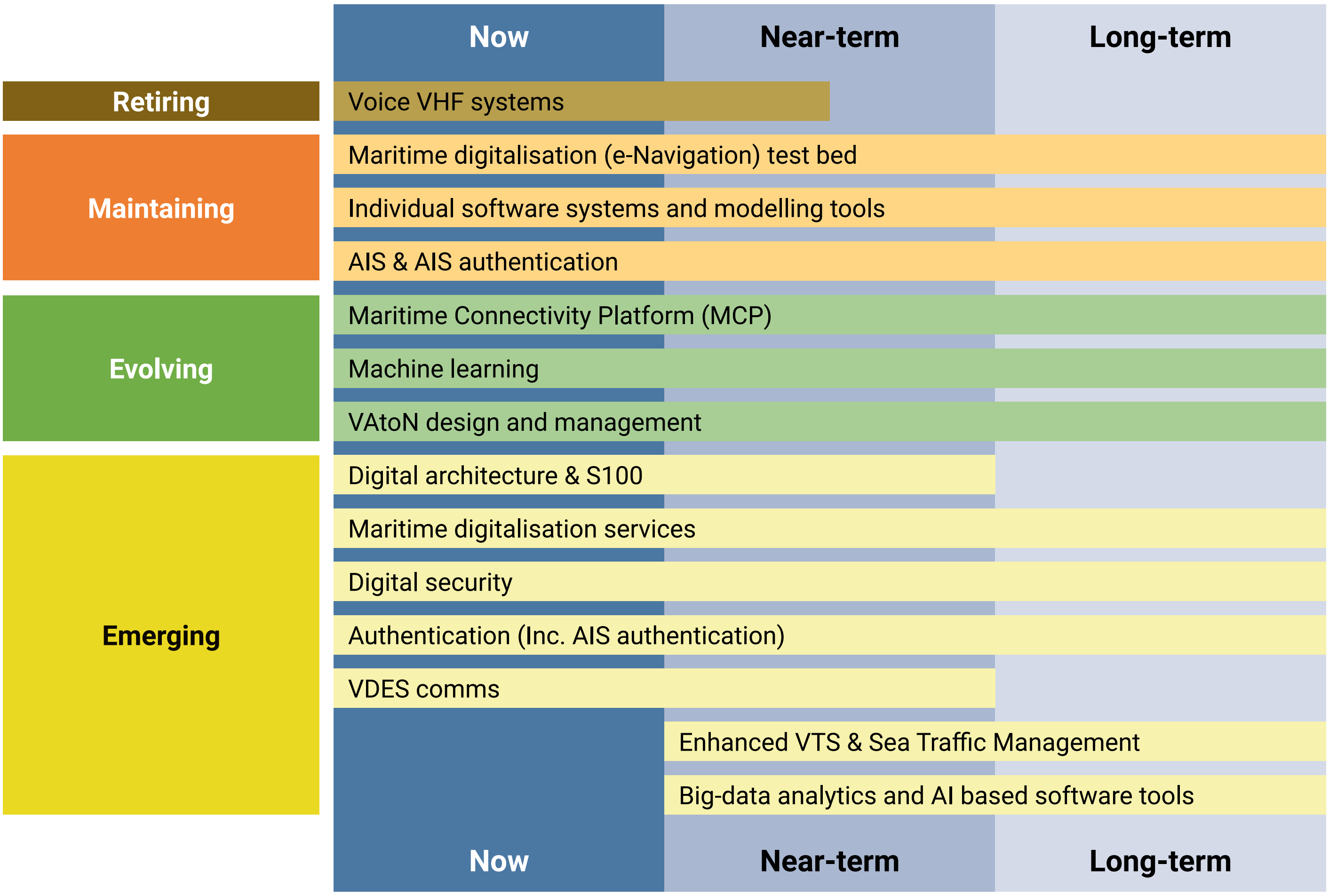
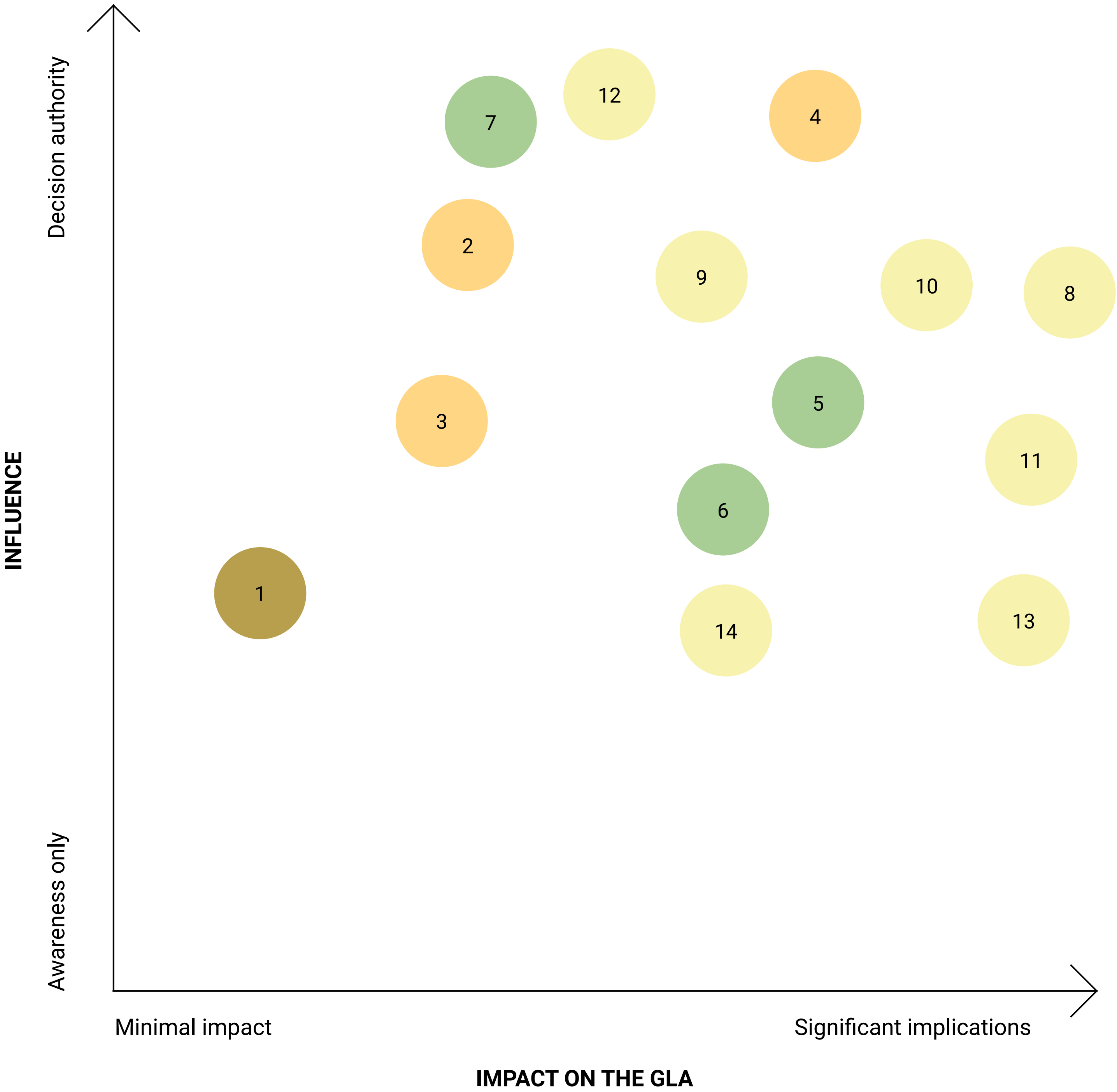


Figure 9: Timeline of maritime digitalisation & connectivity services

5.5.4 GLA Influence vs. Impact of Maritime digitalisation & connectivity services



1 Voice VHF systems	8 S100
2 e-Navigation test bed	9 Maritime digitalisation services
3 Individual software systems and modelling tools	10 Digital security
4 AIS	11 Authentication
5 MCP	12 VDES comms
6 Machine learning	13 Enhanced VTS & Sea Traffic Management
7 VAtoN	14 Big-data analytics and AI

Figure 10: GLA Influence vs. impact of maritime digitalisation & connectivity services

5.5.5 Key aims: Maritime digitalisation & connectivity services

Technology development

- Monitoring the evolving user requirements for digital and connectivity services
- Evaluating emerging technology and potential solutions to enhance performance, cost-effectiveness, and impact on GLA operations
- Develop a suite of digital services of relevance to GLA operations, maturing their Technology Readiness Level
- Explore the potential applications of Artificial Intelligence and Machine Learning technology, and how it may be used to benefit GLA services and technology
- Understand the cybersecurity aspects of digital services, including where authentication is needed and how this might be incorporated, and integrate secure systems approaches throughout development to build this into software by design
- Employ high-standard development processes in the production of new software, including tenaciously recording architectures, interfaces, design, and software
- Understand how climate change may impact connectivity and digital services, and how enhanced service provision may help reduce the impact of climate change on the GLA or help it meets their environmental and net zero targets
- Proactively monitor systems, including all aspects of software, for obsolescence and produce a mitigation plan to prepare for retirement and replacement when needed. Understand and articulate how software and service updates or replacements would be delivered.

Participation in decision-making

- Lead on national and international bodies, such as IALA, IMO, on building digital common architectures, standards, and formats
- Work in conjunction with partner organisations, such as MCA, UKHO, Irish Coast Guard, DfT, Marine Scotland), to understand common research aims and user needs
- Ensure that collaborative technology development decisions incorporate the needs of the GLA
- Actively participate in the STM community, and collaborate where possible on projects of relevance to the GLA
- Provide an expert voice on digital and connectivity services
- Advocate the need for authentication across digital services, building trust in GLA provided services
- Proactively seek out and participate in joint innovation ventures, particularly with academia and SMEs
- Exploit reputation of technical expertise through providing consultancy services

6 Plan for the impact of climate change for the GLA

By 2040, climate change is projected to have significant impact in the UK and Irish waters, which will present new challenges for at-sea operations. The GLA recognise this impact, and that climate change will affect broadly across their operations. The GLA will monitor climate related changes to the environment across its estate, and where possible, make adaptions to protect against these. Further, they are committed to minimising the negative contributions of GLA operations to the environment, and will seek mitigations to reduce emissions and the contribution of GLA operations to the climate change emergency.

The mean sea-level is expected to continue to rise, as the melting of the glacial and polar ice releases freshwater into the seas. The potential warming of the North Atlantic Drift Ocean current could have a major impact and we could experience more extreme weather events such as short periods of heavy rainfall and localised flooding and extreme hot temperatures. In the longer term, this sea level rise will alter the coastline, creating new hazards around the UK and Ireland as well as open other routes to deeper draught traffic. Without effective defences and mitigations this could render some ports unviable and may change navigable approaches. The impact of a sea-level rise on GLA estate and operations will need to be considered, recognising that changes may be required to ensure continued operation.

With increased storm events, there will be damage from high winds and rough seas, as well as indirect disruption to services and operations. Rising sea-levels increase the risk of coastal erosion and flooding from high tides and storm surges. Other disruptions to service include a potentially diminished number of days during which access to floating assets can be checked, maintained, or replaced and a potential temporary loss of access to sites during storm conditions.

Increasing global temperatures could create a warmer climate around the UK and Ireland, and combining with changes to ocean temperatures and currents, it is expected this would increase the frequency and duration of heat-waves and storms. Additionally, climate change is bringing more frequent, larger sized, sea fog events, and this fog is sitting closer to the ocean level. Increased periods of cloud cover will also impact the hours of sunshine available, reducing the energy generation capacity from solar panels increasingly fitted to GLA assets.

Also, of critical importance are the ship and helicopter operations which take place regularly throughout the year. The helicopter is shared between the GLA, and when storms occur during a period of scheduled use, this can present significant logistical and cost challenges to all three GLA programmes.

A risk of temperature increase includes the potential destabilisation of lighthouse asset foundations as a result of the shrink and swell of foundation soils. This will need to be assessed where any of our structures are positioned on shallow, cohesive, or shrinkable geology. Ocean salinity is also changing due to glacial ice melt, and it has been observed that this is creating distinct regions of more and less salty water. This may alter the dielectric properties of the sea surface, and have implications on the communication channels at sea. The release of freshwater combined with increasing temperature gradients is also threatening sea currents, most notably the Gulf Stream. This may have devastating effects, including new ice hazards forming in winter months.

The chemical properties of seawater are changing due to climate change, including changes to the acidity and the salinity of water in different areas. Increased acidity and salinity are problematic for any equipment at sea as it increases the rate of corrosion, makes plastics more brittle and bleaches pigments in paints more quickly. These effects will necessitate additional maintenance of GLA assets, and shorten the lifespan of assets at sea.

With temperatures increasing, aquatic life is also changing around the British and Irish coastline. This has the potential to introduce new biological challenges to the operations of the GLA, especially where new invasive species pose a destructive threat to equipment at sea or coastline assets. Conversely, the positioning of GLA assets at sea could be advantageous as they could act as sentinels for new species arrivals.

Environmental Protection

The coastline contains important infrastructure, vibrant communities, habitats, significant cultural and heritage assets. Projected rises in mean sea level could increase the rate of erosion and number of vulnerable sites. The GLAs are responsible for the management of a significant portfolio of coastal offshore sites including many built and natural heritage structures and we realise the importance of planning for climate adaptation.

The GLA continue to work with partners to assist with observations and the conservation of terrestrial habitats. With the automation of navigation systems around the coast, many of the sites are now being used by local communities for tourism purposes and by environmental scientists for observations and measurements of birds, bats and other wildlife. The GLA have now a responsibility to investigate how these valuable sites can be best utilised to support its biodiversity objectives.

The GLA strive to ensure its operations are conducted in a manner that is respectful of and in adherence to conservation designations under the Habitats Directive such as Sites of Special Scientific Interest (SSSIs) Special Areas of Conservation (SAC), Natural Heritage Area (NHA) and Special Protection Area (SPA). A large portion of assets are located in proximity to such areas and it is a high priority that the delivery of GLA core operations do not damage or interfere with the ecosystems, habitats and species of flora and fauna around at the sites and surrounding environs.

In order to help provide environmental protection legislation has been implemented to prevent or reduce pollution of the atmosphere, water and soil. The law allows for regulation of industrial activities and sets minimum requirements to be included in all permits, particularly in terms of pollutants released. The GLA also have emergency plans and procedures for dealing with environmental incidents at sea including accidental emissions, discharge, and leakages.

The GLAs will work with their respective environmental agencies to ensure that any impact of marine navigation light sources on wildlife, particularly birds and nocturnal insects are as low as reasonably practical while ensuring safety of navigation at sea.

6.1.1 Key trends – Climate change

Gradual and long-term effects – Sea level rise, sea temperature rise, reduction of emissions and net zero, increase in wave power and wave action, increase in coastal erosion;

Climate changed induced events – Increased frequency and intensity of storms, increased fog, sudden loss of sea currents, ice hazards, heat-waves;

Biodiversity and sea chemistry – sea salinity, sea acidification, invasive species, protecting biodiversity, alterations to marine life species numbers and behaviour and extinction, algae bloom events.

6.1.2 Timeline of key Maintaining, Retiring, Evolving, Emerging technologies – Climate change

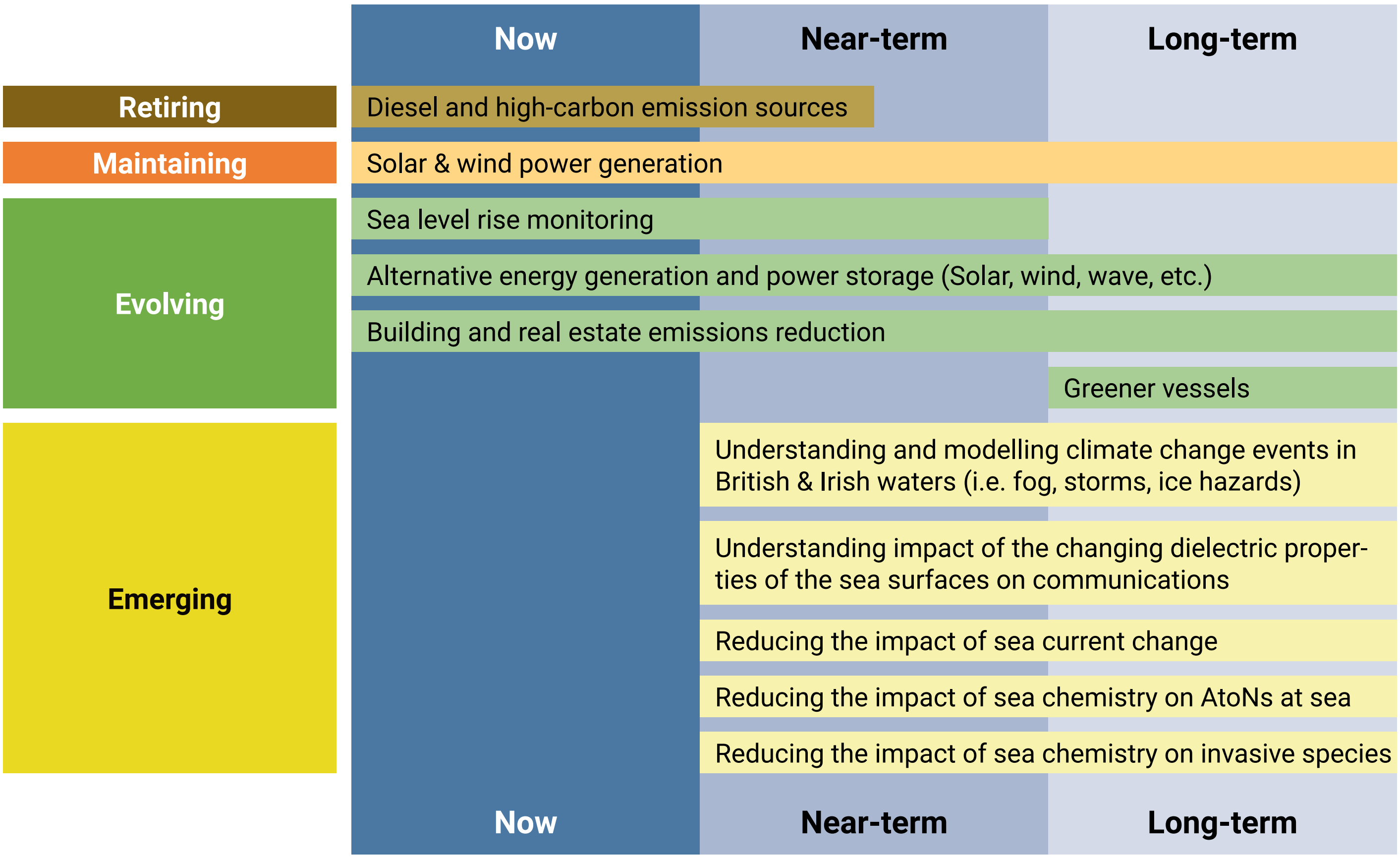
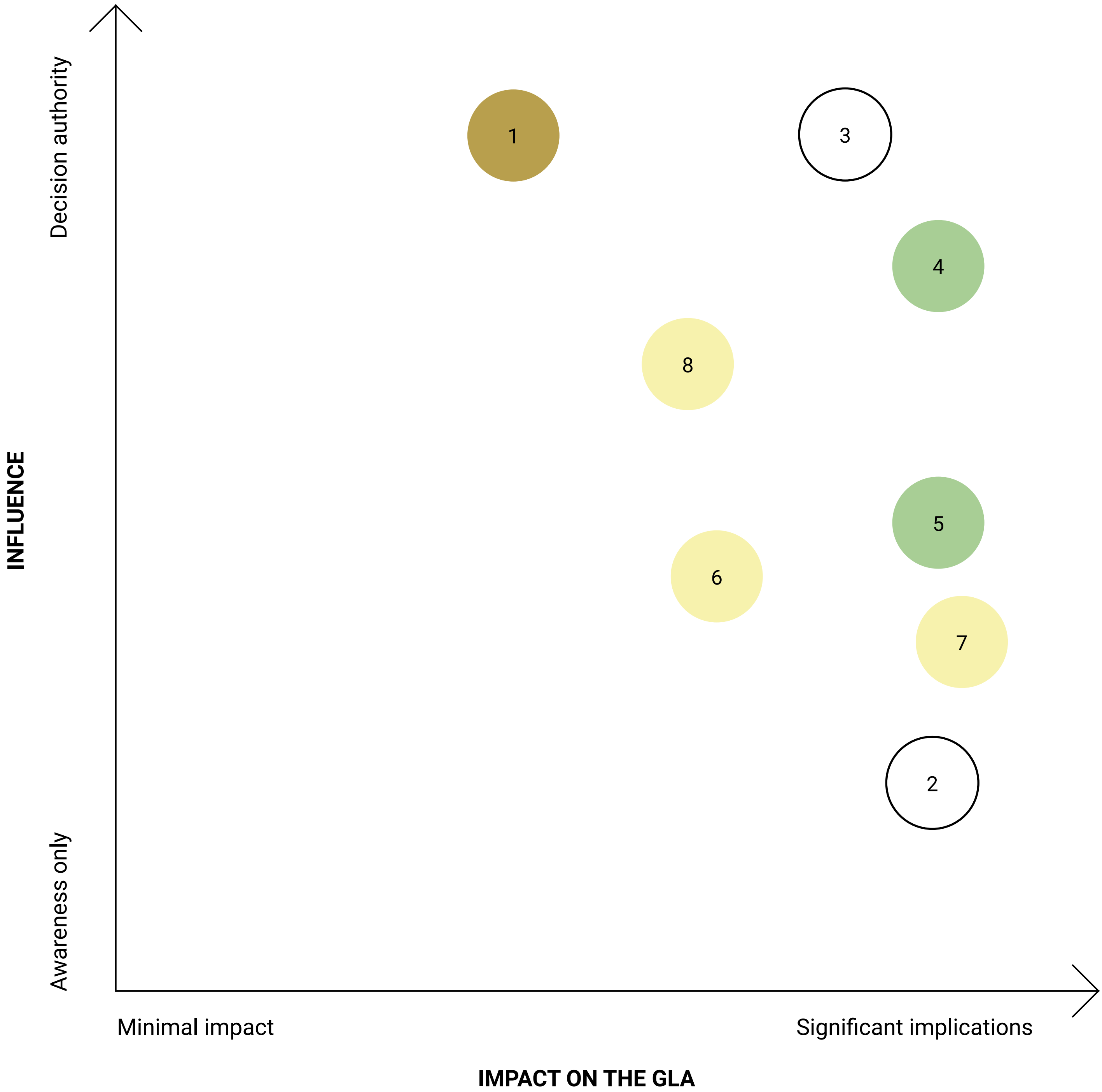


Figure 11: Timeline for climate change aspects

6.1.3 GLA Influence vs. Impact of climate change



1 Removal of high-carbon emission sources

2 Sea level and current change

3 Green energy generation and power storage

4 Real estate emissions reduction

5 Greener vessels

6 Climate change events

7 Biodiversity impacts

8 Reducing the impact of sea chemistry

Figure 12: Influence Vs. Impact of climate change aspects on the GLA

6.1.4 Key aims: Climate change

Technology development

- Researching the impacts of climate change and its impact on the complete set of GLA operations
- Understanding the gradual and long-term effects of climate change, and planning and preparing the GLA for these changes
- Model and prepare a risk-based analysis on climate change induced events, and prepare a plan of mitigations and measures that the GLA could employ in the instance of these occurring
- Research the expected changes in sea-chemistry and biodiversity that could impact floating and fixed assets, and articulate protective measures
- Identify suitable modifications to GLA assets in order to meet net zero and emission based regulations, and invest in research where gaps or challenges arise in meeting them
- Research alternative power generation, storage, and control, and deploy as this matures.

Participation in decision-making

- Commit to reducing the impact of GLA operations on the environment, meeting statutory obligations (including net zero)
- Collaborate with other maritime organisations on understanding and mitigating the effects of climate change, ensuring that collaborative technology development decisions incorporate the needs of the GLA
- Work proactively with maintenance teams, the buoy yards, and suppliers to understand the impacts of sea chemistry changes and biodiversity on floating assets
- Proactively seek out and participate in joint innovation ventures, particularly with academia and SMEs

7 Glossary

AI	Artificial Intelligence
AIS	Automatic Identification System
AtoN	Aid(s) to Navigation
ComReg	Commission for Communications Regulation
DfT	Department for Transport (UK)
DoT	Department of Transport (Ireland)
ECDIS	Electronic Chart Display and Information Systems
EEZ	Exclusive Economic Zone
EGNOS	European Geostationary Navigation Overlay Service
eLoran	enhanced LOng RAnge Navigation System
EPA	Environmental Protection Agency
ESA	European Space Agency
EU	European Union
GLA	General Lighthouse Authorities of the UK and Ireland
GLONASS	GLObal NAvigation Satellite System
GMNP	GLA Marine Navigation Plan (This Document)
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
IALA	International Association of Marine Aids to Navigation & Lighthouse Authorities
IHO	International Hydrographic Organization
IL	Irish Lights
IMO	International Maritime Organization
IoM	Isle of Man
IRCG	Irish Coast Guard
LED	Light Emitting Diode
MCA	Maritime and Coastguard Agency
MCC	Maritime Connectivity Platform Consortium
MCP	Maritime Connectivity Platform
Met Éireann	The Irish National Meteorological Service
ML	Machine Learning
MSA	Merchant Shipping Act
MSC	Maritime Safety Committee
MSR	Multi-System Receiver
NHA	National Heritage Area
NLB	Northern Lighthouse Board
NPWS	National Parks and Wildlife Service
NCSR	Navigation, Communications and Search and Rescue (subcommittee of IMO)
PNT	Position, Navigation & Timing
racon	RAdar BeaCON
RAIM	Receiver Autonomous Integrity Monitoring
RSPB	Royal Society for the Protection of Birds
R-Mode	Ranging Mode
SAC	Special Area of Conservation
SBAS	Space-Based Augmentation System
SOLAS	Safety Of Life At Sea
SPA	Special Protection Area
SSSI	Sites of Special Scientific Interest
SWaP	Size, Weight, & Power
TH	Trinity House
UK	United Kingdom
UKHO	UK Hydrographic Office
VDES	VHF Data Exchange System
VHF	Very High Frequency
VTS	Vessel Traffic Services

8 References

1. The General Lighthouse Authorities of the UK & Ireland, “Navigating to 2040: The GLA Strategy,” 2023.

2. IALA, “PROGRESS WITH IALA’S CHANGE OF STATUS,” 10 September 2021. [Online]. Available: https://www.iala-aism.org/e-bulletin/progress-with-ialas-change-of-status/#:~:text=Upon%20its%20entry%20into%20force,%2DGovernmental%20Organization%20(IGO).

3. IALA, “Technical Documents Catalogue,” 2023.

Marine Navigation Plan 2040

Produced by the General Lighthouse Authorities of the United Kingdom and Ireland

Irish Lights
Harbour Road
Dun Laoghaire
Co. Dublin
A96 H500
Ireland

Northern Lighthouse Board
84 George Street
Edinburgh
EH2 3DA
United Kingdom

Trinity House
Tower Hill
London
EC3N 4DH
United Kingdom

Published January 2024

Commissioners of IRISH LIGHTS Navigation and Maritime Services

Northern Lighthouse Board

TRINITY HOUSE