26th annual INCOSE international symposium

Edinburgh, UK

July 18 - 21, 2016

A Case Study of a Successful System:

The Scottish Lighthouses from the 18th to the 21st Century

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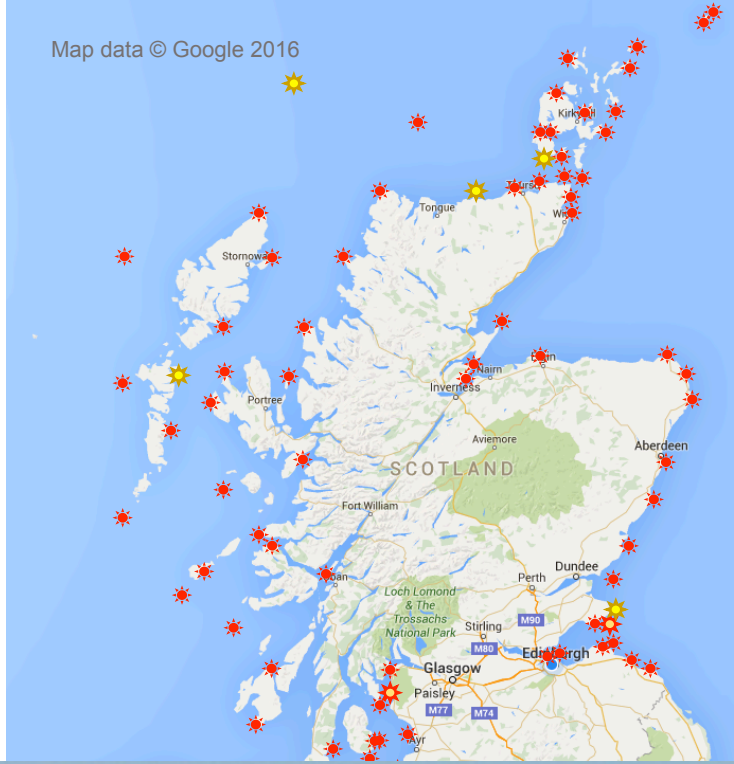
Edinburgh

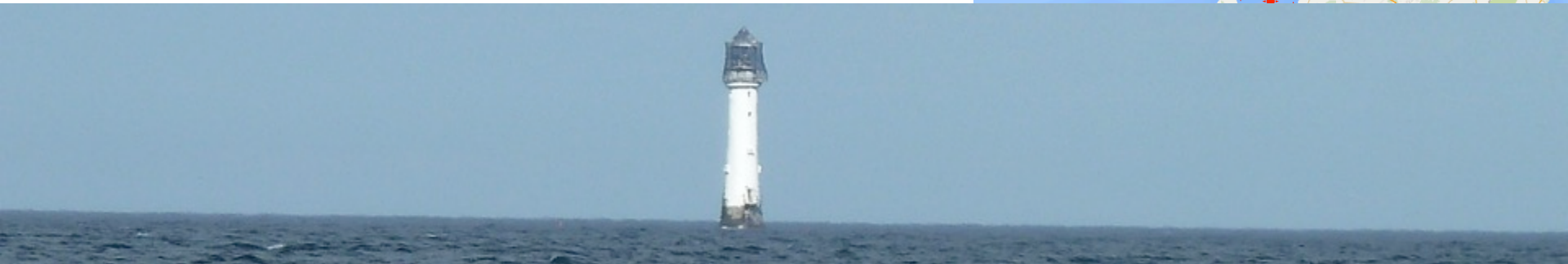
SILLITTO ENTERPRISES

ENGINEERING SUCCESS IN A COMPLEX WORLD

Lighthouses

- Are they a system (and if so, what sort?)
- Can we discern evidence of systems engineering?
- Can we discern evidence of a Systems Architecture?
- Can we discern evidence of “Capability Management”?
- Can we learn from the past?





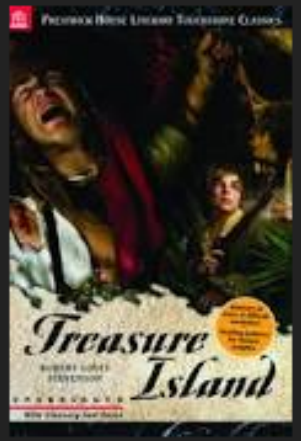
Robert Louis Stevenson

Born Edinburgh, 1850. Died Samoa, 1894

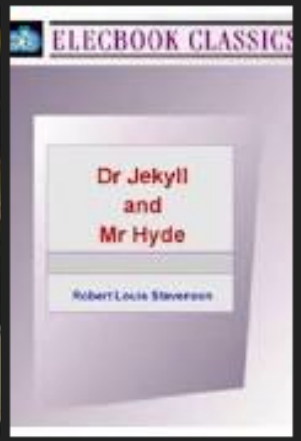
In November 1867, entered the University of Edinburgh to study engineering. "He showed from the start no enthusiasm for his studies and devoted much energy to avoiding lectures."

26th most translated author of all time

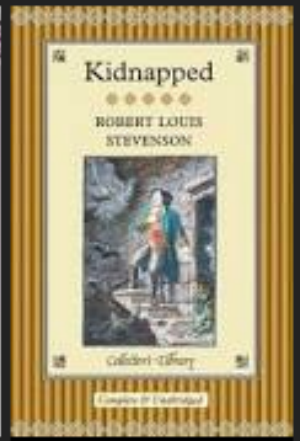
Robert Louis Stevenson / Books / Kidnapped



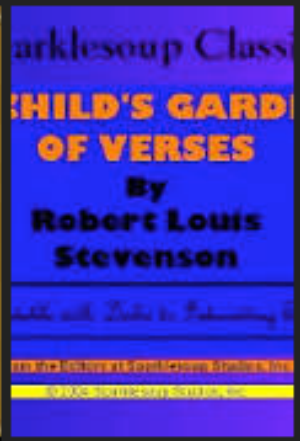
Treasure Island
1883



Strange Case of Dr Jekyll and Mr …
1886



Kidnapped
1886



A Child's Garden of Verses
1885

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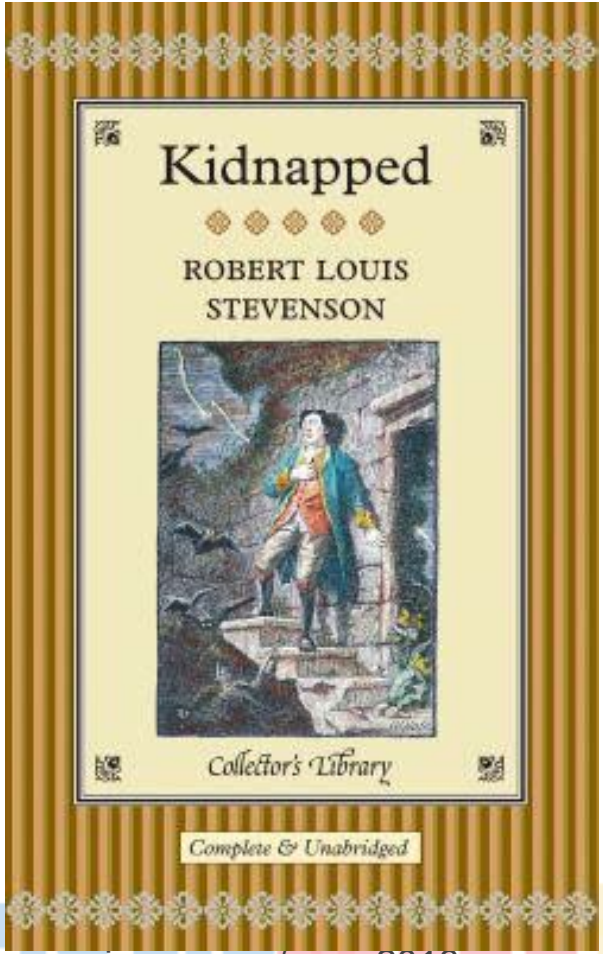
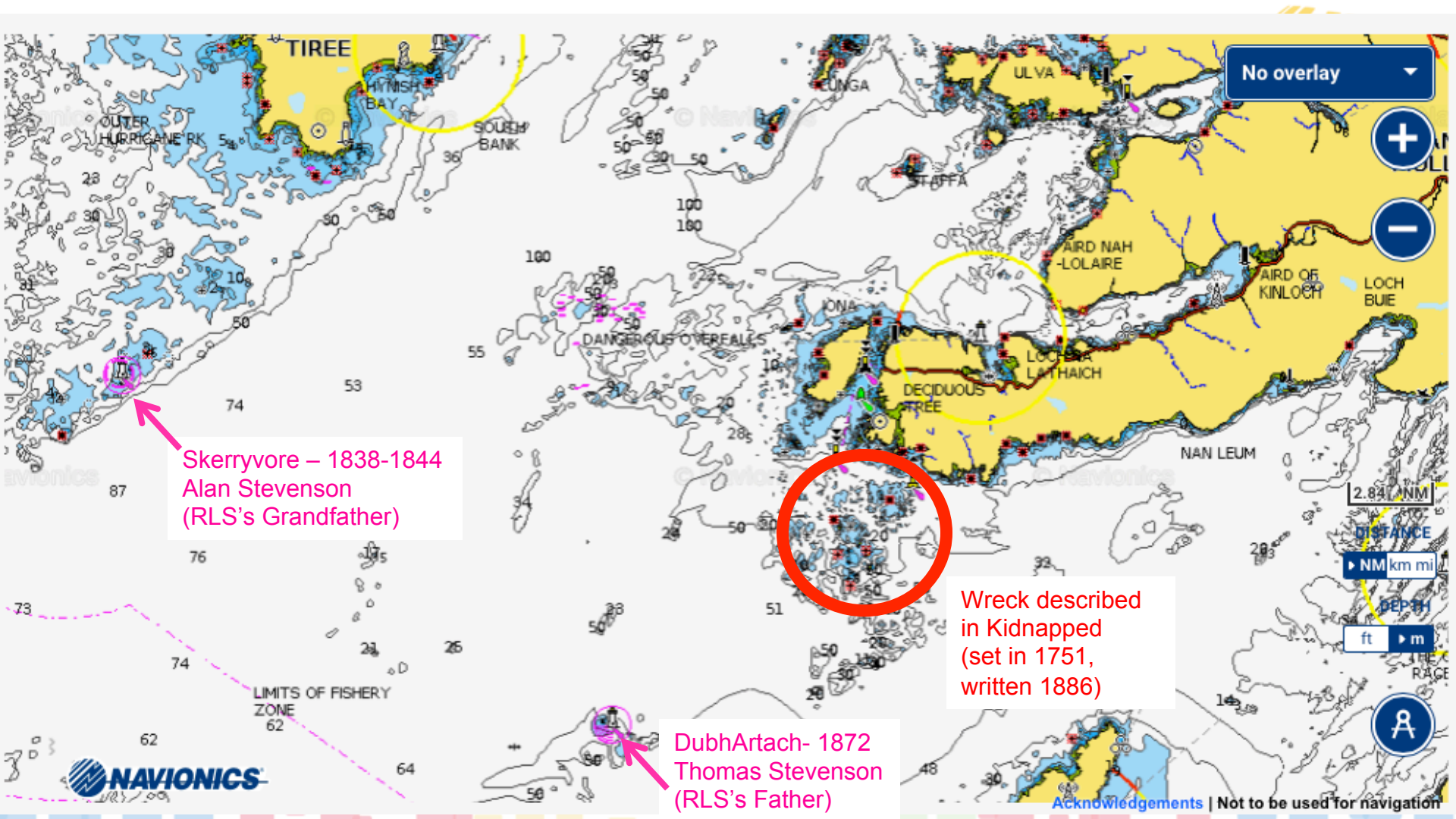
“Kidnapped”, 1886 - brilliant marketing for the family business




TIREE
HYNISH BAY
OUTER HURRICANE RK
SOUTH BANK
ULVA
STAFFA
No overlay
AIRD NAH -LOLAIRE
AIRD OF KINLOCH
LOCH BUIE
IONA
DANGEROUS OVERFALLS
LOCHSA LATHAICH
DECIDUOUS TREE
NAN LEUM
Skerryvore – 1838-1844
Alan Stevenson
(RLS's Grandfather)
Wreck described
in Kidnapped
(set in 1751,
written 1886)
DubhArtach- 1872
Thomas Stevenson
(RLS's Father)
LIMITS OF FISHERY ZONE
2.84 NM
DISTANCE
NM km mi
DEPTH
ft m
NAVIONICS
Acknowledgements | Not to be used for navigation

Can we discern evidence of systems engineering?

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

Operations	Cost & Schedule
Performance	Training & Support
Test	Disposal
Manufacturing	

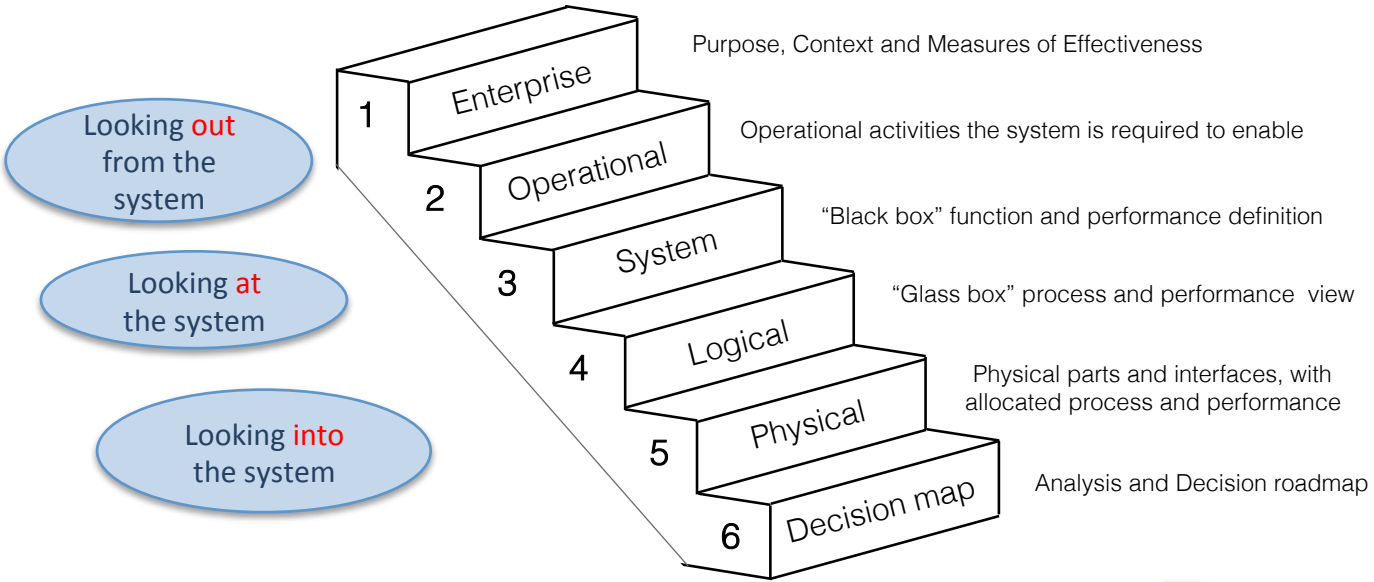
Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

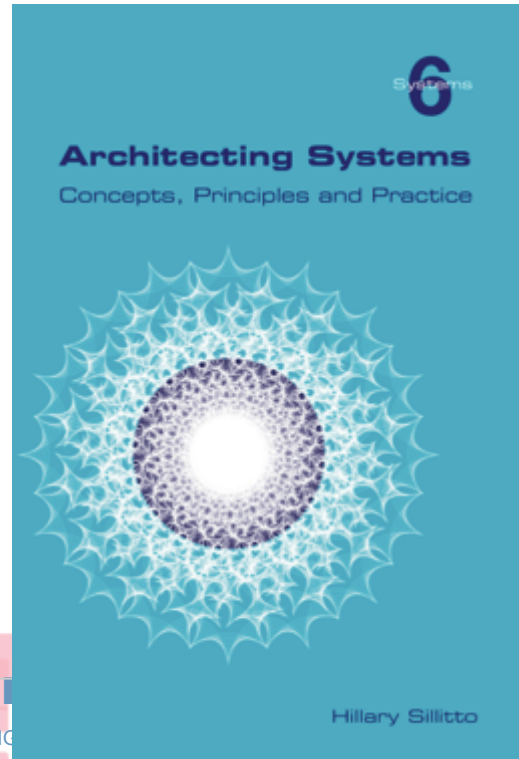
The problematic situation: recorded shipwrecks on Tiree, 1790-1844

1790. The Ship Rebecca of 700 tons lost ; crew saved.
1804. Ship Brigand of Nova Scotia, Wright, master, of 600 tons, lost off Hough, in Tyree ; crew saved.
1804. A Brig, M'Iver, master, lost off Hough; crew saved.
1806. Ellen of Bath, Paterson, master, of 90 tons, lost off Balapliuil, in Tyree ; one man drowned.
1809. Brig Mary, Sanders, master, lost off Balaphuil ; crew saved.
1813. Sloop, Penelope of Wick, 60 tons, lost at Gott Bay, Tyree ; crew saved.
1810. A Brig from New York, Greenlees, master, lost off Hynish Point, Tyree ; crew all drowned.
1813. A Sloop, Eugene M'Intyre, master, lost off Balaphuil; one man drowned.
1814. Brig, Betsey of Leith, Eoss, master, lost off Hough ; crew saved.
1817. A Brig, of 400 tons, foundered off Kennavarah, Tyree; crew all drowned. Numerous casks of butter came ashore.
1818. Sloop, Benlomond of Greenock, M'Lauchlan, master, lost off Balaphuil ; crew all drowned.
1819. Sloop, Bee, Coice, master, of 60 tons, lost off Hough; crew saved.
1820. A Sloop, M'Donald, master, of 50 tons, lost in Reef Bay, Tyree ; crew saved.
1820. Ship, Masters, of Port-Glasgow, Martin, master, of 700 tons, foundered off Skerryvore Rocks, and came ashore at Clate Hynish, in Tyree ; crew saved.
1821. Sloop, Catharine, M'Rae, master lost ; crew saved.
1821. A Sloop, of 60 tons, lost off Hough ; master and three men drowned.
1825. Sloop, Dan of Campbelltown, M'Innes, master, of 50 tons, lost ; crew saved.
1828. Sloop, Delight, of 70 tons, Stevenson, Master, lost.
1828. An Irish Schooner of 100 tons, Montgomery, master, lost off Hough ; crew saved.
1828. Jane of Sligo, Collins, master, lost off Balaphuil.
1829. Van Scapan of Stockholm, Fisherton, master, of 700 tons, lost off Hough ; fourteen people drowned.
1834. Confidence of Dundee, Wesley, master, lost off Hough ; crew saved.
1834. A Schooner of 70 tons, lost ; three men drowned.
1835. Peggy, Bitters, master, of 500 tons, lost off Beist, Tyree ; crew saved.
1841. April 2. Majestic of North Shields, Tait, master, of 400 tons, foundered by a sea off Boinshly Rock, and came ashore at Gott Bay ; captain and four men washed over- board and drowned, and the mate and one seaman had their legs broken when the vessel was struck by the sea.
1842. Fleurs of Liverpool, Thomson, master, of 300 tons, lost off Kennavarah ; crew saved.
1842. March 14. Two deck beams, a knee, and some pieces of deck-plank of a North American built vessel, came ashore at Clate Hynish.
1842. A Barra Boat wrecked, and four corpses washed ashore; two men, a woman and a child.
1842. Pieces of wreck were seen in the Sound of Coll, and at the same time the shores of Tyree were strewed with candles, mostly of wax, supposed to be altar candles for the West Indies.
1843. September 2. The Prussian Barque Formosa, of 326 tons, P. R. Reick, master, lost off Hough ; two seamen drowned.
1844. December 1. The Hull of a Sloop of about 70 tons, was washed ashore off Clate Hynish. The Hull was very much broken up by being in contact with the rocks; and one of the planks, apparently off the taffrail, had the words " Port of Dundee" lettered upon it; the crew supposed to be all drowned.

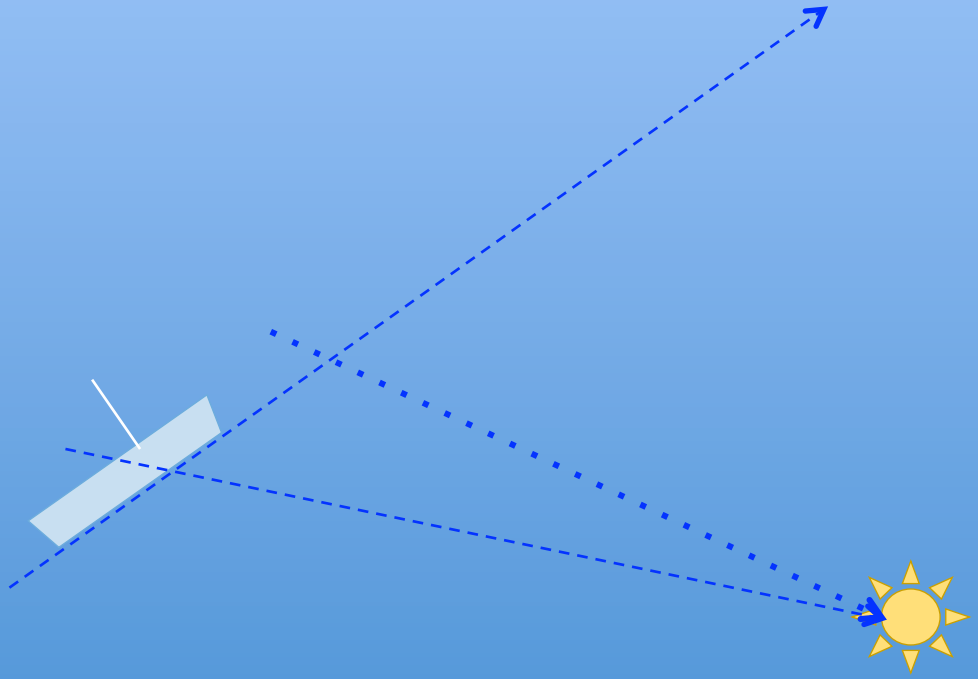
"enterprise perspective"

Can we discern other evidence of a system architecture? Using the six “Architecting Systems” perspectives…

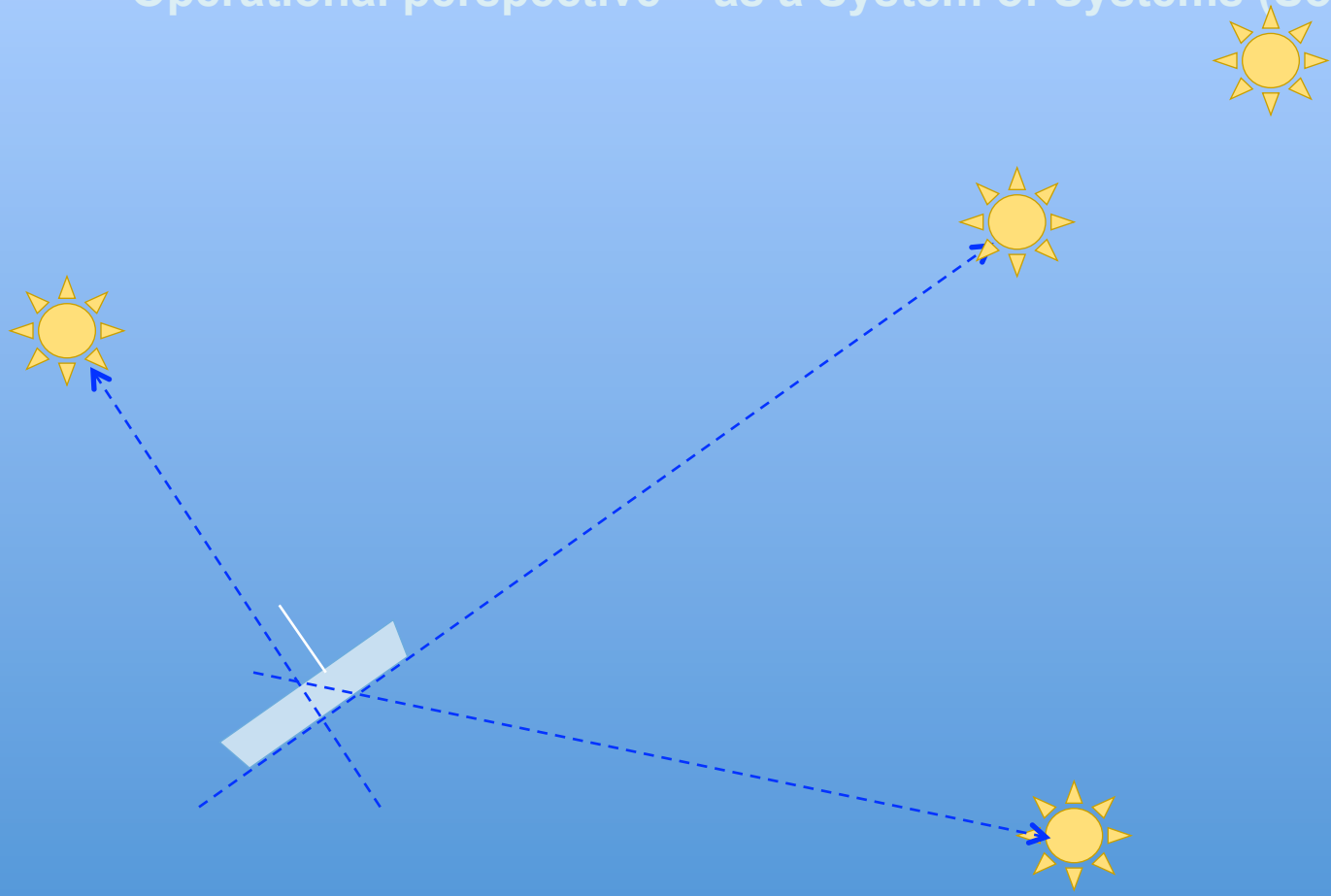




Operational perspective – op. concept for Lighthouse as a System



Operational perspective – as a System of Systems (SoS)

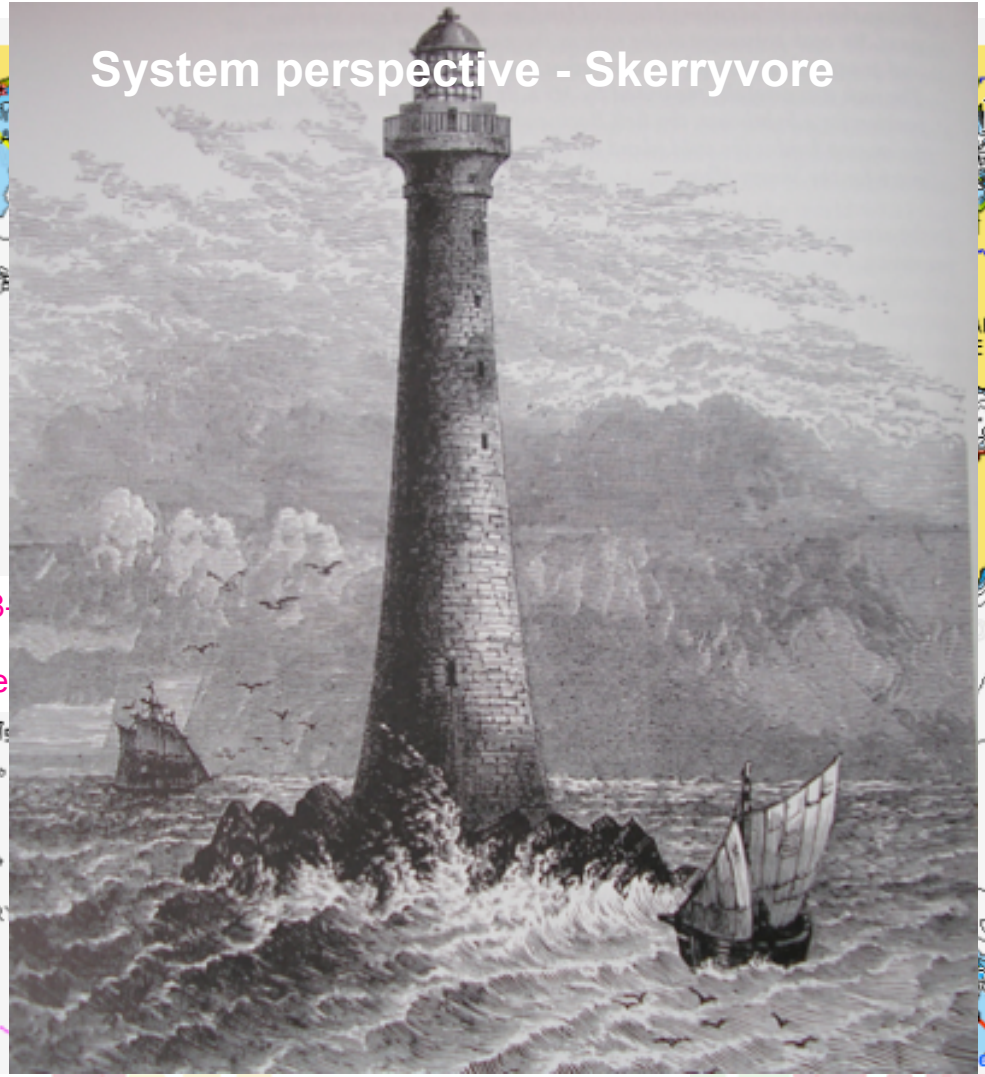


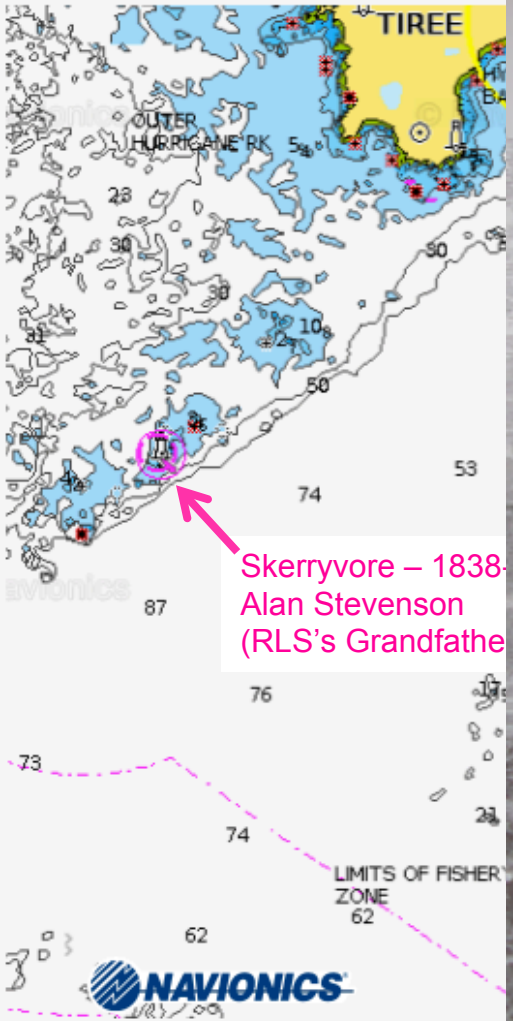
Operational Perspective – money and information flows in future business model

Vessels	Navigation dues	Payment for charts	
Visual and acoustic signature of lighthouses	**Lighthouse System-of-Systems**	Positions and signatures of lighthouses	Request for approval and loan for new builds; Loan repayments
Charts with positions and signatures of lighthouses		**Chart publishers**	
	Approvals for build and charging dues; loans to fund new builds		**Governance**

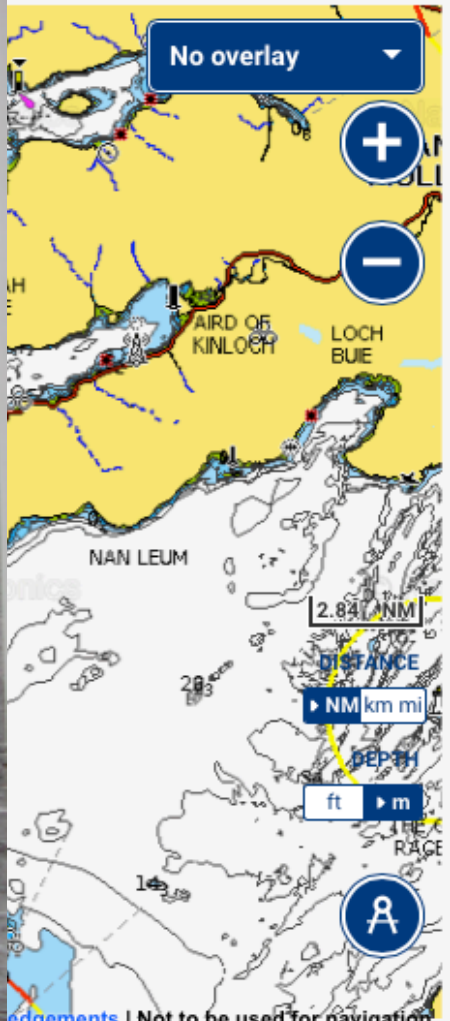
Fig 4: N^2 chart showing slows of information and money in the lighthouse enterprise

System perspective - Skerryvore



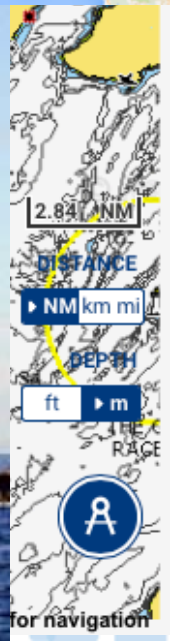


Skerryvore – 1838-
Alan Stevenson
(RLS's Grandfathe



Visible: 23 miles
Height: 48 m (154 ft)
Dia: Base 13 m, Lantern gallery 5 m
Location: tidal rock 12 miles from nearest land
Environment: swept by Atlantic storms
Wave pressure: 29 Tonnes/Sq m (6,000 lb/ft^2)
Weight of structure: 4,377 t
Cost estimate: £63,000
Steps to top: 151
Crew: 3

How did you design, build, operate and sustain something like this - in 1838?



System, Logical, Physical and Decision Perspectives

System

- Provide a flashing light of required brightness and timing
- Place light at correct position and height
- Operate system
- Sustain system
- Protect system from weather
- Provide alternative warning mode(s) when weather degrades the primary mode

Logical

- Store and provide energy
- Convert energy into light
- Create high intensity beam
- Modulate the beam to create the required timing

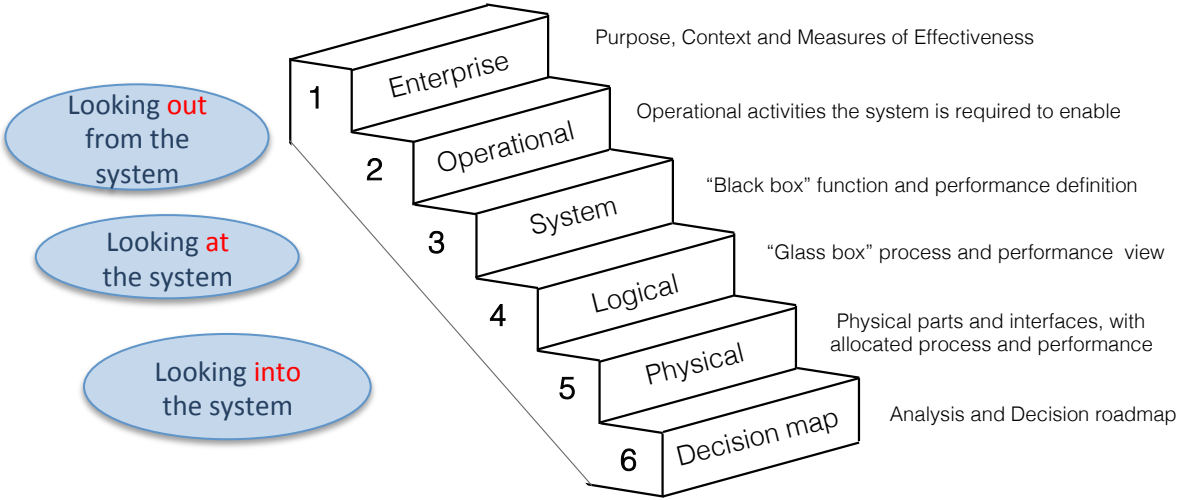
Physical

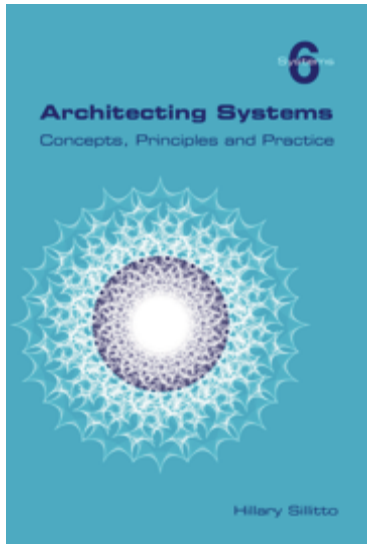
- Multiple options for optical concept:
  - Rotating Collimating optics
  - Flashing omni-directional light
- Multiple options for optical implementation
  - Mirrors
  - Lenses
  - Fresnel lens/prism
- Multiple options for energy
  - Electricity
  - Gas
  - Paraffin (kerosene)
  - Whale oil
- All with implications on the performance, physical architecture and logistics of the wider system

Decision

- Set of coupled trade-offs specific to each site, each epoch of technology
- All lighthouses similar in principle, unique in detail

So: we can discern evidence of a system architecture!

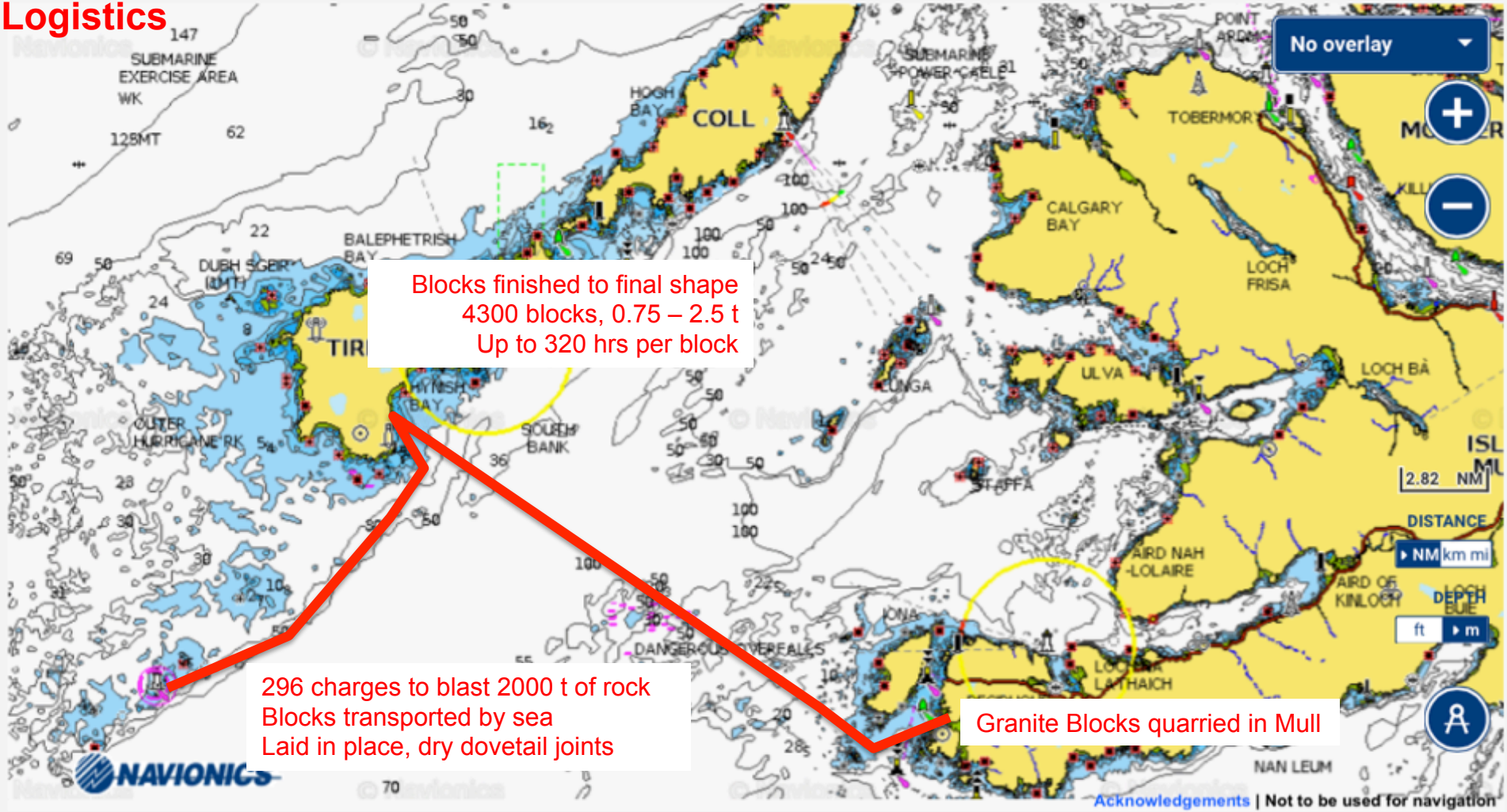




Evidence: The "Lighthouse System" can be successfully "reverse architected" using the 6 Key systems architecting perspectives of ref.[1]

[1] Sillitto, H G, *Architecting Systems: Concepts, Principles and Practice* – College Publications, 2014

Logistics


Blocks finished to final shape
4300 blocks, 0.75 – 2.5 t
Up to 320 hrs per block
296 charges to blast 2000 t of rock
Blocks transported by sea
Laid in place, dry dovetail joints
Granite Blocks quarried in Mull
No overlay
COLL
TOBERMORY
CALGARY BAY
LOCH FRISA
ULVA
LOCH BÀ
STAFFA
IONA
NAN LEUM
SUBMARINE EXERCISE AREA WK
SUBMARINE POWER CABLE
BALEPHETRISH BAY
SOUTH BANK
OUTER HURRICANE RK
2.82 NM
DISTANCE
NM km mi
DEPTH
ft m
NAVIONICS
Acknowledgements | Not to be used for navigation

Enabling systems

500 tonne ship for transport
Barrack 18 m high on stilts

Quarry, jetty, light railway

So: we can discern evidence of systems engineering

Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:

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Systems Engineering integrates all the disciplines and specialty groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Now, we'll look at the Lighthouses as an evolving System of Systems

The first lighthouses

N Ronaldsay (1789)

Eilean Glas (1789)

Kinnaird Head (1787)

Isle of May (1635)

Little Cumbrae (1757)

Mull of Kintyre (1788)

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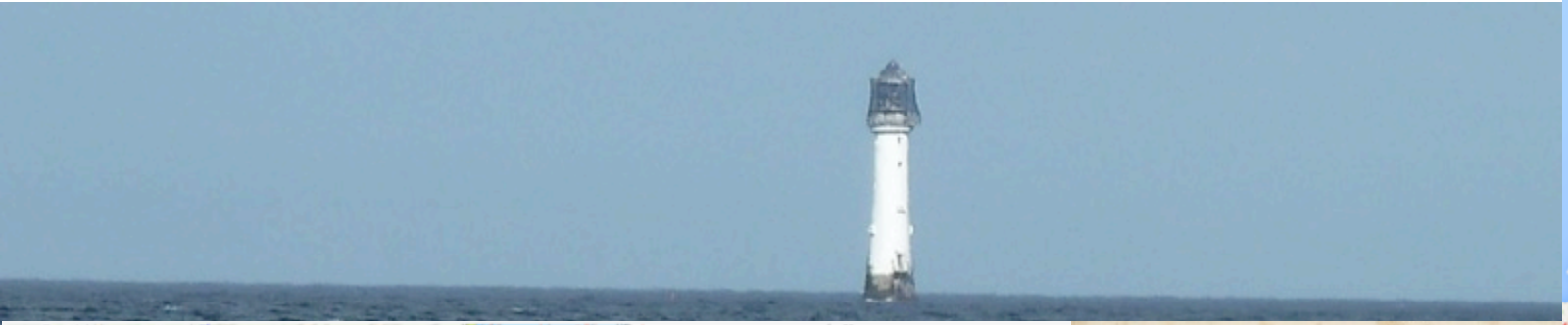
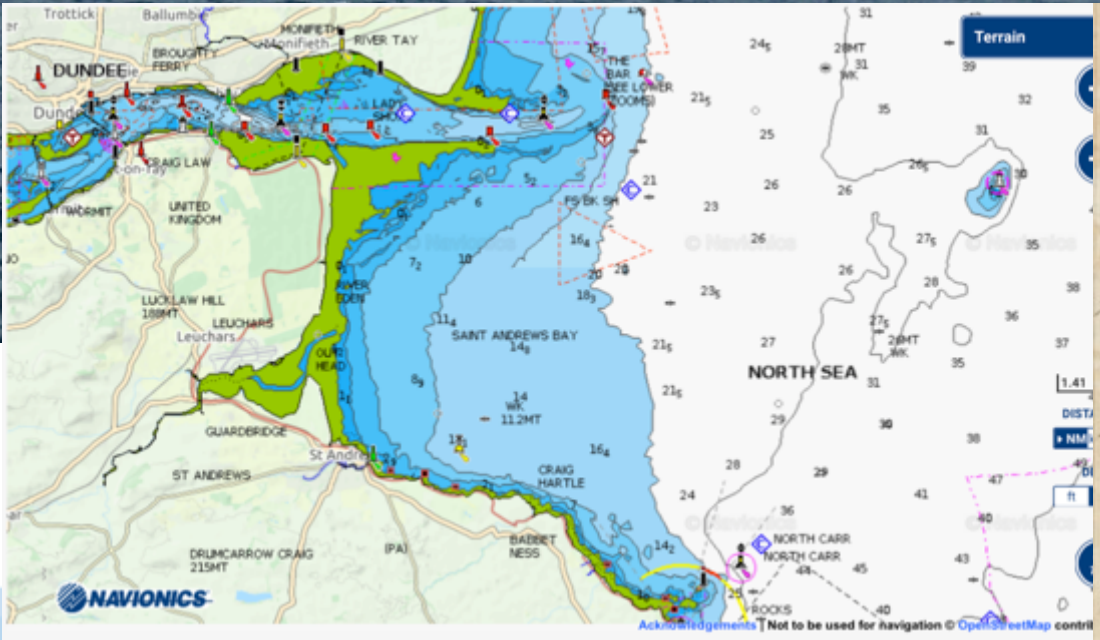
Mull of Kintyre

1790-1811

Bell Rock (1811)

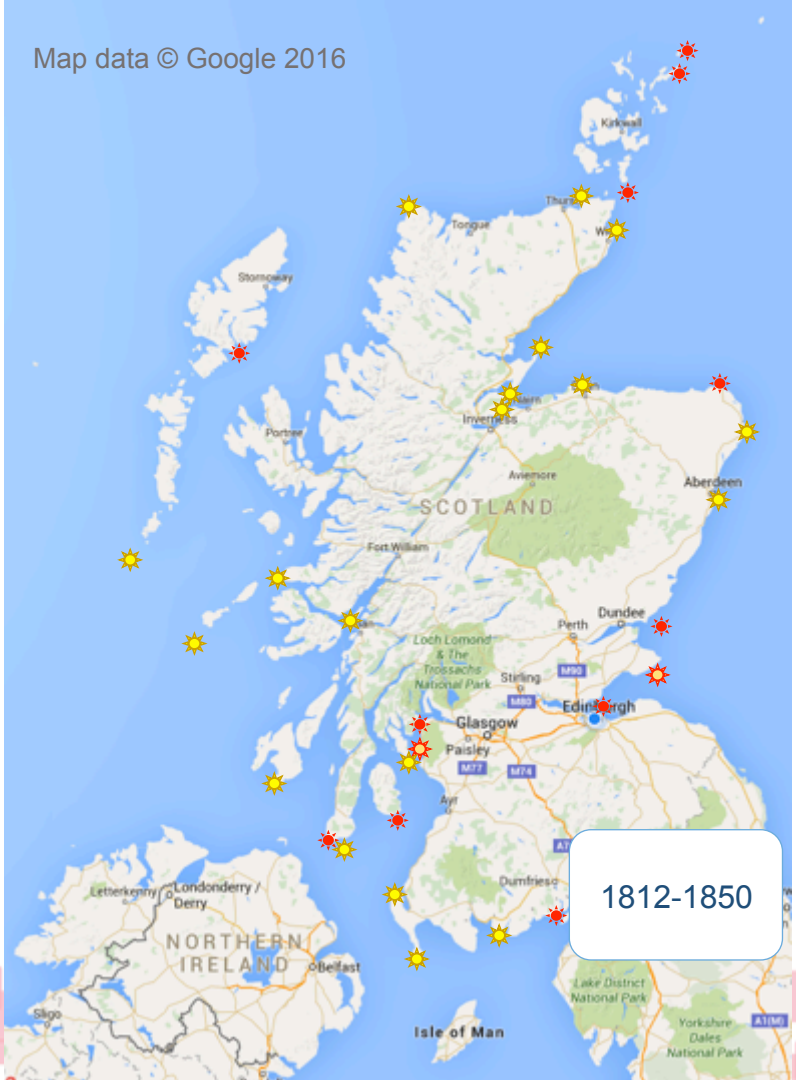
The First Rock Lighthouse – Bell Rock





By Robert Stevenson - An Account of the Bell Rock Lighthouse - 1824, Public Domain, https://commons.wikimedia.org/w/index.php?curid=39536963

1812-1850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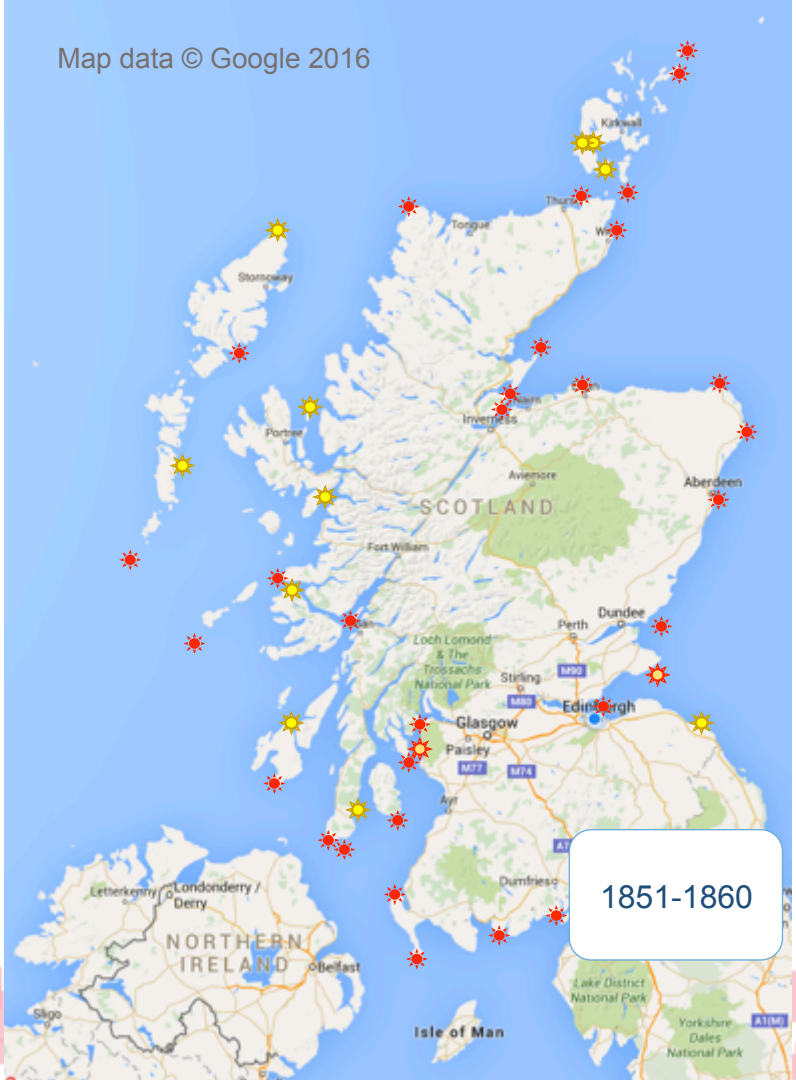
Dundee
Perth
Stirling
Inverness
Fort William
Aviemore
Portree
Stornoway
Tongue
Kirkwall
Paisley
Ayr
Dumfries
Belfast
Londonderry / Derry
Letterkenny
Sligo
Loch Lomond & The Trossachs National Park
Lake District National Park
Yorkshire Dales National Park
1812-1850

Ardnamurchan Point

Barra Head

1851-1860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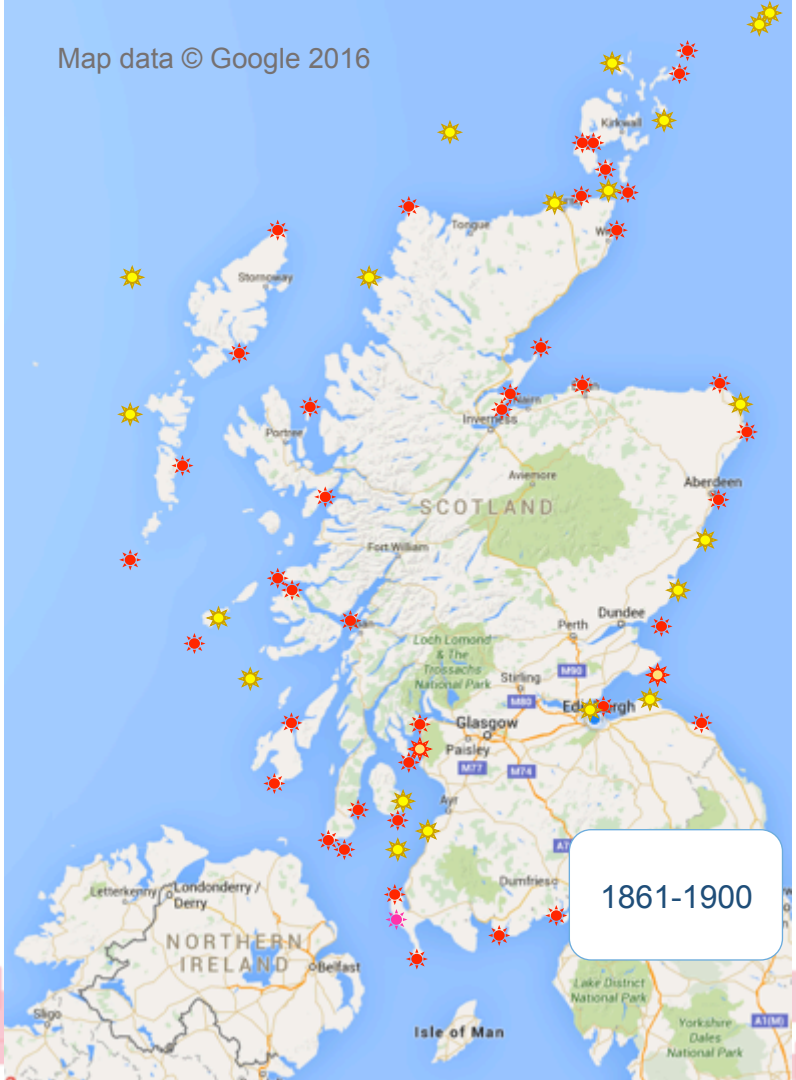
Aviemore
Loch Lomond & The Trossachs National Park
Lake District National Park
Yorkshire Dales National Park
1851-1860

Rubha na Gall
(Tobermory, Mull)

Cantlick Head, Orkney

1861-1900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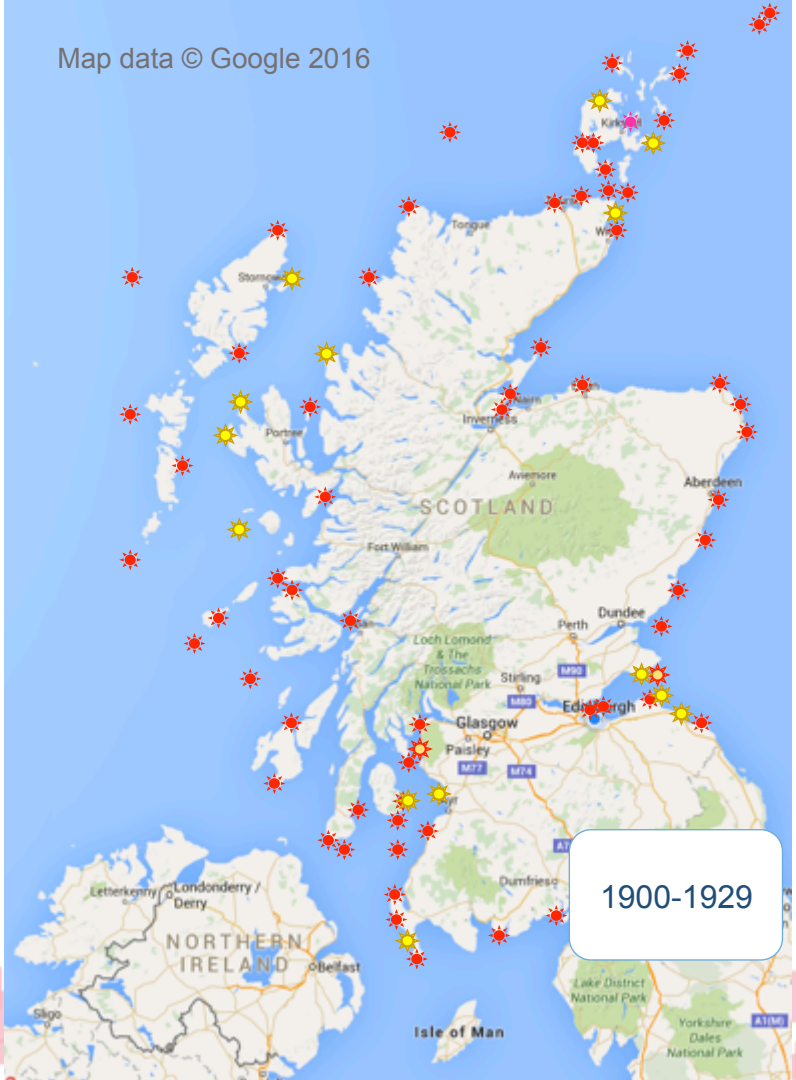
Yorkshire Dales National Park
1861-1900

STOER

1900-1929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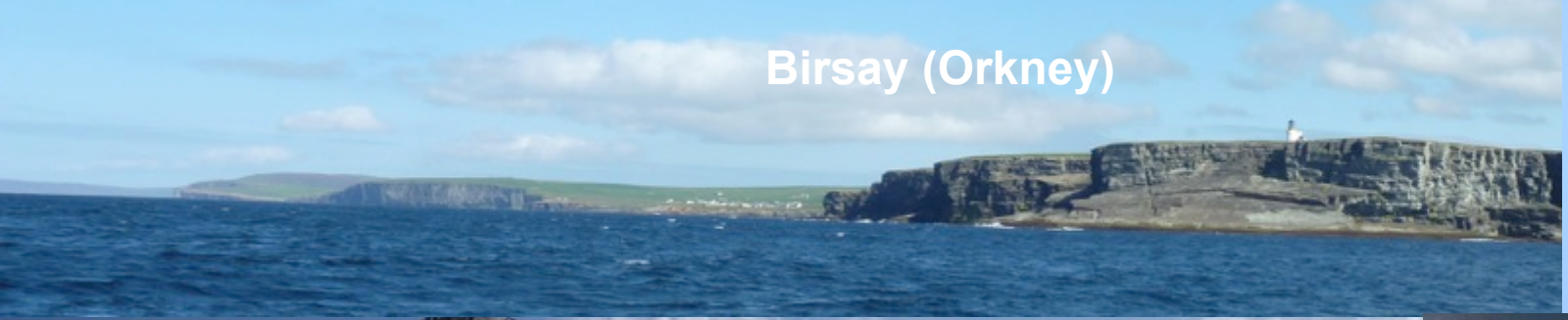
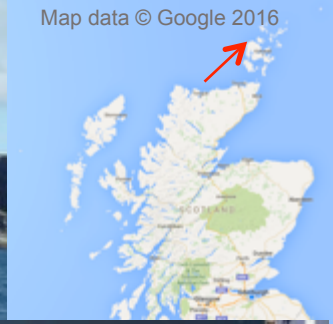
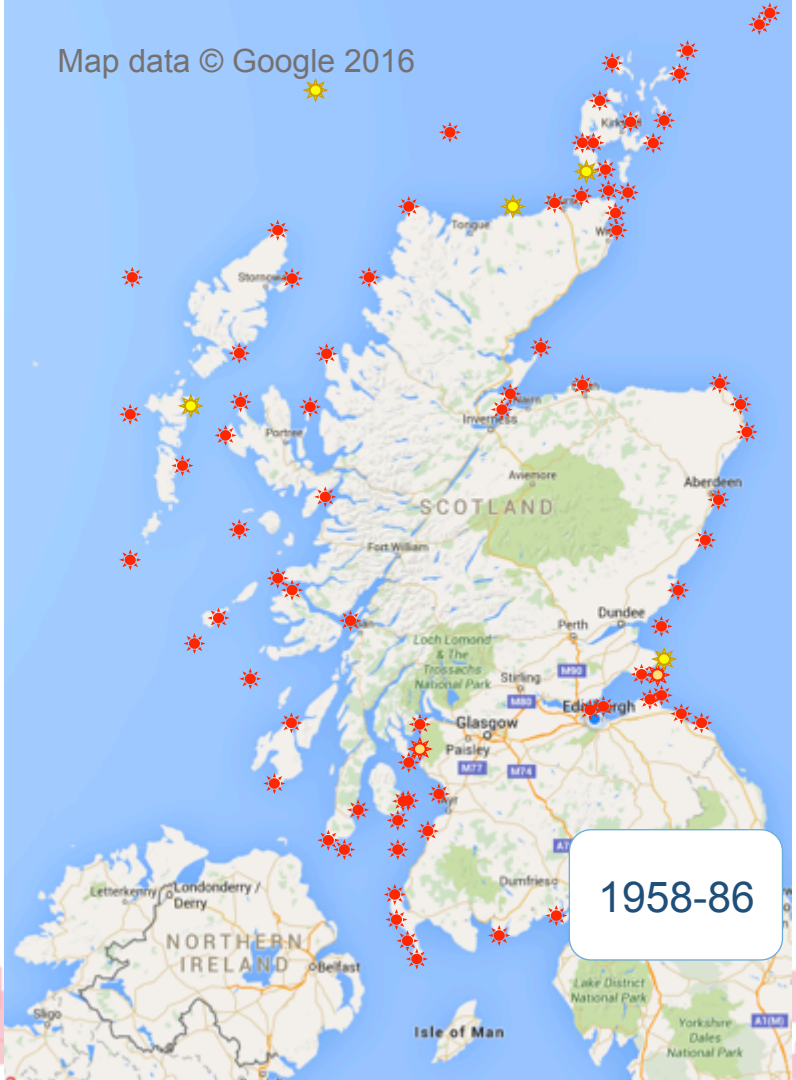
Lake District National Park
Yorkshire Dales National Park
1900-1929

Birsay (Orkney)





1958-1986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Londonderry / Derry
Letterkenny
Belfast
Sligo
Lake District National Park
Yorkshire Dales National Park
Loch Lomond & The Trossachs National Park
1958-86

Three general “patterns” for individual lighthouses

- Rock lighthouses:
  - May or may not be submerged at high tide
  - Subject to intense wave pressure in winter storms
  - Keeper accommodation in the tower
  - Support and relief only possible by sea
  - Tower must be high enough to give required horizon range
- Coastal lighthouses
  - Prospect of land access from local community
  - Back from the sea, not subject to same wave pressure
  - Keepers’ (and if appropriate their families’) accommodation in cottages close to light
  - Tower must be high enough to give required horizon range
- Headland/Clifftop lighthouses
  - Prospect of land access from local community (sometimes)
  - Back from the sea, not subject to same wave pressure
  - Keepers’ (and if appropriate their families’) accommodation in cottages close to light
  - Tower high enough to clear local terrain, accommodate rotation drive
- Each lighthouse is similar in principle but unique in detail

Kinnaird

Keeping the light turning

Capability Management

Can we discern consideration of the various “components of capability”?

– Training, Equipment, People, Information, Doctrine, Organisation, Infrastructure and Logistics

People

Organisation

THE

COMMISSIONERS STORY

IN THE BEGINNING

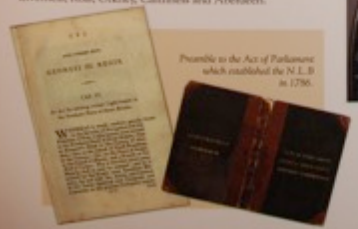
In 1782 a violent series of storms struck the coasts of Britain. Ships were wrecked and many lives lost. Following the storms a number of writers highlighted the need for lights around the coast of Scotland. George Dempster, M.P. for Forfar and Fife whilst Provost of the Burgh of Forfar raised the need for lights at the Convention of Royal Burghs. In 1786 the matter was taken to Parliament. In May the House of Commons established a committee to consider the need for lighthouses 'for improving the navigation of the northern seas of Great Britain'. The Committee recommended to the Commons that a Bill be prepared to set up a Board of Trustees or Commissioners with instructions to build four lighthouses. A Bill was presented to the House of Commons on 31st May 1786. It had been drafted by John Gray, a writer to the signet. With only one small amendment the Bill became law on 27th June 1786.

84 George Street, Edinburgh. Headquarters of the N.L.B.

On 1st August 1786, the Commissioners of the Northern Lighthouse Board met in Edinburgh to begin their task. They were instructed to build lighthouses at Kinnaird Head, North Ronaldsay, Eilean Glas and the Mull of Kintyre. The Lord Provost of Edinburgh, James Dickson was elected as Chairman and John Gray who had so efficiently drawn up the original Bill was nominated to be Clerk. John Gray remained Secretary to the Board until he retired in 1811. The Act allowed the Commissioners to borrow a maximum of £1,200 to build the four lights. The Act also laid down a scale of charges to be made on shipping once the lights had been built. The dues were originally fixed at one penny per ton on British ships and two pennies per ton on foreign vessels passing any of the lights, either leaving or arriving at British ports or passing the coast on passage elsewhere. Exemptions were made for whaling fleets.

The Act of Parliament established a Board to administer the new lighthouses. The Board would consist of Scotland's two Crown Officers, the Lord Advocate and the Solicitor General. Next came the Lord Provosts and Senior Bailie's of Edinburgh, and Glasgow, and the Provost's of Aberdeen, Inverness and Campbeltown. To these were added the Sheriff's of Edinburgh, Lanark, Renfrew, Bute, Argyll, Inverness, Ross, Orkney, Caithness and Aberdeen.

The motto of the Northern Lighthouse Board - 'In Salutem Omnium', 'For The Safety of All'.



Preamble to the Act of Parliament which established the N.L.B. in 1786.

THE KEEPERS STORY

RULES & REGULATIONS

The Northern Lighthouse Board's service regulations covered almost every aspect of the work of the Lighthouse Keepers. Major G H Elliot, Engineer - Secretary of the U.S. Lighthouse Service, reported in 1873.

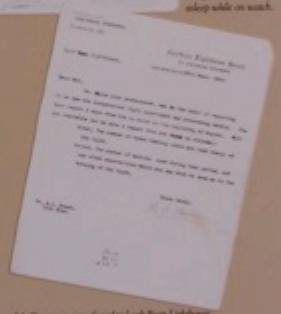
"The regulations affecting the Keepers of the Northern Lights are quite severe, and for any neglect of duty or other misconduct the Keeper is peremptorily dismissed or otherwise punished, and a printed circular, advising Keepers of the facts in the case, is at once sent to all the Stations in the service. The warning thus received tends greatly to promote the efficiency and good management of the Lights!"

The most serious offence a Light Keeper could commit was falling asleep on watch and allowing the Light to go out or alter its character by letting the revolving machinery run down. There was a conspiracy of silence at Sumburgh Head in 1871 by which two Light Keepers agreed not to report each other for sleeping on duty. One was a Principal Keeper with 23 years service. Both men were dismissed.

In the section on Routine Duties, priority was given to cleaning "The optical apparatus, lantern panes and lightroom machinery are to be thoroughly cleansed every day, particular attention being paid to polishing the glass and bright work". There are specific rules on making monthly returns and weather reports, on flying the N.L.B. flag, and opening the Lighthouse to visitors, and even on how to receive Royal visitors. Fines and loss of rank were imposed for lesser offences.

During a relief of the Flannan Isles in 1911 a Keeper lost the mail bag when it was swept away from him in bad weather. According to James Cadger, Master of the Pole Star, the men were almost swept away with all the baggage when they were "unexpectedly overwhelmed" by the sea. In a rebuke from Coventry Dick Peddie, Secretary to the Board "The mail bag should invariably be kept in a place of undoubted safety until taken charge of by the Keeper coming ashore".

Alexander Irvine Grant and Family. Mr Grant was reduced from Principal Keeper to the rank of Assistant Lighthouse Keeper on 11 May 1898 for failing to report the Assistant Light Keeper when he fell asleep while on watch.



Mr Grant was transferred to Loch Ryan Lighthouse. A letter from the Boards Engineer, D. A. Stevenson, asks for reports on the working of the light.

In a service where failure could have meant the loss of ships and lives, breaches of the rules have always been severely dealt with. For the most part however the Lighthouse Keepers of the Northern Lighthouse Board have shown considerable, self-sacrifice, courage and total devotion to duty on the working of the light.

Doctrine

THE KEEPERS STORY

WELFARE & HEALTH

The Lighthouse Board and particularly their Engineers recognised that the only way to secure a good Light was to have a Keeper happy with his job. Once a man joined the Lighthouse service, so long as he fulfilled his duties, he could expect the Board to look after his welfare and the welfare of his family. In the harsh employment climate of the mid 19th century this concern was highly unusual. It is remarkable that in 1894 there was a waiting list of over 200 would be Keepers.

The wages for Keeper's at British lighthouses were standardised for the first time in 1873 by the Board of Trade. For the next twenty years Principal Keeper's wages were fixed at £56.00 rising to £62.00 and Assistant Keeper's wages at £44.00 rising to £48.00 with allowances for rent, heating, lighting, clothing, ground and gardens totalling £28.00. Rock Stations paid better and the Keeper's received a special rock victualling allowance. After a petition from Keeper's, wages were reviewed again in 1896. The new scale paid Principal Keeper's £68.00 per annum rising to £76.00 after ten years service. Holidays with pay were introduced in 1882 with "two clear days and nights twice in each year" and ten years later ten days annual holiday were granted. At this time Keeper's on rock stations served six weeks on the rock then two weeks ashore. Paid holidays would come as a blessing.

Mr John Grant, Lighthouse Keeper (1870 - 1958) with his wife and family.

In addition to pay and housing each Keeper would receive a uniform. The Carpenter to the Board would measure up the Keeper for his new uniform when the Board's ship visited the stations on stores or oiling visits. The style of uniforms have changed over the years. Distinctions in rank have always been drawn between an Assistant Keeper and the Principal Keeper.

In 1896 a silk velvet collar on the jacket was the distinguishing mark of the Principal Keeper. There was also protective clothing provided for use on watch.

Believed to be Mr & Mrs J. Campbell at Fair Isle around 1912.

The Board also operated a kind of health care service by paying a local doctor a retainer to attend to the Keeper's and their families. If a doctor had to be called the Keeper would still have to pay for treatment but the Board ensured that at least the doctor would feel obliged to call. This may have gone some small way at allaying the terror of illness in such remote locations.

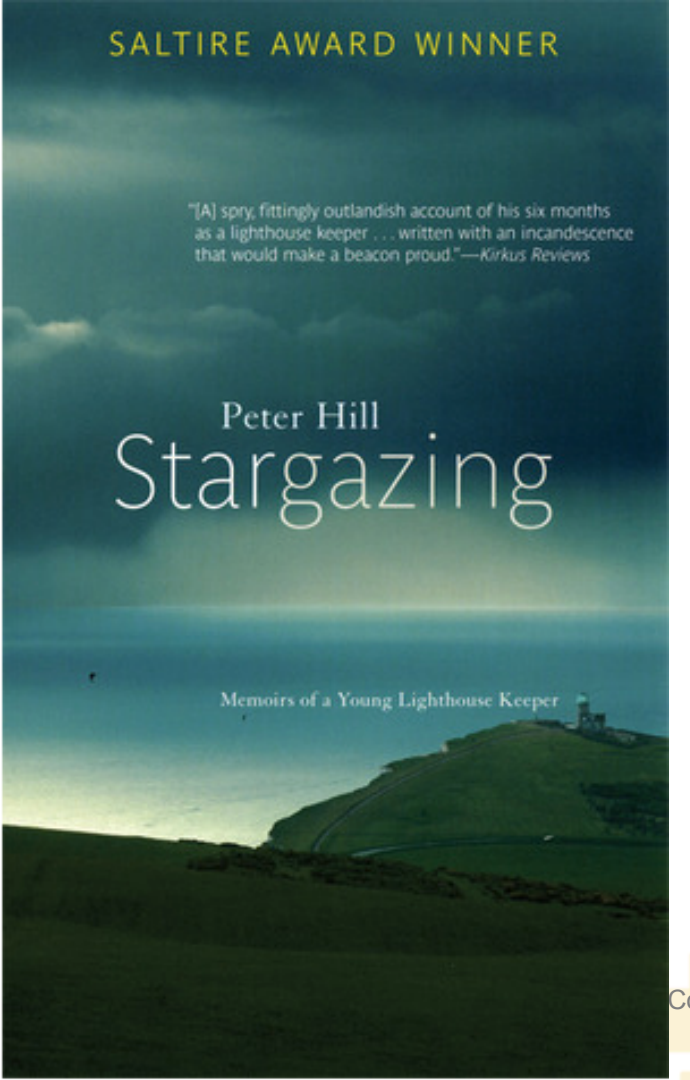
A touring Gramophone Service for Lighthouses.

The Board also concerned itself with the spiritual and educational welfare of its men. It became a rule that the Principal Lightkeeper conduct a Sunday service. The Commissioners also appointed a missionary chaplain to travel round the lights. The Rev. George Easton was appointed in 1852 and remained lighthouse missionary for 41 years, visiting each lighthouse, if possible, at least once a year.

The Board also operated its own library service to ensure a good supply of reading material for each station. To each lighthouse in an area it was arranged to send at regular intervals "two magazines for the adults and three small publications for the wives and children". Also each station would be sent two new books annually.

Generally the Commissioners, largely through the intervention of the Engineers and their own annual tours of inspection, seem to have taken a serious paternalistic interest in the men who served the lights on their behalf.

TRAINING



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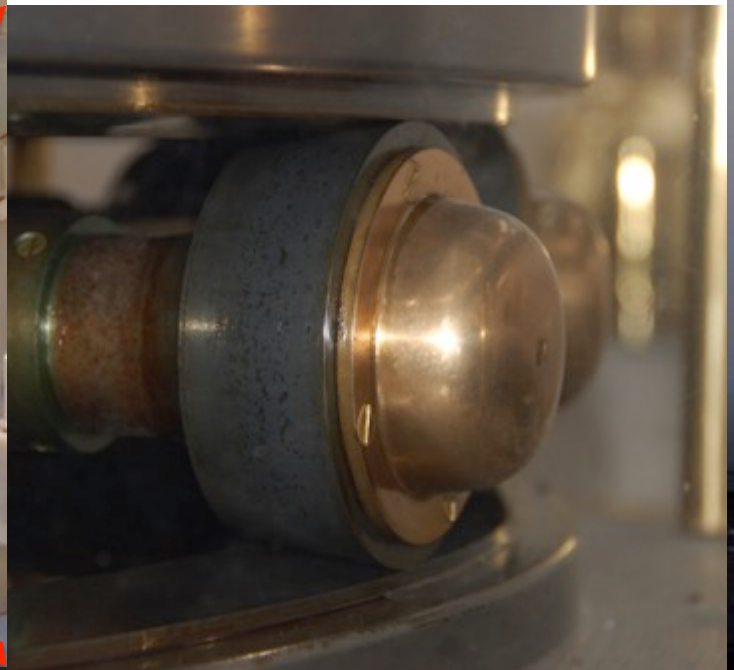
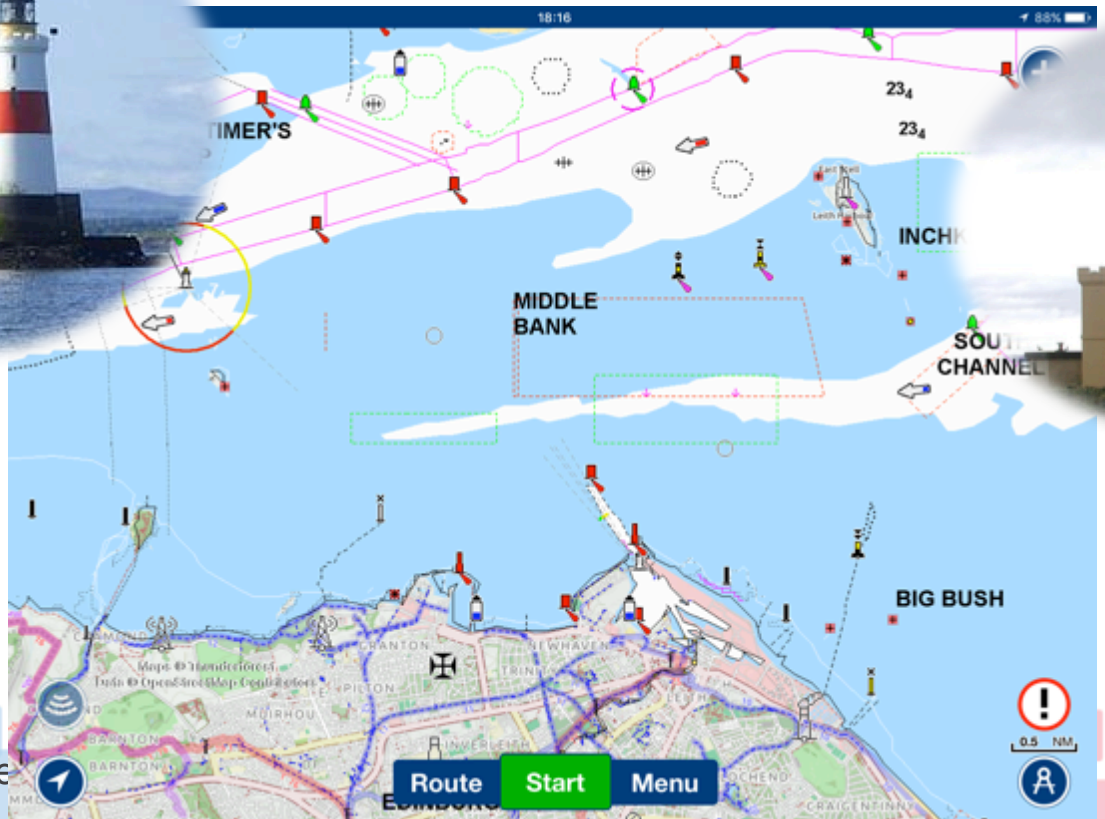
Equipment and Technology



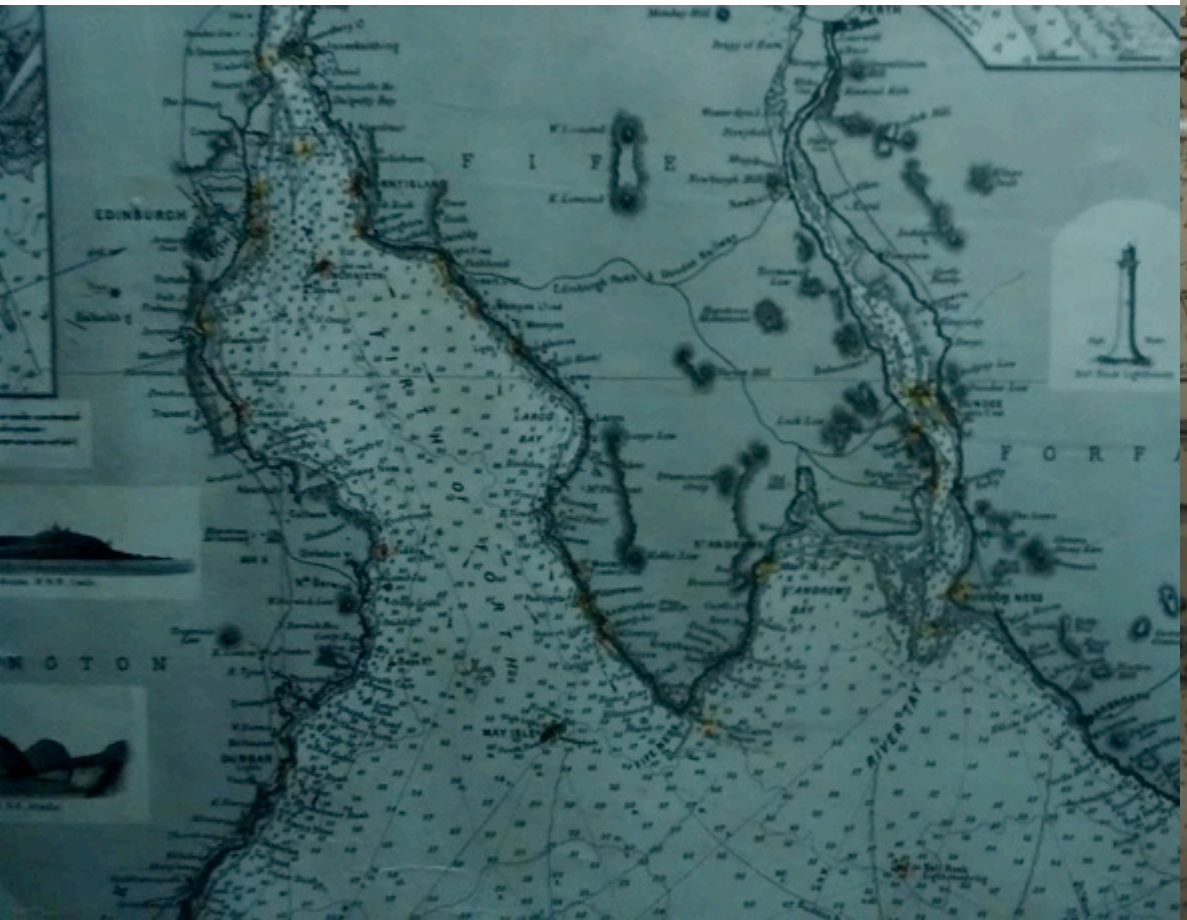
Oxcars – first automatic light in 1894 – lit by gas, controlled by clockwork
Photo Wikimedia Commons

Technology Testing:
Operational lighthouses
with line of sight & easy access from Edinburgh



Inchkeith – test bed for electric lights mid 19th cent
Photo by Ken Dougal RFYC

Information



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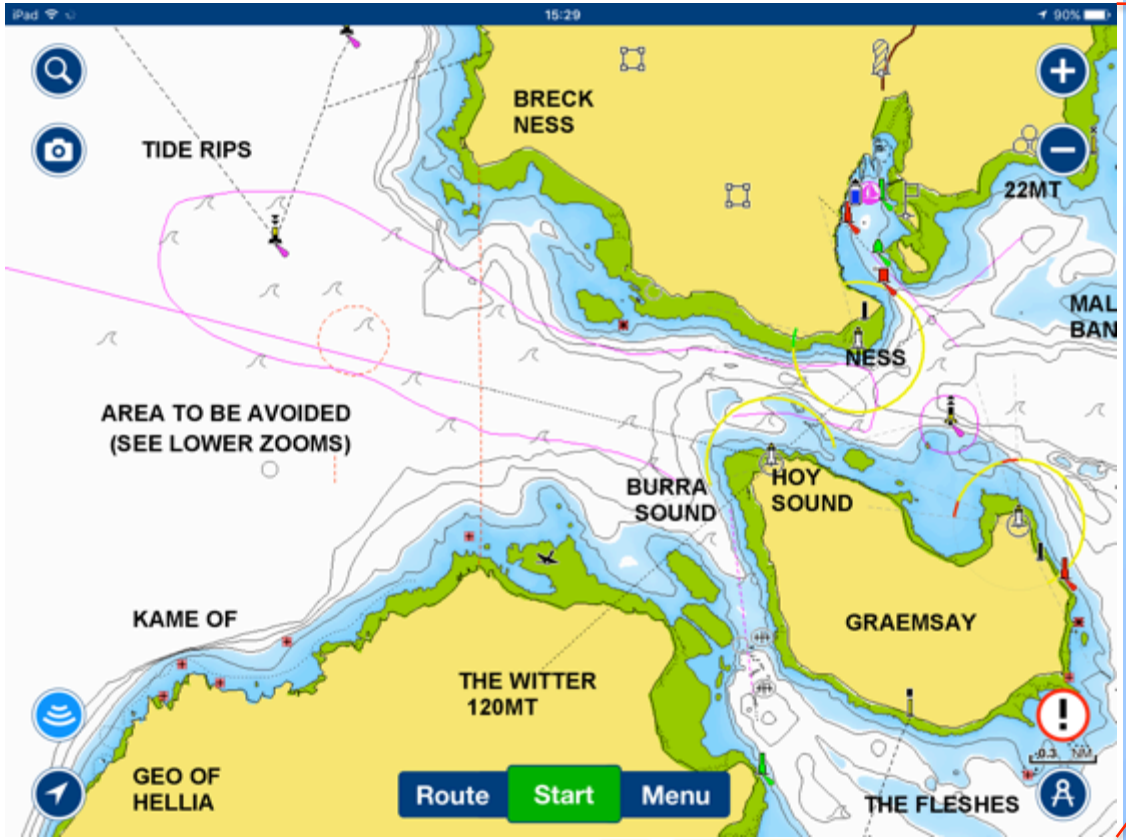
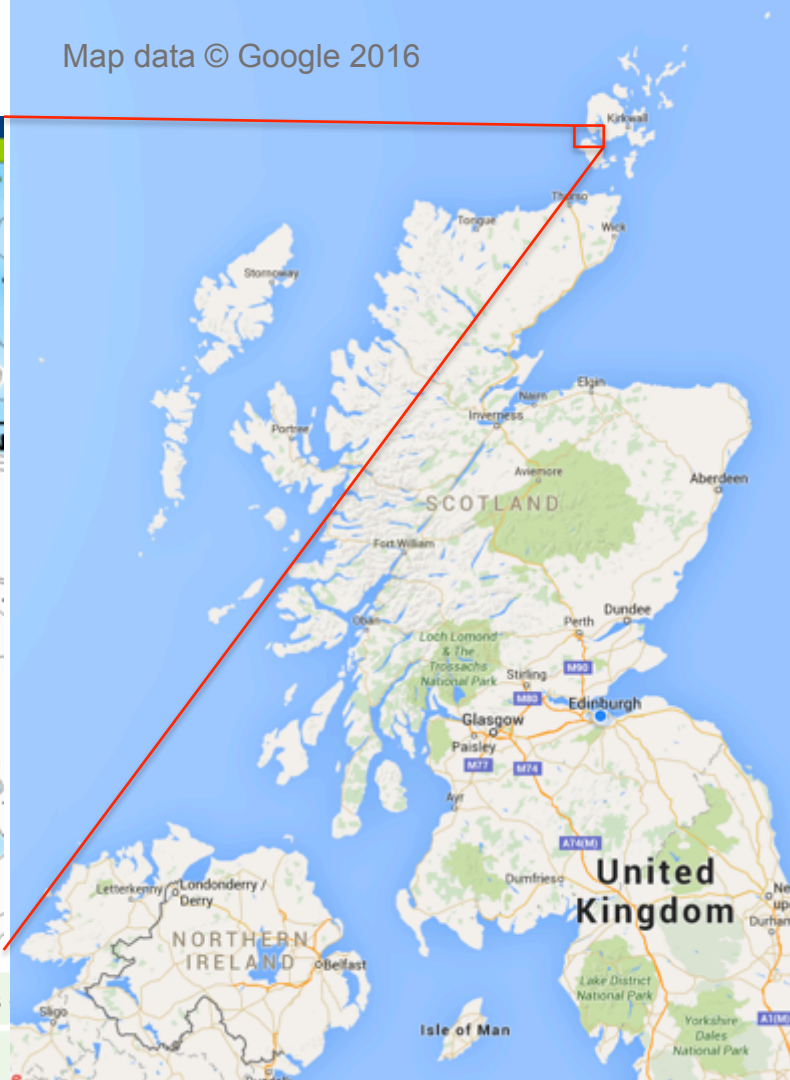




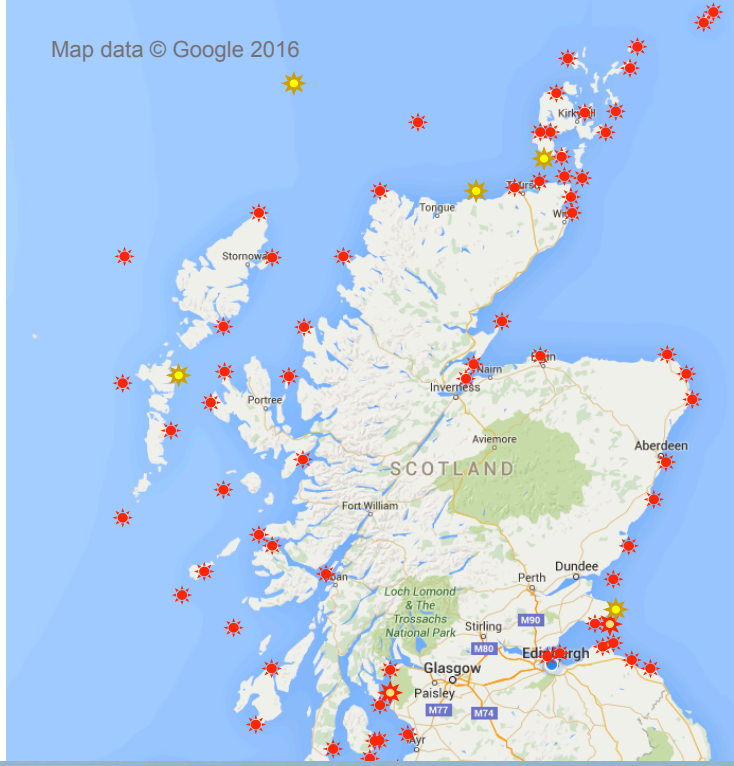
Infrastructure

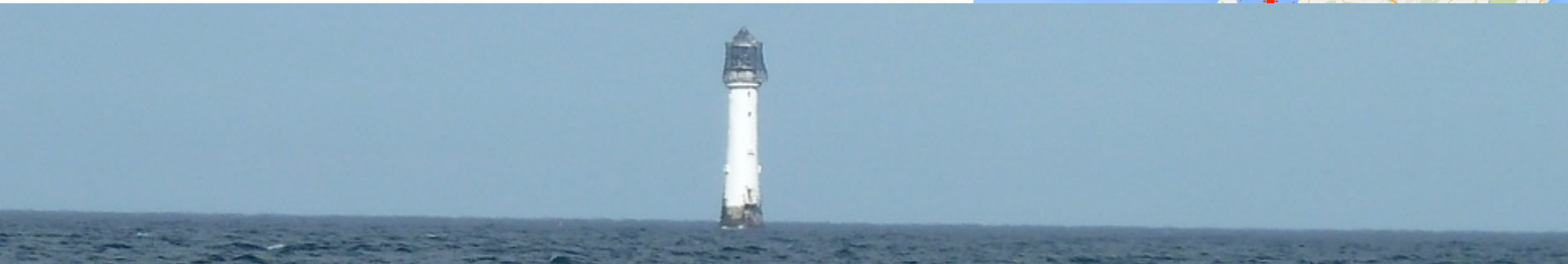
Logistics

Photo by Adrian Shield, 2014

Lighthouses

- Are they a system (and if so, what sort?) ✔
- Can we discern evidence of systems engineering? ✔
- Can we discern evidence of a Systems Architecture? ✔
- Can we discern evidence of Capability Management? ✔
- Can we learn from the past? ?





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Thank you for your attention

Questions?