Maximising Vessel Utilisation Through Channel Design

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Abstract

The Dynamic Underkeel Clearance System (DUKC®) is a real time underkeel clearance (UKC) system used by ports to maximise port productivity and safety. The DUKC® considers all factors that affect the UKC of a vessel transiting a channel to determine the minimum safe UKC requirements. With a track record of 19 years and more than 60,000 vessel transits without incident, DUKC® has a strong history as an operational tool. However, the technology is increasingly being sought to optimise channel designs for port expansions and greenfield developments.

This paper will focus on the channel design work undertaken for Rio Tinto's Cape Lambert expansion. The expansion, referred to as Port B, includes the addition of a four berth wharf and a 1.8km jetty. The Port B expansion is part of a $3.9b package aimed at boosting Rio Tinto's Pilbara iron ore operating capacity from 220Mtpa to 333Mtpa.

The channel optimisation study investigated the potential for incremental draft gains and the corresponding dredge volumes. Applying the anticipated vessel fleet, DUKC® assisted time domain simulations were utilised to provide Rio Tinto with the information required to undertake a reliable cost benefit analysis for the dredging.

This project was somewhat unique in that the scope was very broadly defined. Rather than a detailed work package and set of deliverables, OMC International (OMC) was essentially asked to answer two questions:

- What are the constraints?
- What are the opportunities?

The study identified the critical sailing parameters and demonstrated that vessel utilisation could be increased by approximately 20% with targeted dredging.

After a brief examination of the port development and DUKC® methodology, this paper will detail the study approach and key findings.

Keywords: DUKC®, channel design, dredge optimisation, underkeel clearance.

1. Introduction

Rio Tinto is undertaking analysis for the expansion of its Cape Lambert Port. Referred to as Port B, the expansion will help increase Rio Tinto's Pilbara iron ore operating capacity from 220Mtpa to 333Mtpa.

The port expansion requires the dredging of a new channel to connect Port B with the existing channel. OMC was consulted to apply DUKC® technology to assess the channel capacity and investigate the potential gains with respect to vessel utilisation that could be achieved through dredge optimisation.

2. Cape Lambert Port

The Cape Lambert port, also known as Port Walcott, is located on the northwest coast of Australia, approximately 40km west of Karratha. Operated by Rio Tinto Iron Ore, it currently handles approximate 400 Capesize bulk carriers per year with a total capacity of 80Mtpa.

The proposed expansion is for an additional four berth jetty, which would increase capacity by a further 100Mtpa.

The port exports iron ore on Capesize bulk carriers, with drafts ranging from 15m to 23m. Shipping is restricted to high waters.

Port B would also be restricted to high water departure times. However, it is possible that the sailing window will be extended beyond that which is currently utilised at the existing Cape Lambert port.

The preliminary channel design was performed assuming a design draft of 18.0m with a potential sailing window opening at 150 minutes before high water and closing at high water. This sailing window is a key parameter on which the channel capacity analysis was based.

3. DUKC® System

Traditionally, ports have operated under fixed rules which govern the minimum under keel clearance (UKC) to permit safe transit along port approach channels. To ensure safety, these fixed UKC rules are determined by requirements under extreme swells and negative tidal residuals. The UKC rules must ensure appropriate allowance is made for the vessel's motions, including squat, heel and wave response.

If the requirements are too conservative, ships carry less cargo than they otherwise could, sailing windows are reduced and the operation is not as cost-effective as it might be. At the other extreme, inadequate criteria could jeopardise safety and cause a grounding to occur.

The DUKC® System developed by OMC uses customised numerical models to calculate the UKC requirements of each unique ship sailing in a particular waterway in the environmental conditions prevailing at the time of transit.

DUKC® modelling guarantees accuracy and applicability. UKC requirements are determined 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. Wave spectra, ship speed and water depths vary along the transit and the effect of these variations is computed by the numerical ship motion model used in each DUKC® system. In addition, wave spectra and tidal residuals will change over time, and these effects are accounted for in each system. With respect to squat, individual ships and the pertinent characteristics of the complete approach channel are modelled in each DUKC® system, including the effect of temporal and spatial variation of tidal currents.

In its application to channel design, DUKC® methodology quantifies the UKC requirements of each section of a transit; this information is used to create an optimal channel depth profile which matches the specified channel capacity whilst minimising the dredging requirements. The UKC profile is produced based upon statistical analysis of environmental conditions as well as the range of possible vessel types and speeds. The profile created allows for the full range of conditions under which a vessel may be required to transit the channel.

Because the use of DUKC® technology enables a realistic simulation of future port operations, all access percentages determined reflect future operating outcomes.

4. UKC Model

A UKC model was configured to simulate ship transits for the study assuming that a DUKC® would be used in operations to determine safe sailing drafts and windows.

The UKC model incorporates modules for ship wave response, squat, channel bathymetry and tide plane. For each module, every transit is divided into sections of one hundred metre lengths. For each of these channel sections, UKC calculations are performed based on localised met-ocean conditions (waves and tides), channel configuration, ship dimensions, load state and speed specified for that transit. The transit speeds have been determined in consultation with the pilots as appropriate for the modelled vessels.

5. Channel Design Methodology

5.1 Simulation Vessel Fleet

The simulation vessel fleet was created from a distribution of vessels expected to visit the port.

Using this distribution, a total of 365 vessels representative of those in the distribution, and 1000 stability conditions were selected from OMC's databases. A simulation vessel fleet comprising 5000 vessels was generated by randomly assigning a vessel with a realistic stability data set. The simulation fleet of 5000 vessels was then re-examined to ensure the distribution of drafts was consistent with that originally provided. This process ensured that a variety of loaded conditions were modelled to incorporate the varying effects of the vessels' stability on wave response.

The vessels' summer drafts were also recorded as these were crucial to this analysis. The summer drafts represent the maximum draft that the vessel can achieve, regardless of channel depth.

5.2 DUKC® Simulations

The channel design process involves using the DUKC® to perform simulated transits. Transit simulations covered every high water for the 2006 and 2007 calendar years. For each high water, a vessel transit was simulated every 10 minutes from 2 hours and 30 minutes before high water up until high water (HW), resulting in 16 departures per HW.

A simulation consists of randomly selecting a vessel from the fleet and performing a DUKC® maximum draft calculation for a departure at the nominated sailing time. The DUKC® determines the maximum sailing draft at which that particular vessel could safely depart considering the tide and wave conditions prevalent during the transit. In addition to the maximum sailing draft, the results from the DUKC® calculation also show the UKC at 100m increments along the channel. This provides the data to determine the location along the channel at which the minimum UKC is encountered. This location is referred to as the controlling point.

From these results, there exist two possible outcomes:

1. The maximum sailing draft is greater than the vessel's summer draft:
    - The vessel can transit with the existing bathymetry;
    - No draft gains could be achieved through channel deepening.
2. The maximum sailing draft is less than the vessel's summer draft:
    - The vessel cannot transit at its maximum draft with the existing bathymetry;

- o Draft gains could be achieved through channel deepening.

5.3 Dredge Optimisation

Following the initial simulation set, vessel drafts were increased above their previous maximum sailing drafts. This results in a UKC breach. The channel depths required to accommodate the increased drafts were then calculated.

The draft increments performed were 0.20m, 0.40m, 0.60m, 0.80m, 1.00m, 1.25m and 1.50m. However, when increasing each vessel’s draft, the increment was restricted by the summer draft of the vessel. Using the 0.20m and 0.60m scenarios, Table 1 provides an example of how the summer draft limits the draft increments.

Table 1 Draft Increments Example

Vessel	Initial Draft	Summer Draft	New Draft (0.20m)	New Draft (0.60m)
1	18.00m	17.90m	17.90m	17.90m
2	18.00m	18.10m	18.10m	18.10m
3	18.00m	18.40m	18.20m	18.40m
4	18.00m	18.80m	18.20m	18.60m

For each draft increment scenario, a channel profile was created for each of the following accessibility criteria: 60%, 70%, 80%, 90% and 95%. The accessibility values represent the proportion of channel profiles considered in developing the optimal profiles. For example, the 90% limit indicates that the optimal channel profile accommodates 90% of vessel sailing at their incremental drafts. However, the deepest 10% of channel profiles have been excluded from the optimal design.

Figure 1 provides an example of the channel depth requirements using the departure time of 2 hours and 30 minutes prior to high water and an incremental draft increase of 0.40m.

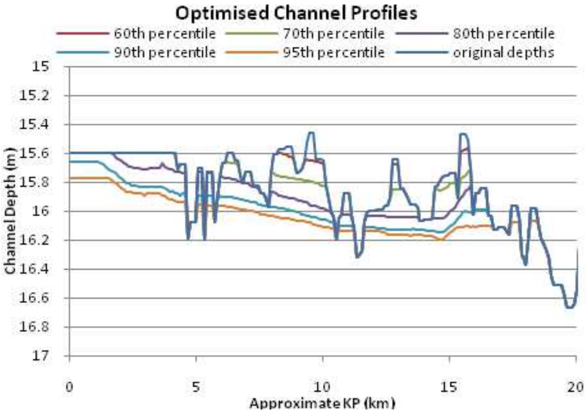

Figure 1 Optimised Channel Profiles Example. Shows channel depth profiles for the 0.40m draft increment scenario for vessels departing at the opening of the sailing window (HW-2h30m). The depths required increase with the accessibility criteria.

Figure 1 demonstrates the change in channel profile associated with increasing the accessibility criteria.

6. Results

Analysis of Sailing Window

In analysing the results, two key performance criteria were examined. The first is Lost Draft. This is difference between a vessel’s summer draft and the maximum draft available to the vessel for a particular departure time. It represents the opportunity foregone, in terms of additional draft and therefore tonnage, due to the limitation of the channel depth. The second parameter examined is Draft Gain. This is the increase in draft that results from dredging considering the limitations of both the channel depth and the vessel’s summer draft.

To determine a baseline against which to evaluate any proposed channel profiles, the draft results using the existing channel depths were evaluated. Figure 2 shows Lost Draft considering all departure times combined. It shows that for approximately 72% of vessels additional dredging would yield no benefits as they can already sail at their summer drafts.

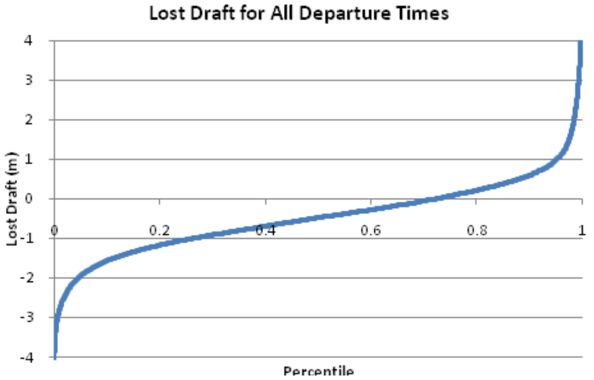

Figure 2 Lost Draft for All Departure Times. Approximately 72% of vessels would not benefit from a deeper channel.

The above result considers the combination of all departure times within the sailing window. The next step in the analysis was to consider the effect of departure time within the sailing window.

Figure 3 shows the Lost Draft results for the opening, closing and middle of the sailing window. It is clear that the greatest potential for improving vessel utilisation lies at the opening of the sailing window, which, at 55% is well below the average of 72% for all departure times.

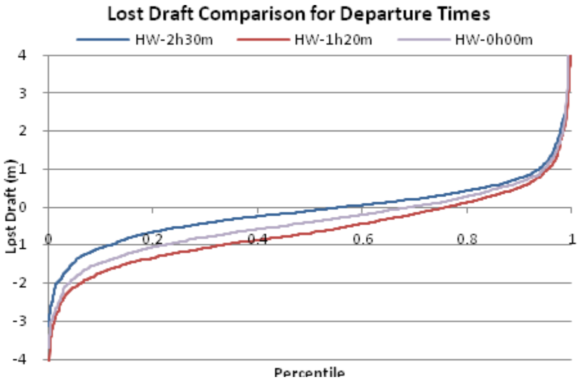

Figure 3 Lost Draft Comparison for Departure Times. Departures at the opening of the sailing window have a vessel utilisation of 55%. These vessels have the greatest potential to benefit from a deeper channel.

Upon presentation of these results to Rio Tinto, they approved further work focusing solely on departures at the opening of the window. Specifically, four channel profiles were selected for analysis. The channel profiles corresponded to the two draft increments of 0.20m and 0.40m and the channel accessibility criteria of 80% and 90%.

For each of the four channel profiles, the simulations were rerun to determine the increase in draft that resulted from the additional channel depths. The results for the average gains are shown in Table 2.

Table 2 Average Draft Gains

Channel Profile	Median Draft Gain
0.20m increment, 80%	0.10m
0.20m increment, 90%	0.16m
0.40m increment, 80%	0.15m
0.40m increment 90%	0.20m

The dredge volumes were calculated for each channel profile. Based on the dredge volumes, the client nominated the 0.40m draft increment scenario at 90% for further analysis.

The draft gain results are shown in Figure 4.

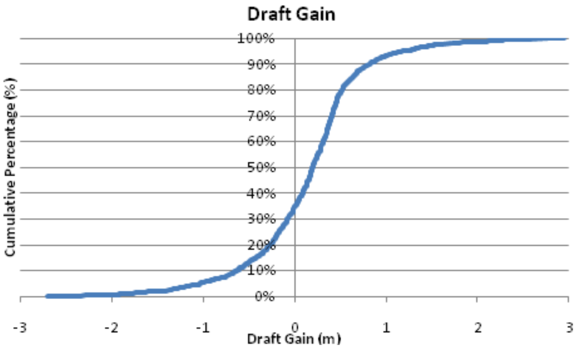

Figure 4 Distribution of Draft Gains Post Dredge. With a randomised fleet, some vessels yield lower drafts post dredge due to differences in summer drafts.

The draft increase values show the gains achieved through the dredging. However, these values need to be treated with care. As a new random fleet of vessels was selected for each scenario, some of the draft gains will result merely from vessel selection. Table 3 highlights this issue.

Table 3 Effect of Summer Drafts on Draft Gains

	Existing Depths		Optimised Profile		
	DUKC® Draft (m)	**Sum. Draft (m)**	**DUKC® Draft (m)**	**Sum. Draft (m)**	**Draft Gain (m)**
1	18.0	17.9	18.4	17.50	-0.4
2	18.0	18.1	18.4	18.10	0.1
3	18.0	18.1	18.4	18.60	0.4

In all three examples provided, the dredging results in deeper DUKC® draft calculations. However, the overall effectiveness of the dredging is dependent on the summer drafts of each comparison vessel. The highlighted value for each depth scenario is the one that limits the overall draft.

In Example 1, the summer draft limits the ship's cargo capacity in both depth scenarios. With the dredged channel, a smaller ship is simulated such that it shows as a loss in draft despite the DUKC® draft having increased.

In Example 2, the dredging results in a potential increase in draft of 0.40m, however the vessel is only able to utilise an additional 0.10m in draft.

In Example 3, the vessel is able to utilise the full 0.40m in draft achieved through the dredging.

In an effort to provide greater clarity to the client, the simulations were again run for the selected channel profile (0.40m draft increment, 90% accessibility). However, this time the same vessels were used as for the original analysis. This allowed for a direct comparison, transit by transit, between the existing depths and proposed channel profile. To minimise the effect of the vessel distribution on the results, the maximum draft calculations were compared for the original fleet against a randomly allocated fleet. Figure 5 shows the cumulative frequency distribution of drafts for four scenarios:

1. Existing bathymetry;
2. Post dredge bathymetry using the original vessel fleet;
3. Post dredge bathymetry using a newly randomized vessel fleet; and
4. Summer drafts. This scenario represents the best possible distribution of drafts that can be achieved irrespective of the channel depth.

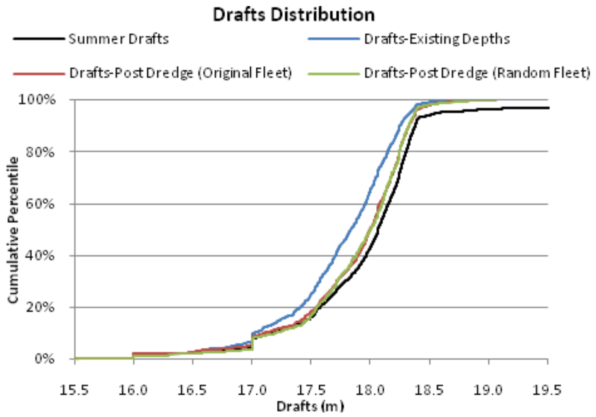

Figure 5 Draft Distribution Pre and Post Dredge. The summer drafts represent the best possible outcome regardless of channel depth. The draft distribution is not significantly affected by the random selection of vessels. The proposed channel profile considerably improves the distribution of sailing drafts.

The results from Figure 5 are very useful in addressing the complications that arise when using the randomly selected fleet. They indicate that it is appropriate to use the original vessel fleet to estimate the potential increase in draft that can be achieved due to the dredging. Using the original vessel fleet eliminates the extreme values and negative values seen in Figure 4 from the analysis. This improves clarity when interpreting the results.

The Draft Gain results, using the original vessel fleet, are shown in Figure 6. The increase in draft, averaged over all sailings, is 0.10m. However, considering only those vessels capable of taking additional cargo, the average gain in draft is 0.33m.

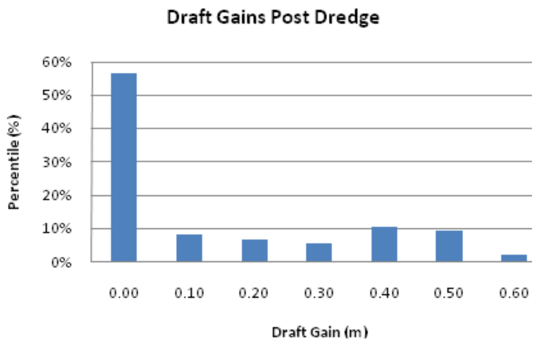

Figure 6 Draft Gains Post Dredge. Using the original vessel fleet provides greater transparency in assessing the increased drafts achieved through the proposed channel profile.

The Lost Draft results are shown in Figure 7. Recalling that the Lost Draft represents the opportunity foregone due to the channel restriction, Figure 7 shows that the optimised channel profile increase vessel utilisation from approximately 55% to 77%.

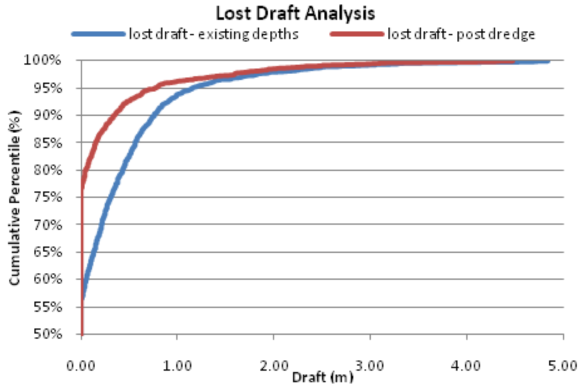

Figure 7 Lost Draft Analysis. The lost draft represents the draft, and therefore tonnage, that a vessel could have loaded if the channel had been deeper. The optimised dredge profile improves vessel utilisation from 55% to 77%.

Using the information present in Figures 6 and 7, the client was able to undertake a cost benefit analysis to evaluate whether the dredging was warranted and if so the optimal expenditure against operational return.

7. Summary

A real time approach to management of ship drafts and sailing windows through the application of technology such as DUKC® can provide significant benefits over static rules. These benefits are realised in terms of both safety and efficiency.

The technology can also be applied to optimise channel design and minimise dredging requirements.

This paper has provided a case study where DUKC® was utilised to determine a set of optimal channel profile designs and then evaluate the potential benefit that the proposed channel deepening could deliver.

The key challenge in this project was evaluating the effect of the vessel fleet and, in particular, the limitation that each vessels' summer draft had on the benefits available through a deeper channel.

Starting with a very broadly defined scope, the direction of the analysis was refined through presentation of interim results to the client. This process evolved into three phases, namely:

1. Identifying critical departure times;
2. Identifying a selection of potential channel profiles; and
3. Selecting and evaluating a final channel profile.

From Phase 1, it was determined that vessels sailing at the opening had the greatest potential to benefit from a deeper channel. Phase 2 demonstrated that the optimal increase in drafts was between 0.20m and 0.40m. Beyond this range, the benefits diminish whilst the dredging volumes increase exponentially. Phase 3 analysed the benefits available in terms to increased draft, and therefore tonnage, through the deeper channel.

The results showed that the optimal channel profile yielded an average gain of approximately 0.10m averaged across all vessel, or 0.33m considering only those vessels large enough to carry the additional tonnage. Furthermore, vessel utilisation, defined as the proportion of vessels sailing at their summer drafts, increased from 55% to 77%. This information allowed the client to evaluate the business case for the channel deepening project.

8. References