Towards autonomous superyacht navigation

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Abstract. The paper aims to show possible ways in which increasing automation can be utilised in vessel navigation control especially in relation to Superyachts. It will start with a brief section on how navigation systems have been evolving to where we are now. It will then explore what is currently accepted and what benefits superyachts in particular may gain from further autonomy mainly from the aspect of possible changes to space utilisation. Finally a suggested path of evolution towards autonomy, in order to give enhanced owner and guest experience, will be outlined.

1. Evolution of navigation systems

Navigation is widely agreed to have existed since the early middle ages and in the 15th century the first world explorers utilised very basic instrumentation such as compasses to use landmarks and celestial observation and thus conduct and repeat voyages. By the early 18th century Sextants and chronometers were in use to conduct ever more predictable voyages.

In the United Kingdom regulations regarding navigation originated in the early 19th century and were developed by Trinity House and the Admiralty covering such things as rules for avoiding collision and display of navigation lights. The sinking of Titanic in 1912 was the main catalyst for the first International Convention for the Safety of Life at Sea – SOLAS 1914. This convention has been updated ever since to the latest version; SOLAS 1974, which has been regularly updated to incorporate latest technological developments.

Early in the 20th century there were very basic bridges with lookouts posted on bridge wings and sometimes up a mast in the crow’s nest. These lookouts were to observe by both sight and hearing as rules existed specifying navigation lights and sound signals such that the lookout could report to the officer of the watch what other vessels in the vicinity were doing as well as observations of shoreline features including lighthouses. Upcoming weather and sea conditions could also usually be observed better from higher observation points.

Along came radar which assisted the lookout function especially in poor visibility. It has long been the understanding that keeping an effective lookout shall be not just by sight but also by hearing with sound signals being a requirement for vessels navigating in restricted visibility. The evolution of fully enclosed bridges effectively meant the lookout coming inside and thus the requirement was made of sound reception facilities on vessels with fully enclosed bridges. Taking of sights is also more difficult as bridges became more enclosed. However electronic navigation systems had meant less need for sights except in event of failure which become increasingly rare as reliability improved.

A helmsman was on duty at all times until autopilots evolved initially just for use deep sea and then as they became more sophisticated, so they became used potentially throughout passages.

Radar systems were developed to allow detection of surface objects in reduced visibility these developed into ARPA (automated radar plotting aid). Echo sounders give details of proximity of the seabed and trends in depth. Paper Charts are being replaced with ECDIS (electronic chart display information systems). Radar and AIS data can be integrated with the ECDIS to provide good situational awareness. Dynamic Position Systems have developed to enable very accurate station keeping of specialist vessels which require special skills especially related to such things as knowing when human intervention into control systems is needed.
2. Current expectations

2.1 General

Vessels' bridges are governed by regulations covering layout and visibility primarily in SOLAS V\(^1\), with lookout requirements contained in STCW (International Convention on Standards of Training, Certification and Watchkeeping for Seafarers, 1978) Chapter VIII Regulation VIII/2.

![Photo. 1, An example of a yacht bridge with lounge above.](image)

2.2 Bridge layout and visibility

SOLAS V Regulation 22 covers bridge design to ensure good visibility. The specifications are for ships of 55m or more in length built on or after 1 July 1998. Administrations are given discretion for ships of unconventional design which may be a useful factor for development of autonomous vessels.

The length requirement means that many Large Yachts do not strictly fall under these requirements however the REG Yacht Code\(^2\) Section 18.6 requires navigation bridge visibility to comply with SOLAS V/22 with vessels under 55 metres in length required to comply as far as reasonable and practicable. Windows may be inclined from the vertical plane provided that, where necessary, appropriate measures are taken to avoid adverse reflections from within. Where the ship's side cannot be fully visible from the bridge wing, wing station or manoeuvring station, the use of cameras may be specially considered by the Administration giving consideration to image quality, night vision, display screen size and location.

When the ship's bridge is totally enclosed Sound reception facilities are required under SOLAS V Regulation 19 2.1.8 to enable the officer in charge of the navigational watch to hear sound signals and determine their direction; This feature and the use of cameras for viewing blind spots are examples of technological developments that will help towards less conventional bridges in the future and indeed potentially the eventual moving control off vessels.

2.3 Watchkeeping

STCW Chapter VIII Regulation VIII/2 states that the officer in charge of the navigational watch is responsible for navigating the ship safely during their periods of duty, when they shall be physically present on the navigating bridge or in a directly associated location such as the chartroom or bridge control room at all times. This is one of the main regulatory hurdles in the move to unmanned bridges.

The regulation also states that an appropriate and effective watch or watches shall be maintained for the purpose of safety at all times, while the ship is at anchor or moored. Also an appropriate and effective watch or watches has to be maintained for the purposes of security.

A dedicated lookout is needed at night in addition to person in charge of navigational watch. One man bridge operation was proposed to IMO several years ago but was rejected at that time.

Casualties resulting from the watchkeepers being asleep has resulted in such developments as comprehensive hours of work and rest regulations under both IMO (International Maritime Organisation).
and ILO (International Labour Organisation). Also the fitting of Bridge Navigation Watch Alarm Systems (BNWAS) has become a requirement under SOLAS V, Reg.19.2.2.3. However casualties still occur where the alarm is not switched on.

2.4 Emergency situations
In most superyachts the bridge tends to be the emergency control centre as many safety systems are indicated there and external communication systems are also located there as well. Various developments are occurring related to autonomy in such areas as remotely controlled lifebuoys for assisting with respect to rescuing persons overboard.

As manning levels reduce so more automation of onboard safety systems will be needed as there will be less persons available to assist in such actions as firefighting, casualty handling, and even such areas as emergency towing arrangements.

It will also be necessary to develop suitable means for external assistance to board the vessels but of course this presents problems of the conflict between security and accessibility.

3. Possible benefits of increased automation of navigation systems
With improved visual and audio sensors etc. bridge manning requirements could be reconsidered, there are currently possibilities for safely removing personnel from the bridge, certainly during long quiet ocean passages. Reduced manning of bridge frees up personnel for other duties. Use of optical sensors could easily improve the all round lookout when compared to the current practices with human lookouts. The consequent improvement in overall safety could be seen as beneficial.

It is imperative that the interaction between autonomous systems and humans is fully considered. Even in changes in bridge design over the years new problems have crept in. For example a forward mounted bridge with bridge windows unconventionally orientated was considered a significant contributory factor in a collision investigated by the U.K. Maritime Accident and Incident Investigation Board (MAIB) where relative motion illusion[3] affected the situational awareness of the Pilot. These kinds of factors will be amongst those in need of consideration if significant reliance is to be put on human interpretation of numerous display screens.

Financial benefits are possible from the possibilities of reducing crew numbers and thus the associated operational costs. Further benefit can potentially be gained by changing space utilisation which is investigated in more depth in the following section. Any perceived financial benefit would of course have to consider ongoing maintenance costs as well as costs of any additional verification etc. which would be in addition to the capital cost of installing the necessary systems.

In general it would be expected that the cost of installing systems on vessels will not be directly proportional to the size of vessel with a system on a small vessel probably costing nearly as much as on a larger one although of course larger vessels would probably need more sensors and cabling etc. That said proportionately the benefits of space reutilisation would be greater for smaller vessels as shown in table 1 and section 4.

There are possibilities of developing technology that can be utilised for developing convoy systems for the relocation of superyachts from one cruising area to another provided there is a good level of standardisation in the automated systems being developed. Thus just the lead vessel would be manned with the others following at safe distances behind. Similarly Superyachts that currently tow tenders may benefit from having these tenders operating independently without the need for personnel on board. Thus tender and mother vessel will not be subject to towing forces which not only affect structure but stability as well and of course this would remove the need for monitoring and marinating the tow line. Even of tenders are towed then there are benefits from good monitoring data of their condition being transmitted to the mother vessel.

4. Possible space reallocation within Superyachts by utilizing automated systems for navigation.
4.1 Typical Current space utilisation
Commercial sensitivity considerations make conducting a proper cost benefit analysis difficult, so it was decided to examine the available general arrangement and safety plans of 13 existing superyachts and a comparison of percentage of enclosed space utilized for various functions was made. The names of the yachts chosen have not been included in order to avoid infringing confidentiality, tonnages are approximate Gross Tonnage. From that a very basic design; m.y. Example was developed to demonstrate possible effect on these ratios by rededicating current bridge space and reducing manning (see figure 1). There are of course significant other cost variations especially from an operational cost point of view and in many ways a more autonomous yacht would be best designed as that from scratch, rather than just adapting an existing conventional design.

**Figure 1.** m.y. Example, rough G.A. plan.

4.1.1. **Space Utilisations considered.** Guest Cabin, Guest General Use, Crew Cabin, Crew Recreation, Technical spaces, Garage space (space used for storing tenders and “water toys”), Service spaces (Pantries, Bars, Galleys, Storage rooms) Bridge.

4.1.2. **Assumptions.** Only spaces with reasonable headroom were considered with alleyway and stairway spaces being allocated in accordance with use of the immediately adjacent spaces. Engine Control Rooms are included within Technical Spaces as they represent under 1% of total useable interior space.

4.1.3. **The data.** Table 1 below shows the data obtained with a line for each yacht and percentages being given for each space on it. The first 12 entries are certified as Large Yachts and the 13th is a Passenger Yacht. Data used for m.y. Example which uses space allocation similar to the mean values is also shown, as this is used as the basis for the effects comparison in subsequent tables.
Table 1. Comparison of space utilization in various superyachts.

| Tonnage | Guest Cabins | Guest General | Crew Cabin | Crew Recreation | Technical Spaces | Garage space | Service spaces | Bridge | Guest / Crew numbers |
|---------|--------------|---------------|------------|----------------|------------------|--------------|----------------|--------|----------------------|
| 399     | 26           | 23            | 10         | 5              | 12               | 7            | 12             | 5      | 10/7                 |
| 496     | 29           | 24            | 15         | 3              | 11               | 0            | 11             | 7      | 12/9                 |
| 642     | 25           | 17            | 12         | 3              | 29               | 3            | 7              | 4      | 12/13                |
| 656     | 26           | 21            | 13         | 3              | 19               | 5            | 8              | 5      | 12/13                |
| 769     | 14           | 24            | 16         | 6              | 23               | 0            | 11             | 6      | 12/11                |
| 996     | 30           | 20            | 9          | 6              | 14               | 5            | 13             | 3      | 12/16                |
| 1102    | 25           | 21            | 11         | 5              | 16               | 2            | 16             | 4      | 12/14                |
| 1416    | 14           | 25            | 14         | 5              | 29               | 2            | 9              | 2      | 12/22                |
| 1428    | 16           | 23            | 12         | 2              | 25               | 3            | 15             | 4      | 12/14                |
| 1592    | 23           | 22            | 12         | 3              | 23               | 6            | 8              | 3      | 12/18                |
| 2658    | 20           | 28            | 9          | 4              | 19               | 11           | 6              | 3      | 12/27                |
| 2744    | 15           | 31            | 14         | 2              | 23               | 5            | 8              | 2      | 12/30                |
| 6862    | 21           | 22            | 13         | 3              | 22               | 10           | 7              | 2      | 31/43                |

4.2 Effect of reduced human lookout
This section assumes a vessel remains much the same but with no requirement for a human lookout at night which could reduce crew numbers to say 11 and reasonable to assume a small reduction in space needed albeit not exactly proportional to total crew space due to consideration of such issues as cabin sharing. This sees guest space increase from 45% to 46% as shown in table 2, m.y. Example 2r.

Table 2. Showing space utilisation by removing human lookout requirement.

|                  | Guest Cabins | Guest General | Crew Cabin | Crew Recreation | Technical Spaces | Garage space | Service spaces | Bridge |
|------------------|--------------|---------------|------------|----------------|------------------|--------------|----------------|--------|
| m.y. Example     | 22           | 23            | 14         | 5              | 17               | 5            | 11             | 3      |
| m.y. Example 2r  | 22           | 24            | 13         | 5              | 17               | 5            | 11             | 3      |

4.3 Effect of rededicating the bridge area usage
This section uses the example vessel and demonstrates possible changes without any reduced manning.

Table 3. Showing space utilization with bridge space rededicated and control remaining on board.

|                  | Guest Cabins | Guest General | Crew Cabin | Crew Recreation | Technical Spaces | Garage space | Service spaces | Bridge |
|------------------|--------------|---------------|------------|----------------|------------------|--------------|----------------|--------|
| m.y. Example     | 22           | 23            | 14         | 5              | 17               | 5            | 11             | 3      |
| m.y. Example 2   | 22           | 25            | 14         | 5              | 18               | 5            | 11             | 0      |
| m.y. Example 3   | 24           | 23            | 14         | 5              | 18               | 5            | 11             | 0      |

4.3.1. Bridge used as Guest General Space. Probably an observation lounge which would reasonably practically give possibility of retaining some navigational equipment in the space. It is assumed that part of technical space would be rededicated as the navigational control station. Thus guest space increases from 45% to 47% as shown in table 3, m.y. Example 2. That said yacht bridges already usually have seating areas that can be utilized by selected guests.
4.3.2. Bridge used as Guest Cabin. Unlikely that navigational equipment would be retained in the space. Essentially a similar change of space allocated to guests occurs from 45% to 47% as shown by m.y. Example 3.

4.3.3. Bridge space used for guest space and navigation functions transferred ashore. Essentially this means no increase in technical space needed as shown in table 4, however no manning reduction is considered in this table and guest spaces increase from 45% to 48%. m.y. Example 2a is with bridge space used as general guest space and m.y. Example 3a with use as guest cabins.

**Table 4.** Showing space utilization with bridge space rededicated and control moved off the vessel.

|                | Guest Cabins | Guest General | Crew Cabin | Crew Recreation | Technical Spaces | Garage space | Service spaces | Bridge |
|----------------|--------------|---------------|------------|-----------------|------------------|--------------|----------------|--------|
| m.y. Example   | 22           | 23            | 14         | 5               | 17               | 5            | 11             | 3      |
| m.y. Example 2a| 22           | 26            | 14         | 5               | 17               | 5            | 11             | 0      |
| m.y. Example 3a| 25           | 23            | 14         | 5               | 17               | 5            | 11             | 0      |

4.4 Additional effect of potential reduced manning
This section considers changes of space allocation possible by removing say 3 navigational related seafarers as well as removal of the bridge. This shows guest space increasing from 45% to 52% for m.y. Example 2n.

**Table 5.** Showing space utilization with redeclaration of bridge and seafarer number reduction.

|                | Guest Cabins | Guest General | Crew Cabin | Crew Recreation | Technical Spaces | Garage space | Service spaces | Bridge |
|----------------|--------------|---------------|------------|-----------------|------------------|--------------|----------------|--------|
| m.y. Example   | 22           | 23            | 14         | 5               | 17               | 5            | 11             | 3      |
| m.y. Example 2n| 22           | 30            | 10         | 5               | 17               | 5            | 11             | 0      |

4.5 Conclusion with respect to potential financial benefits of space reallocation
The increases in relative guest space allocation is quite modest and at this moment in time it is unlikely that the expense of the necessary sensing and monitoring systems needed would be justified. Unfortunately, there are large variations in construction costs of superyachts with numerous factors and commercial confidentiality does make conduct of full cost benefit analysis difficult.

Of course some owners do just want the latest technology even at a large cost so there are possibilities there.

There main benefits will potentially be for yachts close to the various sizes where regulatory compliance changes, such as 400GT. for MARPOL certification requirements, for SOLAS 500GT is a major changing point. Here if a vessel just under the relevant criteria can have an actually larger guest space than one just over then the benefits of automation may be larger, in other words it becomes a situation where a smaller yacht could have the same guest space as a larger one.

In the examples of bridges effectively being done away there is another drawback which is that it means there is less space being used by crew members to meet up.

It would be reasonable to assume a construction cost of say $25 million for a vessel like m/y example so a 1% change in useable space could be considered worth $250,000 Similarly if a crew member position cost $50000 per year to fill over 20 years that would be a $1million saving by not having to carry such a person. Although very rough these figures give some idea of the additional costs of fitting automated systems that could be financially justified. However very few superyachts have high utilization rates, so not that much time is spent at sea, thus navigational watchkeeping is not required all the time. However, security considerations mean that the technology that is utilized for reducing lookout requirements at sea can similarly be utilized for changing the way security watches are conducted in port, many vessels already utilize security cameras to assist with this.
5. Possible path of evolution for Superyachts by utilizing automated systems for navigation

5.1 Reduced human lookout requirements

The first stage could be to utilize the greatly improved visual and audio sensors and systems to remove the need for a separate dedicated lookout stationed on or in immediate contact with the bridge, thus enabling single watchkeeper operations in many circumstances.

The overall bridge design will still be expected to conform to requirements for visibility etc. Instead of a Human lookout this function would be undertaken by optical and audio sensors which would be programmed to alarm at pre set criteria and provide similar or enhanced information to that would be given by a typical human lookout.

The main advantage of this would be that the automated lookout system should not get “tired” and fall asleep. Also the automated system should not be afraid to report things, as sometimes occurs with human lookouts where there may be cultural and other clashes between the officer of the watch or Master.

The main drawback with this could be that excessive alarms so the appropriate programming of the sensors is important and elements of “machine learning” need to be carefully considered.

A further development of this would be along the lines of the current thinking on a B0 (B0 – a conditionally and periodically unmanned bridge) type scenario which is essentially for a tradition wheelhouse type arrangement but with it being periodically unattended in much the same way as engine control rooms often are. Here the main savings would be by reduced manning requirements. Without the need for continuous manning savings would very much depend upon operational areas and the residual demand for attendance on the bridge.

5.2 Partial rededication of bridge space

The next stage could be to allow for operation from an operating station still in the traditional wheelhouse location but where that space is used as a guest lounge and the navigational equipment has a smaller footprint and is only used during navigation or possibly just for maneuvering. The cost benefit is also difficult to determine here due to the numerous variables involved.

5.3 Effective Relocation of bridge space

This stage would see the moving away from the traditional bridge location and maybe sharing with engine control room in a location where space cannot really be utilized by guests or is certainly less attractive for guest use. There would still be a remote operation capability from a position suitable for direct observation of operations by a human.
It should be noted that the views contained in this paper are those of the author and not necessarily the organisation for whom he works.

References

[1] Various references have been made to publicly available International Maritime Organization documents throughout the paper for example; STCW including 2010 Manila Amendments, 2017 Edition - SOLAS Consolidated Edition, 2020 - MARPOL, Consolidated Edition, 2017 - Current full listing at: <http://www.imo.org/en/Publications/Pages/CurrentPublications.aspx>

[2] Red Ensign Group Yacht Code January 2019 Edition; https://www.redensigngroup.org/media/1094/reg-yacht-code-january-2019-edition-part-a.pdf

[3] MAIB investigation report 3-2017: City of Rotterdam/Primula Seaways; https://assets.publishing.service.gov.uk/media/58984f60ed915d06e1000025/MAIBInvReport3-2017.pdf