IMPROVING NAVIGATIONAL SAFETY AND PORT EFFICIENCY

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ABSTRACT

Static underkeel clearance (UKC) rules, widely adopted for the transit of large ships through draught-restricted port approach channels and waterways are, by their very nature, unresponsive to environmental changes and therefore, on any given day, can range from very conservative to unsafe. They will not warn of pending groundings and it is likely that the only risk prevention control is the ship handler experience.

This paper looks at how a change in the methodology on how UKC is calculated and regulated can improve safety for all ports. It considers all the factors that need to be taken into account when assessing UKC, and outlines a proven dynamic UKC technology which ensures safety, releases economic benefits, accounts for changing environmental conditions and provides risk mitigation tools when unanticipated developments such as engine failure occur during transit. The paper concludes with a brief discussion on new developments in UKC information exchange for e-Navigation.

LIMITATIONS OF STATIC UKC RULES

The majority of regulatory authorities in the world use static rules to determine the minimum required UKC of a vessel. These traditional rules were devised when vessels were smaller, their speeds lower, ship/shore communications poor and technology generally unavailable to determine ship motions accurately. They often use the vessel's draught as the baseline to determine the UKC. A simple method of calculating a safe UKC was needed, and the accepted practice was to calculate the UKC as a proportion of the vessel's draught. The most common clearance ratio is "ten percent of draught", which is unfortunate as the PIANC(1985) guidelines on UKC clearly states that this is a minimum suggested safety clearance and is *for calm waters only*, and that twenty, even fifty, percent may be required, especially for areas that are subjected to wave induced motions.

The most recent PIANC guidelines for UKC management are contained in Chapter 2 of PIANC (2014). These guidelines promote the need for ports to assess all factors relevant to UKC management, including water level factors, ship related factors and bottom related factors (see Figure 1).

A Static UKC rule tries to capture all these UKC factors in a single allowance but this method can be problematical because it is based on the assumption that the clearance so calculated is sufficient regardless of the prevailing environmental conditions. Therefore, where depths are critical and environmental conditions are more variable, there may be times when the allowance is marginal or even unsafe.

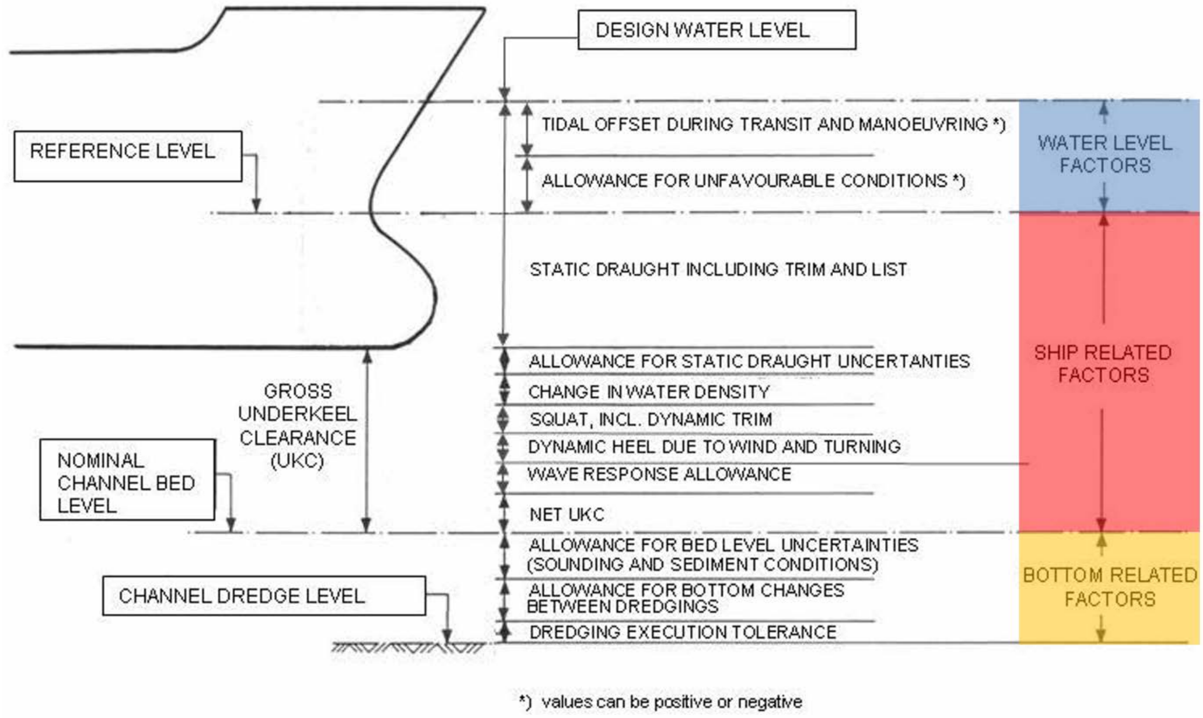

Figure 1: Channel Depth Factors (Figure 2.1 in PIANC (2014))

The **"static rule" approach is a "top-down" approach**, where the fixed **(gross)** clearance allowance is determined from the draught but the actual **(net)** UKC is unknown.

The absence of environmental inputs and ship loading state in the calculation of Static UKC allowances is illustrated in Figure 2.

Essentially the only controllable factors are the tide height (and therefore transit time to critical UKC points in the waterway) and speed (which determines the amount of squat[1]). Assuming that the tide height for a safe transit has been calculated accurately it can be seen that **speed is an absolutely critical element** in maintaining safe UKC. But evidence has shown that vessels do not always maintain the planned speed, or proceed at an appropriate speed for the transit. If the transit is too fast, the ship will squat, and heel, in excess of the predicted amounts; both effects are approximately proportional to the square of the speed. By contrast if the vessel transits slower than planned, it will not reach way points at required times and, in tidal waterways, may have less water than predicted so that the transit may now be unsafe.

The biggest drawback with static rules is that the actual clearance is wholly reliant on the environmental conditions. If they are too optimistic, safety could be jeopardised or too conservative, they become uneconomic. They are a blunt compromise, and for safety reasons need to be derived for the worst case scenario[2]. Evidence shows that for most of the time the

[1] *Squat is a hydrodynamic phenomenon by which a vessel moving through water creates a localised area of lowered pressure that causes the vessel to "apparently increase in draught" and be closer to the seabed than would otherwise be expected. It is approximately proportional to the square of the speed of the ship. http://en.wikipedia.org/wiki/Squat_effect*

[2] *The probability that ship-bottom contact in the long term results in the loss of a ship, or large contamination of the marine environment or the beaches, should be virtually zero. PIANC (1985)*
The chance that a vessel touches the channel bottom during its transit must always be less than 1% for all (weather) conditions. Savenije R (1996)
PIANC (1997) grounding probability studies show the risk of grounding is in the region of $3x10^{-5}$ (one ship per 33000 movements)

static rules will therefore be conservative, but up to five percent of transits are marginal, if not unsafe[3].

A further drawback of using simple static rules is that they do not account for change in ship loading state which means that no account can be taken of ship stability parameters which affect roll response and heeling on turns. A small change in GM, the metacentric height of the ship, for example, will change the natural period of roll response and, depending on the wave encounter frequency, potentially cause a significant increase in roll and associated vertical displacement at critical points on the keel of the vessel.

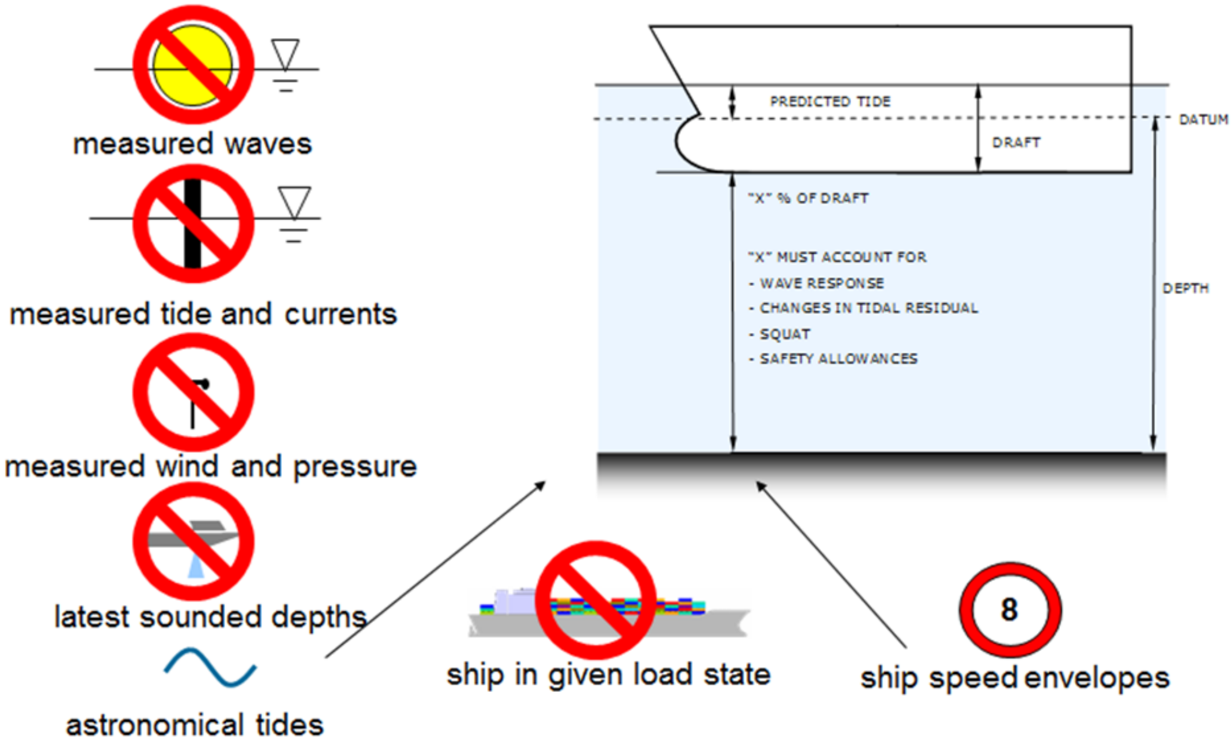

Figure 2: Inputs for Calculation of Static UKC Allowance

The normal application of the **static rules is a gross approach** to underkeel clearances, and because of the variances of the environmental conditions, the risk is variable on any given day.

The actual **net** clearance is dependent upon the environmental and load state conditions, but static UKC rules are unresponsive to change in these conditions. This means an authority cannot maximise efficiency when conditions allow. Of more concern, an authority will not be aware when conditions are actually unsafe**, because when static rules are used, the level of risk is variable and the net UKC on any particular transit is unknown.**

[3] *OMC's historical records show approximately 95% of vessel transits are conservative, 4% marginal and 1% potentially unsafe*

In practice, the actual safety clearance is determined by the conditions on the day, and under static rules, the clearance for a vessel varies for every transit. This issue was highlighted in 2003 in Whangarei, New Zealand, when two post-Panamax tankers[4] touched bottom in the approach channel whilst operating under a Static UKC rule that had been used without incident during the previous thirty years.

A CHANGE IN METHODOLOGY, MOVING TO A SAFER NET REGIME

The 2014 PIANC guidelines for channel design state that there are six factors that need to be considered as components of Gross UKC, one being the *Net UKC* which defines a minimum safety limit that must not be breached. This factor provides the basis for development of a much better methodology than using a Gross UKC approach. Maintaining a net UKC at all times ensures that, no matter what the environmental or ship loading conditions, the risk for a touch bottom incident is fixed (constant) because the required water level must be calculated as sufficient to ensure a safe transit is maintained.

However, the five other UKC factors will vary along the transit which infers that the user needs to assess all factors to derive the Gross UKC and hence the minimum water depth required at each point along the transit.

A net regime requires the navigator to consider all potential factors that could influence the transit and affect the underkeel clearances and compensate for them accordingly. While some of these factors can be pre-calculated, predicted wave response (in real time) is impossible to calculate without significant processing power and access to environmental data.

A net regime allows for real-time inputs and the associated dynamic assessment of UKC components; these are natural consequences which follow from adoption of a Net UKC methodology.

Guidelines for appropriate safety limits for Bottom Clearance (BC) and Manoeuvrability Margin (MM), used in a Net UKC methodology, are provided in PIANC (2014).

DYNAMIC UKC REGIMES

A key differentiator of a dynamic UKC regime from a static rule regime is the use of **real-time environmental data** such as tide, current, wave and wind data augmented with the use of ship stability data to accurately predict the expected ship motions.

A dynamic UKC system calculates the required UKC in near real time, depending on the prevailing environmental and vessel conditions which ensures every transit satisfies appropriate risk standards. With safety assured, economic and efficiency benefits are realised when conditions allow deeper draughts and/or extended tidal windows.

The utilisation of a fixed (constant) risk profile in a dynamic system ensures that safety is never compromised as marginal conditions will require additional water height. But the same risk profile

[4] *Whangarei, 2003. Two vessels "Capella Voyager' 16 April 2003 and 'Eastern Honour' 27 July 2003 grounded in the entrance channel under existing static rules, which had previously been considered safe.*

also allows greater tidal windows and/or draught when the conditions are suitable. In general terms, a dynamic system considers all factors that affect the UKC of a vessel transiting a channel to determine the minimum safe UKC requirements. The system does not use the vessel's draught as the baseline, but instead uses a pre-determined safety limit. Dynamic underkeel clearances are calculated based on the actual vessel and its stability parameters, real-time met-ocean conditions (wave height, period and direction, water levels, currents, tidal plane, wind), vessel transit speed and waterway configuration, including detailed bathymetry, at the time of sailing (Figure 3). The result gives the minimum water level that is required to ensure safety at all times throughout a planned transit.

The methodology behind dynamic UKC has been internationally recognised, and the improved certainty and information that a dynamic system can deliver has seen international bodies such as IHO and IALA support such systems as an essential Aid to Navigation (AToN). These bodies are now developing standards for the outputs from dynamic UKC systems because of the significant benefits which such systems provide as a risk mitigation tool.

A dynamic system can be considered as a **"bottom up" approach** and the system has, at its core, minimum limits[5] that must not be breached. Each of the factors are computed in real time, and then added until the minimum tide height is found that ensures a safe transit. Thus when the conditions are favourable vessels may have greater tidal windows and/or can sail with a deeper draught; but when conditions are not then tidal windows are reduced, and may even be closed, or a vessel may be able to proceed but with a reduced draught.

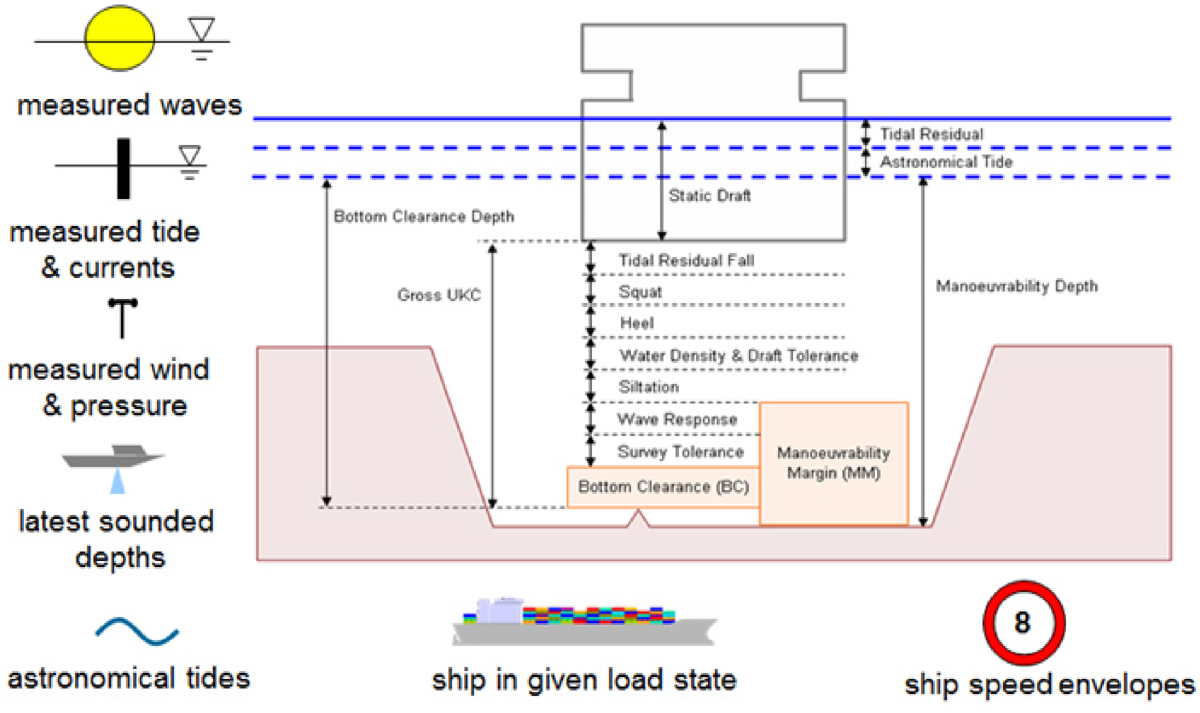

Figure 3: Inputs for Calculation of Dynamic UKC Allowance

The use of a dynamic system is increasing as the maritime industry needs to safely sail ever larger ships into ports, at the same time ensuring economic returns. From a legal and risk mitigation

[5] *The limit/s can be found in PIANC, 1985 (Underkeel Clearance for Large Ships in Maritime Fairways with Hard Bottom. Report of a Working Group of the Permanent Technical Committee II. Supplement to Bulletin No. 51 (1985)). The limits used in a dynamic system are PIANC's Bottom Clearance and Manoeuvring Margin limits, but any stipulated minimum limit could be used.*

viewpoint, ports are being required to show that all reasonable steps have been taken to assess the grounding hazard and that systems have been implemented to reduce this risk to as low as reasonably practicable (ALARP). **Dynamic systems are seen as an effective mitigation control for grounding hazards.**

A DYNAMIC UNDERKEEL CLEARANCE SYSTEM (DUKC®)

DUKC® is a proven safety and risk management technology and is a recognised core e-Navigation concept, which is available and operational today. The author created the first DUKC® system for the Port of Hay Point coal terminals in Queensland, Australia in 1993. OMC has now installed the technology in more than 25 ports worldwide and has ensured the safety of more than 150,000 deep-draught transits to date, most of which have sailed with deeper draught or wider windows than static rules would have allowed. T***he day-to-day operation of DUKC®, in preference to static rules for UKC, has moved the system from academic theory into world best practice.***

The system is customised for every port and implements the "dynamic allowances" mentioned above. The core functions of DUKC® systems have always been to provide ports and users with dynamic passage planning advice on:

- maximum draught for tides
- earliest and latest sailing times (tidal windows)
- UKC for specific transits

The system provides comprehensive reports for ports and pilots which improves the decision making process and enhances the master/pilot information exchange (an example report is shown in Figure 4). It also serves as a historical database for auditing and risk analysis purposes.

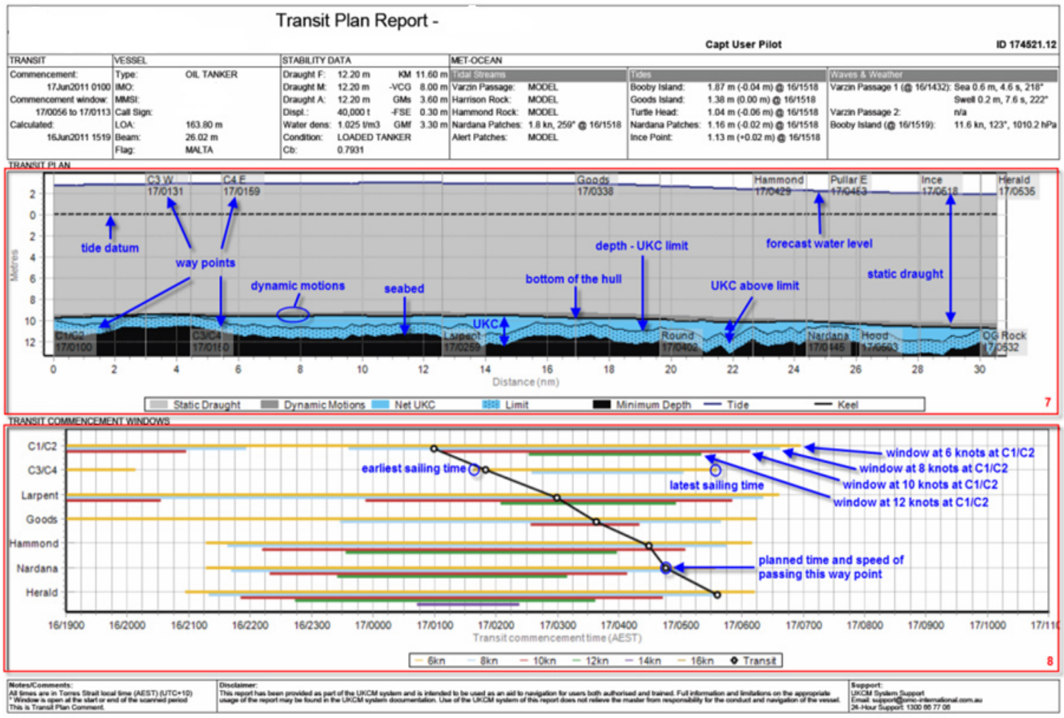

Figure 4: Overview of master pilot information report

A DUKC® system[6] is predictive so that if a navigator wishes to adapt his transit plan (especially the transit leg speeds), or if there is an unforeseen event (e.g. an engine issue or berth congestion), or a change in the environmental conditions, the system will automatically update the safe transit windows.

This in-transit functionality has been used a number of times by the pilot and VTS working together to alleviate the risk of channel blockage during vessel breakdown mid-transit.

Wave conditions, tidal streams, ship speed and water depths vary along the transit and the effect of these variations on UKC is computed by the numerical ship motion model used in each dynamic system. In addition, wave conditions and tidal residuals will change over time, and these effects are accounted for in the system.

With respect to squat, individual ships and the pertinent characteristics of the complete approach channel are modelled in each dynamic system and include the effect of temporal and spatial variation of tidal currents during the transit. The squat models used in DUKC® systems are calibrated specifically for particular waterways and specified vessel hull shapes, using full scale measurements accurate to within 10 cm. OMC has undertaken more than 500 such measurements, which is unprecedented worldwide.

Integration of the sophisticated numerical calculations (the "engine") with real time and forecast (up to 7 days) environmental data (wave, current and tide) ensures integrity and quality at the critical interface between the DUKC® system and the dynamic data. Validated numerical models[7] are used to ensure accurate vertical displacements for any vessel type, size and stability condition and vessel speed, in any channel width, configuration, lengths and wave condition, tidal regime and current speed. Each installation is customised using these numerical models to calculate the UKC requirements of the particular ship sailing in the particular waterway in the environmental conditions at the particular time. For this reason, a dynamic system can be designed to satisfy the internationally-accepted levels of risk for safely managing the UKC of vessel transits[8].

High resolution multi-beam survey data is primarily used to describe the sea bed in much greater detail than is typically available from a standard ENC or navigational chart. By conducting extensive and comprehensive geospatial analysis of raw sounding data (Turner et al, 2010) the system can accurately quantify minimum depths and manoeuvrability depths on a much finer resolution than a standard UKC calculation which uses declared depths. This allows vessels to load deeper when performing dynamic passage planning analyses based upon actual channel depths derived from raw sounding data rather than from a usually conservative estimate of channel depths. For channels that have major siltation issues and require regular sounding, these can be readily input into the DUKC® system as soon as they are made available. The DUKC® is therefore

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[6] *DUKC® is a registered trademark of OMC International Pty Ltd*

[7] *Accurate, and validated, numerical models are fundamental to the assured safety of a DUKC® system. This is done through full-scale measurements of vessel speed, track and vertical displacements, using survey grade DPGS units. OMC has undertaken measurements on more than 500 ship transits in a wide variety of channel widths, configurations and lengths, vessel types, sizes and stability conditions, vessel speeds, wave conditions, tidal regimes and current speeds.*

[8] *The system has also been rigorously and independently tested by specialist risk management consultants to ensure that it satisfies internationally-accepted levels of risk for safely managing the UKC of vessel transits. The Port of Melbourne also undertook two independent risk assessment studies and these extensive risk management studies concluded that the full complement of DUKC® software would significantly reduce the risk of large vessels grounding in port approach channels.*

always operating on the latest available hydrographic depths, with an allowance for siltation where appropriate from the date of the latest survey.

Whilst these functionalities remain at the core of the DUKC® system, specific user needs and how they want their results computed and delivered often drive new developments, which have universal application for all waterways. One such development is the delivery of dynamic information to the pilot (and vessel), in a format that is readily understandable, and does not interfere with the primary requirement of navigation. Chart overlays were identified as the most appropriate method, which can be readily incorporated into the pilots' portable pilotage unit (PPU). Chart overlays present a simple visual indication on which areas meet UKC limits, and are safe for traversing, and which areas do not meet UKC limits, and should be avoided (Pearce, 2014).

DUKC® Chart Overlay was specifically designed for pilots and mariners and displays UKC information geospatially through a Marine Information Overlay (MIO) on a compatible Electronic Charting System (ECS) such as one running on a Portable Pilot Unit (PPU) carried on board to monitor the passage in real time. In parallel, the overlays can be displayed on the web within the DUKC portal, allowing a shore station to view the same dynamic overlay that the pilot is viewing.

An example of the chart overlay is displayed in Figure 5. The simple presentation of predicted Go/No Go areas for the time of the vessel arrival in those areas allows the pilot to anticipate required deviations from the transit plan. This anticipation allows time for various options to be considered and enables proactive rather than reactive navigation.

Because of the dynamic nature of DUKC® systems, OMC provides 24/7 support for each system, with a guaranteed uptime greater than 99.8%. Dynamic UKC systems cannot operate successfully and reliably without such support. In addition, the close association with a wide variety of users which such supporting activities engenders, provides an excellent feedback mechanism for continual refinement of DUKC® systems and extension of their functionalities (for example, chart overlays described above now form an integral part of the latest Series V DUKC® systems).

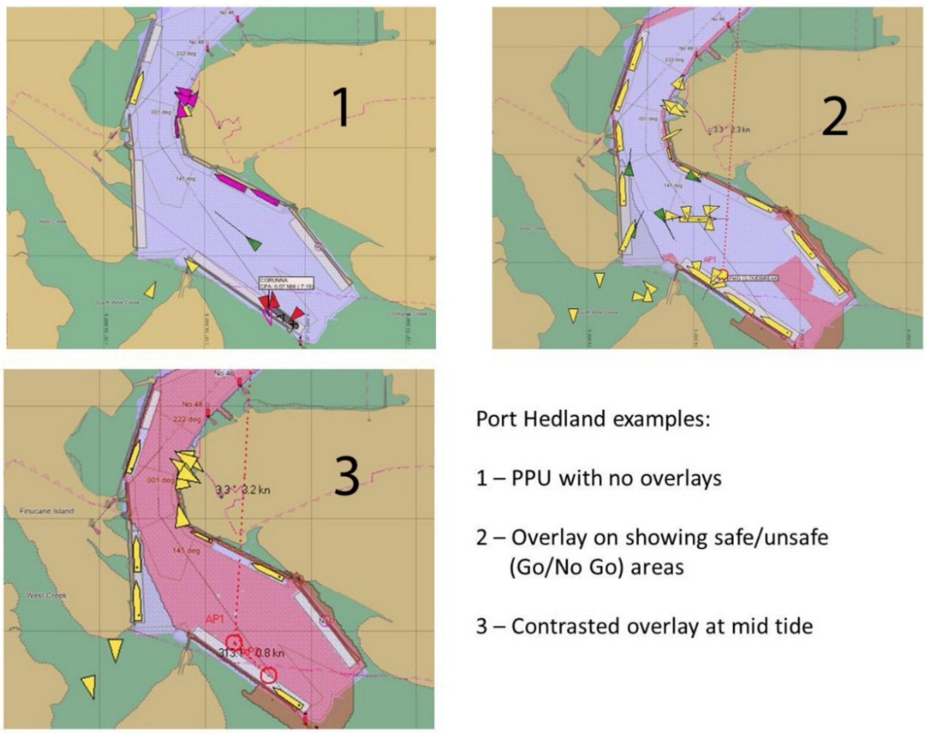

Figure 5: Actual PPU displays with overlays on/off and differing tidal conditions

NEW DEVELOPMENTS IN UNDERKEEL CLEARANCE MANAGEMENT (UKCM) INFORMATION EXCHANGE FOR E-NAVIGATION

The use of AIS to deliver on board UKCM information is now in its infancy with various testbeds, including Torres Strait and the Straits of Malacca and Singapore (SOMS), being implemented to promulgate UKCM information from shore to ship by AIS.

The SOMS testbed study has demonstrated that AIS is a viable communications method for relaying UKC data in an operationally practical and meaningful way to vessels but that there are obstacles to effective implementation and use. These are mainly regulatory in nature in that, while text messages can be received, visual ECDIS data has portrayal complications that will need to be addressed with the appropriate bodies and equipment manufacturers.

Because of its track record of pioneering the development, validation and operation of UKCM systems, OMC has been invited to participate as an Expert Contributor in the current IHO Underkeel Clearance Management Information Project Team (UKCM PT*) to develop an IHO S-100 based product specification for Underkeel Clearance Management (UKCM) information to enable the outputs of UKCM services to be displayed for users (IHO, 2015*). IHO Member States represented on the UKCM PT include Sweden, Korea, USA, Singapore and The Netherlands; the Project Team is chaired by a representative from the Australian Maritime Safety Authority (AMSA). The work of the UKCM PT will include defining the features and attributes needed for the display of UKCM information and defining the UKCM data model and is expected to be completed in 2018.

Chart overlays are an important component of any e-Navigation system as they deliver navigational and safety information in formats that are readily understandable to pilots and ship masters. The type of data that can be communicated is diverse, and is already beginning to revolutionise today's navigational practices. Implementation of IHO's S-100 based product specification will benefit the delivery of this information to a ship's ECDIS, or other navigational systems, rather than just the pilot's PPU, and the proposed VHF Data Exchange System (VDES) will also be an important/necessary development as data requirements increase.

CONCLUSION

Serious consideration is needed as to whether **Static** UKC rules are suitable at many ports, and if all UKC factors are understood. The paradox of the static rules is that without an incident, a port's static rules may appear validated and considered safe. In reality, where underkeel limits are critical and conditions variable, there may be times when the clearance is marginal and the port has experienced an unknown "near miss".

A **Dynamic** UKC system ensures safety through accurate planning and continual monitoring of the UKC of large vessels during transit along shallow waterways. This decision support tool, and the integration into navigation systems, such as a pilot's PPU, allows the effect of alternative speed/sailing options on UKC to be quickly investigated by pilots and masters in situations where the passage does not proceed as planned. The information that is now available from OMC's DUKC® systems enhances the decision making processes of all users, and complements the master/pilot information exchange. The availability of results to both vessel and shore, in real time, also enhances contingency planning in the event of an unforeseen incident.

DUKC® systems have a proven track record and their use is expected to increase throughout the maritime industry. As the methodology builds on the concept of a minimum clearance limits that must not be breached, DUKC® systems effectively control the risk of a touch-bottom/grounding incident. This level of risk cannot be achieved with static rules because the clearances vary and are determined by the environment present on the day.

Dynamic UKC chart overlays, included in the functionality of Series V DUKC® systems, are an evolutionary step in delivering UKC information to the navigator in a visually understandable format. It is an operational and proven e-Navigation solution that can only increase the safety of vessel transits in draught-restricted waterways.

REFERENCES

IHO (2015): "Underkeel Clearance Management Information Project Team (UKCMPT), Terms of Reference and Rules of Procedure", Annex A to IHO CL 84/2015

Pearce,J (2014): "Enhanced Safety Through The Use Of Real-Time Dynamic Charts Overlays ,OMC International, XVIII IALA-AISM Conference, A Coruña, Spain, 26-31 May 2014

PIANC (1985): "Underkeel Clearance for Large Ships in Maritime Fairways with Hard Bottoms", Report of a working group of the Permanent Technical Committee II, Supplement to Bulletin No. 51

PIANC (1997): "Approach channels: A Guide for Design". Final Report of the Joint PIANC-IAPH Working Group II-30 in cooperation with IMPA and IALA, Supplement to Bulletin 95, Brussels, June.

PIANC (2014): "Harbour Approach Channels Design Guidelines", Report No. 121 -2014.

Savenije R (1996): "Probabilistic admittance policy deep-draught vessels", PIANC Bulletin 91, June.

Turner, M.R, Villella, M.A. and O'Brien, P.W., (2010) "El Mejoramiento De La Seguridad De La Navegacíon Utilizando El Sistema Dukc®", VI Congreso Argentino de Ingeniería Portuaria Seminario Latinoamericano Desarrollo Sustentable de la Infraestructura Portuaria Marítima y Fluvial en América Latina.1