Slide 1
Title slide

Slide 2
The session learning outcomes are:

- Review the information needed by the navigator and the means used to provide this information;
- Relate the changes that have occurred to navigation equipment in recent history;
- Recognise the impact that the changes have had on navigational performance and trading capability.

Slide 3
Success of a maritime venture

- The success of a maritime trading venture can be measured against a number of benchmarks:
    - It's an economic success for all parties involved in the venture:
        - Shipowner
        - Charterer (if appropriate)
        - Cargo owner / shipper

Slide 4
Success of a maritime venture

- In order to achieve this economic success, the cargo must arrive at its destination in good order and to achieve this:
    - The cargo must be stowed and carried correctly
    - The ship must complete the voyage in a timely manner

Slide 5
Successful completion of the voyage

- In order for the ship to complete the voyage in a timely manner the ship must know:
    - Where it is;
    - Where it is going;
    - Where other ships are located;
- These navigational needs have always been the same only the method of determination has changed;
- Any improvement in navigational performance will also enhance the opportunity for success of the venture.

Slide 6

21st Century navigation equipment

In the 21st Century the principle navigation tools are:

- Satellite position fixing system (typically GPS)
- Echo sounder
- Radar
- Gyro compass
- Log
- Charts and publications

Satellite position fixing system

Typically, the satellite position fixing used is GPS or DGPS which provides a continuously updated position of the ship on a global basis often with an accuracy of less than one metre.

Echo sounder

The echo sounder is a sonar device which provides a continuous indication of the depth of water below the ship's keel.

Radar

Radar enables the ship to detect the presence of other vessels and land mass when in fog or other conditions of restricted visibility. Correctly used radar assists the ship to fix position and avoid collision so that she can continue to navigate safely in these adverse conditions.

Gyro compass

The gyro compass provides a very reliable directional datum for steering purposes also heading inputs to other navigational equipment.

Log

The log is typically a sonar device which provides a continuous indication of the ship's current speed and the distance travelled from a specified point.

Charts and publications

These provide information on the hydrography and topography to enable all vessels to navigate safely around the globe.

Slide 7

Whilst not strictly classed as a navigation tool this equipment also has an important role to play in the ship's trading capability:

- Satellite communications system
- Automatic identification system (AIS)

Satellite communications system

This communications system is capable of providing near global communications on demand for both ship to shore and shore to ship purposes.

Automatic identification system (AIS)

This is system which automatically identifies ships to each other and to the shore authorities.

Slide 8

Navigation in 1977

Let's turn the clock back to 1977 (less than 40 years ago at the time of writing in 2015) to a voyage I undertook as the navigating officer on board a 21-knot reefer (refrigerated cargo ship). We were running from Nagoya (Japan) to Iquique (Chile) with a cargo of cars.

Given that the ship was a reefer then the fact that we had a cargo of cars may seem rather strange. This cargo paid the cost of the bunkers (fuel) to re-position the ship to the Eastern side of the Pacific Ocean. Here the ship could pick-up the perishable cargoes that she was designed for and which commanded much higher freight rates.

A typical voyage pattern and cargo was:

- Japan to South America with cars;
- South America to Central America in ballast (no cargo on board);
- Central America to the USA with bananas;
- USA to Japan with citrus fruit.

The principles of this voyage pattern are a modern example of the 'silk road of the sea'.

Slide 9

Navigation in 1977 – Nagoya to Iquique

At 21 knots the voyage time from Nagoya to Iquique was approximately three weeks with nothing but the horizon to see on route!

1977 was in the pre-GPS era consequently when out of sight of land we fixed position by observations of the Sun and Stars (celestial bodies). A sextant was used to measure the angle between the horizon and the celestial body at a specific time indicated by a chronometer (a sophisticated wind-up clock). Calculations based upon these observations were made using hard copy logarithm tables and an almanac providing details of the positions of the celestial bodies. Typically, it would take 30 minutes to observe and calculate a position using the Stars or some three hours when using the Sun.

Positions could generally be obtained three times a day at dawn, noon and dusk (there are situation specific exceptions when the Sun and another celestial body are visible during daytime). At best the accuracy of the observed position was one mile. All depended on being able to see both the celestial body and the horizon, if either were missing then: no position!

At that time, in my experience, it was quite common to cross the North Atlantic in Winter without being able to obtain a single position!

Slide 10

Navigation in 1977 – Landfall at Iquique

Given the problems associated with obtaining a position when out of sight of land then the most dangerous part of the voyage was making the transition from ocean navigation to coastal navigation, commonly termed ‘making a landfall’.

None of the navigating officers on board had been to Iquique before consequently, with good reason, we were very cautious with our final approach.

The coastline in the vicinity of Iquique is orientated in a North/South direction and with respect to radar, featureless. Radar would provide an indication of the distance off the coast (our longitude) but no indication of where we were along this coast (our latitude). The seabed doesn’t rise significantly until close inshore; therefore, the echo sounder would give little warning of grounding. The Sailing Directions gave the following detailed advice:

“The coastal mountains appear from a distance as an unbroken ridge with no distinctive features. On closer approach Punta Gruesa wiyth three white patches on its N side and Monta Tarapache, 4½ miles E, the highest in the vicinity, are among the first identifiable features. A railway which ascends the slope behind the city in a zig-zag is a useful landmark.”

(Great Britain, 2015)

Originally, we were due to arrive during the hours of darkness. In view of our navigational concerns we slowed down so that the final approach was made in daylight.

On the morning of our arrival the sky was clear and the white patches clearly observed. Consequently, we were where our celestial observations indicated that we should be! With this initial confirmation that our celestial navigation had been correct we continued our approach, the railway line became identifiable, and we safely berthed in Iquique.

Slide 11

Navigation improvements

Had we had GPS then, arguably, we wouldn’t have lost this time waiting for daylight. In previous times with inferior equipment and data then it wasn’t just time that would have been lost but potentially the ship, cargo and all on board.

An overview of the improvements in the quality of navigation and the consequential impact on trade is appropriate.

Slide 12

Position fixing – Line of Position

In ancient times observation of natural phenomena, migratory bird routes, wave trains, wind directions were used to in determining position and direction of travel, however, this was based upon local knowledge at least in relative terms. The principles of fixing position suitable for navigation on a global scale by scientific observation have not essentially changed in centuries.

In essence, it is the use of triangulation. If an object (navigation mark, light or celestial body) which is:

- Visible
- Positively identifiable
- In a known position (on a chart or in space)

Then observation of this object enables a line of position (LOP) to be determined and drawn on a chart. The ship's position will lie somewhere along this line. (Great Britain, 2008)

Slide 13

Position fixing – Position Fix

If multiple LOPs can be determined for a given time then where they cross is the position of the ship. (Great Britain, 2008)

Slide 14

Coastal navigation

The provision of aids to navigation, lighthouses, buoyage, electronic positioning systems etc. have had a major impact on the safety of coastal navigation. In 1977, it was possible to sail right around the coast of the UK without losing sight of a major lighthouse or light vessel. The emphasis in 2015 has shifted from these traditional aids to electronic aids i.e. Differential GPS and E-Loran (at some time in the near future).

In addition it is the charting and provision of information relating to these aids to navigation and other navigationally significant objects that has improved. These are considered further in the section on Charts & Publications.

Slide 15

Ocean position fixing

This is the process that has seen the keynote changes in recent history with the advent of the chronometer, nautical almanac and satellite position fixing systems.

- Latitude sailing
- Longitude, time and the nautical almanac
- Morning and Noon Sun sights
- Satellite systems: Transit & GPS

Slide 16

Latitude Sailing

Observation of the Sun and the Pole Star (in the Northern hemisphere) to obtain latitude has been used since antiquity as there is no requirement for an accurate knowledge of time to obtain the ship's latitude.

Observation of longitude demands an accurate knowledge of time and this was not available to seafarers until the late 18th century.

Without an accurate knowledge of time then navigation when out of sight of land was perilous at best. The practice was to navigate to a latitude which when followed in an East or West direction would lead the ship clear of a navigational hazard or into port. The danger lay in knowing your longitude when you reached this parallel of latitude.

Knowledge of longitude in these circumstances is obtained by use of dead reckoning; a best guess would be a more suitable name. Dead reckoning depended on knowledge of ship's speed, distance travelled and course made good over the ground since your last known position. Course made good required knowledge of the effect of wind and currents on the ship.

The instrumentation for determining speed was crude similarly that for determining depth of water (log and lead respectively). Data on currents was often sparse.

Given that the length of ocean crossings under sail was measured in weeks and months rather than days then the room for error in any dead reckoning calculations was significant.

I have had experience on a powerful modern ship capable of 22 knots which was hove to in storm force winds for two days when several hundred miles out into the Atlantic off the Bay of Biscay. When the weather abated and we could fix position by the Sun we found that in that time that the ship had travelled some 20 miles astern! What hope of knowing her longitude would a sailing vessel in such circumstances have had without knowledge of time.

Slide 17

Longitude

It was the loss of four warships of the Royal Navy together with their crew of some 1500 men on the Isles of Scilly in October 1707 that prompted action on a means to determine longitude. It is debatable whether it was knowledge of longitude alone that was the primary cause of this disaster but it is undeniable that the lack of knowledge of an accurate position that did. (Gould, 2013)

The British Parliament's Longitude Act of 1714 offered a £20,000 prize for a method which would enable determination of longitude within certain constraints.

Two main contenders contested for this prize:

- Lunar Distance Method, a method of astronomical calculation which enables the determination of the time at Greenwich (Royal Observatory);
- The marine chronometer which provided direct knowledge of time.

It was the chronometer which won the day (but not the prize!) as the Lunar Method calculations were very complex with many opportunities for error. Raper, quoted in Lecky's Wrinkles, stated that Lunar Distances:

"Great practice is necessary for measuring the distance successfully; and the application of so many small corrections as are necessary where accuracy is required is, even with extraordinary care and some skill, scarcely compatible with extreme precision."

(Lecky STS, 1917)

When the first practical chronometer was tested on an 81-day trans-Atlantic voyage it was found to have lost 5 seconds during the crossing which equates to 1.25 minutes of longitude, approximately 1 nautical mile. This accuracy necessitated establishing the daily rate (loss or gain in time per day) before departure which could then be applied once at sea. (Gould, 2013)

Initially the cost of chronometers was enormous but subsequent developments reduced production costs made them attainable and increased demand. Lecky states that chronometers could be purchased new for £25 in 1881 and for much less second hand. So much so that they had become “a drug on the market”! (Lecky, 1917)

At this time, the majority of well-found vessels carried three chronometers, if only two were carried you wouldn’t know which was wrong if there was a difference between the two but if you had three then it would be clear which was in error. With the advent of radio time signals which enable calibration of the chronometers on a daily basis from an external source then it became common practice to carry two

Slide 18

Modern Celestial Navigation

In this context ‘modern’ covers the 200-year period from the 1770s to the 1970s when celestial navigation became superseded by satellite navigation systems.

There is a common misconception that once you know the time then it is very easy to determine longitude at the time of obtaining your latitude from the Sun at Noon.
This is not the case!

At Noon, the rate of change of the Sun’s altitude is so slow that it is impossible to measure the exact time that it is at its maximum when the Sun is on the meridian.
(Bowditch, 2004)

In practice, the approximate time of meridian passage will have been calculated in advance and you would commence checking the altitude about five minutes in advance. As the Sun gets higher increase the measured angle on the sextant as the Sun approaches the meridian but never reduce it. Once the Sun’s altitude starts to fall then you will know that the Sun is starting to move away from the meridian. You have already recorded the maximum altitude, when the Sun was on the meridian, but you do not know the exact time that this occurred. Hence no accurate longitude can be obtained.

With knowledge of accurate time then it is possible to obtain LOPs from the full range of celestial bodies at other times of the day.

Slide 19

Position fixing by the Sun

At any given time, it is only possible to get a single position line (LOP) from a celestial body and this will be at 90° to the direction of the body. Consequently, at Noon when the Sun is either directly North or South of you then the LOP will run in an East/West direction i.e. it is the latitude.

Conversely an ideal time to observe a celestial body to obtain longitude is when the body is bearing East or West of you, when it's on the Prime Vertical. With the Sun, it is impractical if not impossible to achieve this, nonetheless it is possible to obtain a LOP at other times.

Slides 20 & 21

Sun, Run, Sun

Given that only one LOP can be obtained at any one time then the method used to obtain a position from the Sun alone is a running fix, commonly known as Sun, Run, Sun.

Sun, Run, Sun - Plot

Typically, the method is to:

- Take a morning sight (observation) of the Sun. Usually three observations would be taken as close together in time as possible. If all three produce similar results then the accuracy is confirmed. If one of the sights is errant from the other two then this result would be discarded and the two in agreement used;
- Plot this LOP on a plotting chart;
- Calculate the time of local Noon (meridian passage);
- Calculate the distance that will be run from the time of your morning sight to Noon;
- Knowing the course steered and distance run plot a dead reckoning position (DR) for Noon (hence the term running fix);
- Plot the LOP from your morning sight through this DR, any error in this assumed position will lie along the LOP;
- Observe and calculate the latitude at Noon;
- Plot this on your plotting chart;
- Where the LOPs from your morning sight and Noon cross is the ship's observed position.

Slide 22

Sun, Run, Sun position accuracy

Clearly the accuracy of this method is very dependent upon your knowledge of ship's speed and the course made good over the period of time between your morning sight and Noon. This will be determined by:

- The accuracy of the log or other speed/distance measuring method;
- The helmsman's or the autopilot's course keeping capabilities in the current conditions, in rough weather there are likely to be unquantifiable errors between the course steered and the course made good;
- Data available on ocean current predictions.

Slide 23

Simultaneous LOPs

Occasionally it may be possible to obtain simultaneous LOPS from the Sun and Moon or Sun and one of the planets during daylight and where the two position lines cross is the ship's observed position.

Multiple position lines can also be obtained from the stars, however, remember that in order to observe the altitude of the star then the horizon must also be visible. Consequently, this is not usually possible during the night hours. The exception could be when there is sufficient Moonlight to show up the horizon.

Slides 24 & 25

Position fixing by Stars, Planets and the Moon

Normally it is only during morning twilight and evening twilight that it will be possible to see both the horizon and the stars. Typically, there will be a 20-minute period of opportunity to obtain your observations.

When possible a minimum of four observations will be taken from a selection of bright stars (easily visible) which have sufficient horizontal angles between them so that the plotted LOPs cross at the optimum angles.

Star sights are considered to provide the most accurate position because, other than the short distances run between the individual star observations, none of the inaccuracies associated with a running fix occur.

In my experience star sights are also the method most likely to be affected by the environmental conditions. Given the short window of opportunity during twilight if there is any momentary cloud cover then it will not be possible to take any observations. With the Sun there is a greater window of opportunity, some two to three hours, between sights.

For some 200 years these were the significant ocean position fixing methods until they were superseded by the artificial star: the satellites.

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Radar
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