An investigation of bank effects by means of vessel track analysis combined with simulator work

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Abstract

Port Adelaide channel is affected by tidal streams. Therefore, Flinders Ports currently imposes sailing restrictions while the tide is rising or falling faster than a specified threshold due to concerns about reduced manoeuvrability at these times. A manoeuvrability study, with a specific focus on bank effects on large Post-Panamax container vessels, was undertaken in order to confirm the suitability of sailing restrictions based on tide rate of change, and to determine other factors that contribute to bank effects and thus reduced manoeuvrability. Two complimentary investigative approaches were used.

The first approach was an analysis of vessel tracks for 6 months of supplied AIS data. Situations where vessels approached the channel boundaries were investigated for correlation to environmental conditions, such as tidal streams and wind forces, and other conditions such as under-keel clearance (UKC) and vessel speed. The results of this analysis found that tide rate of change showed no correlation with vessels approaching the channel boundaries. A correlation was observed between increased vessel speed and a higher chance of approaching the channel boundaries.

The second approach was a desktop simulator study, to identify which transit factors induce a higher risk of approaching the channel boundaries. For this study, a design vessel was designated by Flinders Ports as a Post-Panamax container vessel with 300m LOA, 40m beam, and 13m static draft. While a vessel maintains a centreline track, bank effects tend to balance out. However, once a vessel deviates from this track, the various factors contributing to bank effects can very quickly have a large impact on vessel manoeuvrability.

The approach of combining theoretical simulation with actual measured vessel behaviour proved a useful method to investigate the underlying factors influencing vessel behaviour at Port Adelaide.

Keywords: bank effects, manoeuvrability, shipping, container vessels

1. Introduction

Port Adelaide is the main port servicing the city of Adelaide, South Australia. It is operated by Flinders Ports, who also operate six other ports throughout South Australia.

At present, Flinders Ports restricts large (Post-Panamax) container vessels from transiting the Port Adelaide channel to or from the Outer Harbour Container Terminal to times when the rate of change in tide is less than 0.3m/hr (flood) or 0.2m/hr (ebb). This is due to a concern about the reduction in manoeuvrability caused by these tidal streams.

Flinders Ports approached OMC to conduct a manoeuvrability study, with a specific focus on bank effects.

The aim of this study was to identify when transits with a higher risk of approaching channel boundaries are likely, allowing mitigation or avoidance strategies to be enacted. Another aim was to provide guidance to Flinders Ports on scenarios where port efficiency might be increased.

1.1 Bank Force and Yawing Moment

Bank effect is a term that describes the movement of a vessel induced by its proximity to a channel bank. Its influence is also dependent on several factors including channel profile, vessel size, speed, UKC and prevailing environmental conditions.

Bank effects consist of two separate but related effects: bank force and bank generated yawing moment.

Bank force is a sway force, either an attractive force toward the bank, or a repulsive force away from the bank. Whether it is attractive or repulsive is dependent on the depth/draft ratio of the vessel to the channel. As the depth/draft ratio reduces, there is a cut-off below which the typical attractive bank forces becomes a repulsive force. This cut-off ratio is approximately in the range of 1.1 – 1.2 and is reported in the literature [1][2].

Bank generated yawing moment is generally of more concern. The yawing moment causes the bow of the vessel to swing away from the closest bank and can cause the vessel to sheer across the channel resulting in potential loss of control of the vessel.

In this study, a positive bank force represents repulsion, and a negative bank force represents attraction. Yawing moment has been reported as the total combined yaw experienced from the vessel swinging in both directions over a simulation (i.e. the largest positive and negative moments are combined).

2. Location

The Flinders Adelaide Container Terminal is located north-west of the city of Adelaide, South Australia, at the mouth of the Port Adelaide River. This location is shown in Figure 1.

Figure 1 Location of the Flinders Adelaide Container Terminal with respect to the city of Adelaide. Map data © 2019 Google

Vessels transiting to or from the Flinders Adelaide Container Terminal use the channel shown in Figure 2.

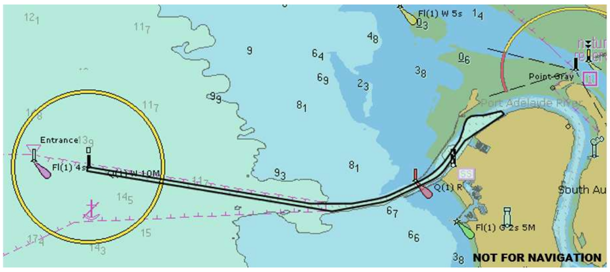

Figure 2 Port Adelaide channel from Sea to Outer Harbour (OH) Berths 6, 7, and 8, including turning basin. Large container vessels berth at OH6 and OH7. [3]

The area of interest with regards to vessel manoeuvrability is around the bend, during the transition from deeper water to a clear-cut channel with well-defined banks.

3. Methodology

For this study, two complimentary analyses were undertaken:

1. Historic transit analysis based on AIS data supplied by Flinders Ports. This investigation is to identify when vessels approach the channel boundaries and seek to identify contributing conditions.
2. Theoretical analysis based on SimFlex simulation software to identify transit scenarios and environmental conditions under which bank effects are significant, and hence which transits should be classified as at higher risk of approaching the channel boundaries.

3.1 AIS Recorded Vessel Tracks

An investigation into the AIS recorded tracks of container vessels transiting to and from the Outer Harbour Container Terminal was made to determine how close vessels are coming to the channel boundary. Concurrently the prevailing environmental conditions (e.g. tidal stream or wind) as well as tidal height were recorded to identify any correlation with these factors.

The AIS data used was provided by Flinders Ports for the period 2018-01-01 to 2018-07-06. It is noted that Flinders Ports did not confirm the accuracy of the AIS received from the vessels. The AIS data was QC checked and filtered so that only vessels meeting the following criteria were analysed:

- Container vessels to/from the Outer Harbour Container Terminals
- Post-panamax sized vessels
- Transits with AIS data that met minimum quality thresholds

From this AIS dataset, the vessel positions were extracted for each transit. Using the vessel position and dimensions, the closest point to the edge of the channel was determined. An example of this is shown in Figure 3.

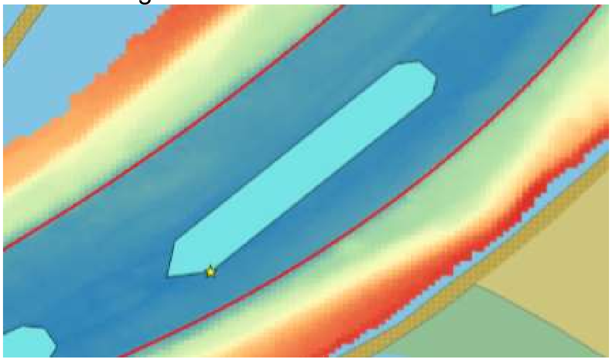

Figure 3 Example of the determination of closest point on vessel to channel boundary for an instantaneous point in time. Red lines indicate channel boundary, closest point on vessel to boundary starred. In the analysis, the closest point from vessel to boundary was determined based on the vessel swept path. [3]

Using the calculated minimum distance between vessel and channel boundary, each transit could be checked against prevailing environmental conditions to determine factors resulting in closer proximity to channel boundary.

For this analysis, the channel was divided into four sections, shown in Figure 4. This was done in order to identify spatial trends in the channel boundary proximity analysis. Section 1 started at the Outer Harbour Berth area and the sections propagate seaward with Section 4 terminating shortly after the end of the bend in the channel. The Berth Area itself was not analysed as the transit speeds in this section are very low, and therefore bank effects will be not be significant.

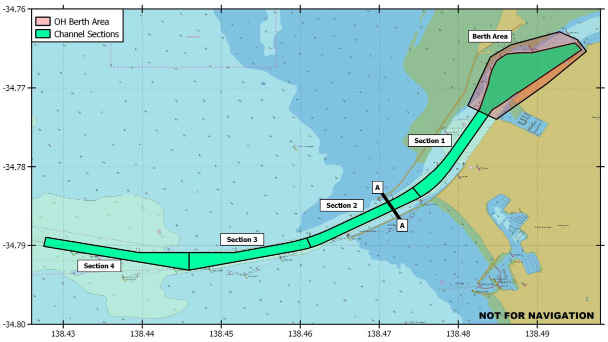

Figure 4 Independent sections analysed for vessel proximity to bounds. Channel cross section from Section 3.2.2 marked A-A [3]

3.2 Simflex Desk Top Bank Effect Simulation

To compliment the historic vessel track analysis detailed in Section 3.1, desk top simulations were undertaken utilising the SimFlex simulation software, to investigate theoretical bank effects and determine transit conditions that may be considered at higher risk of approaching the channel boundaries.

SimFlex is a software package developed for use in full bridge mission simulators and also for desktop navigation simulation studies.

The desktop simulations were undertaken for the following key input parameters:

- A design container vessel
- A bank profile representing the channel banks close to the breakwater
- A straight-line channel

Several different scenarios were then investigated based on varying the following conditions:

- Wind
- Tidal stream
- Tide level (and therefore UKC)
- Vessel speed through water
- Bank proximity

3.2.1 Design Vessel

The design vessel selected was SimFlex vessel Blue Moon (ID 3690) The vessel particulars of the design vessel are shown in Table 1, approximating a 5,000 TEU post-panamax container vessel. The vessel was modelled at a fixed draft of 13m.

Table 1 Design Vessel Particulars

Particular	Value
LOA	300.0 m
Beam	40.0 m
Draft	13.0 m
Displacement	92,685 t

3.2.2 Bank Profile

The bank profile used in the simulations is described in Figure 5, compared to the actual cross section at the location described in Figure 4. Design depth is 14.0m below LAT throughout.

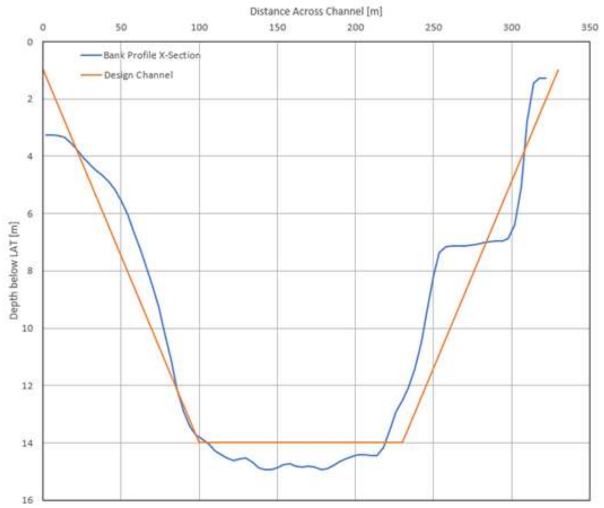

Figure 5 Design Bank comparison with channel profile taken near the end of the western breakwater. Channel profile oriented inbound (left = west)

3.2.3 Base Case

A base case was defined with a transit speed of 10 knots, a tide level of 2m, an initial proximity to the channel boundary of 25 m from the port side of the vessel and no wind or tidal stream forcing applied

4. Results: AIS Vessel Track Analysis

4.1 Summary

A total of 189 AIS recorded transits meeting the criteria of Section 3.1 were analysed. These covered the period 2018-01-01 to 2018-07-06. A summary of the analysis data is presented in Table 2. Negative distance indicates the vessel swept path exceeded the channel boundaries.

Most of the instances of vessels exceeding the channel bounds occurred close to the Outer Harbour, in Sections 1 and 2. On average vessels transited closest to the boundary through sections 2 and 3.

Table 2 Summary of minimum distance to channel boundary for all transits. Negative values indicate channel boundary was exceeded. Note summary values only count each vessel once even if they approach the channel boundary in multiple sections.

Section	**Min Distance to Channel Boundary all Transits**	**Avg Min Distance to Channel Boundary**	**No. Transits outside channel**	**No. Transits within 10m of Channel Boundary**
1	-18.6 m	28.2 m	8	14
2	-16.3 m	22.0 m	7	24
3	-26.3 m	24.0 m	4	19
4	-2.9 m	28.9 m	1	5
Overall	-26.3 m	25.8 m	16 (8%)	45 (24%)

4.2 Detailed Results

Results presented here are for section 1, closest to the berth. Results for sections 2-4 are omitted, as the trends for section 1 are reflective of the results in the other sections.

The distribution of minimum channel boundary clearance is shown in Figure 6. The distribution is skewed with 82.5% of the observations having a clearance of 20m or more from the channel boundary. The median clearance is 30.7m, while the 10th and 90th percentile values are 15.0m and 39.6m respectively. Their relative distance from the median illustrates the skewness of the distribution.

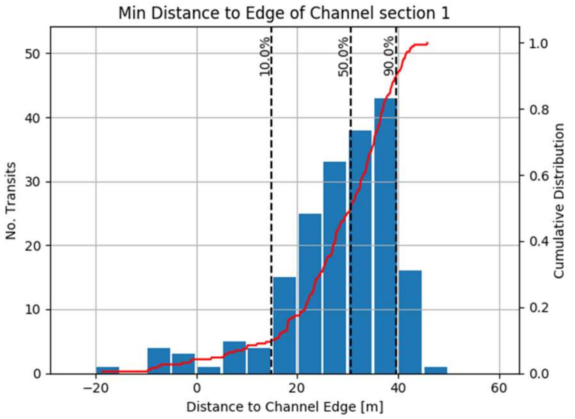

Figure 6 Histogram of bank proximity section 1

The distribution of the minimum channel clearance relative to the rate of change in tide level is shown in Figure 7. The region where the rate of change of tide exceeds the existing port limits is shaded. Again, the median, 10th and 90th percentile lines are shown as horizontal lines.

There are 12 transits that were performed when the tide rate of change was greater than the port's limit in section 1, however these transits all demonstrate the typical range of minimum transit clearance. If this higher tide rate of change was having a significant impact on the vessel manoeuvrability, it could be expected that these points would have a lower minimum clearance.

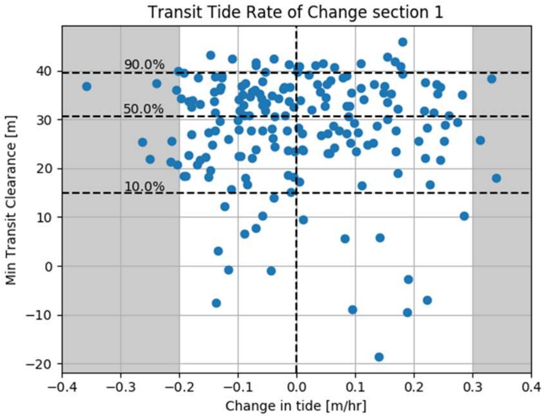

Figure 7 Tide rate of change for transits in section 1. Areas greyed out represent port limits (0.3 m/hr flood, 0.2 m/hr ebb)

For the values with a low minimum clearance, there does not appear to be any clear pattern, with events occurring when the rate of change of tide varies from -0.15 m/hr to slightly more than 0.2 m/hr.

Given that there was no obvious relationship between minimum transit clearance and rate of change of tide, the minimum transit clearance was compared with other variables (wind force, UKC and vessel speed) with the aim of identifying key underlying relationships. However, upon analysis, wind force and UKC did not demonstrate any clear correlation to instances where the vessels approached the channel boundary. As the Port Adelaide channel is a restricted channel, particularly near the berths, tide rate of change has been taken as a proxy for tidal streams aligned with the channel. The correlation between any cross currents and minimum transit clearance could not be investigated due to a lack of measured current data.

Vessel speed did show some correlation. Figure 8 and Figure 9 show cumulative distributions for vessel transit speed in section 1 against minimum transit clearance.

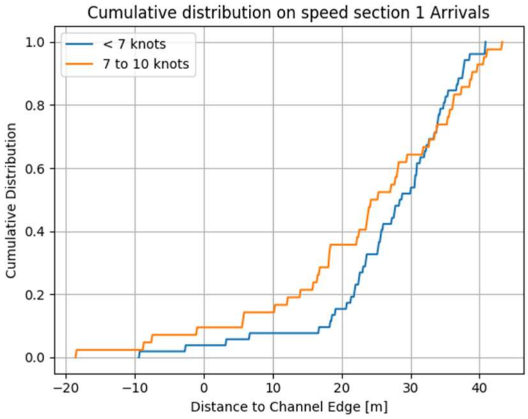

Figure 8 Cumulative distribution for different speed bins in section 1 for inbound transits

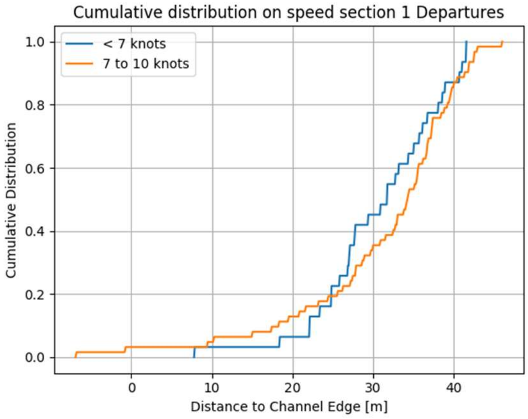

Figure 9 Cumulative distribution for different speed bins section 1 for outbound transits

Although the results are not definitive, there does appear to be a trend through the sections that the higher speeds are more frequently related with vessels approaching closer to the channel boundary. In Figure 8 and Figure 9, for vessels within 15 m of the channel boundary those with speeds of 7-10 kn are twice as likely to be within 15 m than those vessels with speeds less than 7 kn. This trend is also seen in Sections 2 and 3, however in Section 4 no clear trend was seen. Also, the effect of speed on clearance is more pronounced for inbound transits rather than outbound transits, and this inbound/outbound pattern is observed in all sections.

4.3 Discussion

This analysis has shown that approximately every 1 in 4 transits has an instance of the vessel approaching within 10m of the channel boundary.

A small number of vessels appear to have sailed outside the defined channel boundary at some point during their transit.

Other than the relationship with speed, no clear correlation was apparent between any environmental condition and vessel proximity to channel edge. Exceedances were more common on the southern edge of the channel, corresponding to the outer edge of the channel turn. Specifically, for the recorded transits, higher rates of change of tide were not linked with reduced minimum transit clearance.

One of the limitations of this analysis is that it assumes the idealised path to be down the centreline, where as a designated route may deviate from the centreline on occasions (when negotiating a turn for example). This analysis may be more refined by focusing on deviation from a designated route (on a PPU for example), rather than just considering distance from the channel edge.

5. Results: Simflex simulator

Beyond a relationship between minimum transit clearance and vessel speed, the analysis of the recorded vessel position data did not yield any clear relationships between minimum transit clearance and the environmental conditions presented. The SimFlex simulator analysis was performed to demonstrate theoretical relationships between the factors with the aim of better identifying the critical conditions. The more important simulator results are detailed below.

Figure 10 demonstrates the increase in bank yawing moment for an increase in vessel speed through water, as well as different tide levels which directly affects the vessel UKC. A clear trend of increasing yaw moment with increasing speed is obvious, as well as the role UKC plays in increasing yaw moment. For the tide levels analysed, which are of the typical range for Port Adelaide, each meter increase in tide approximately halved bank effects. The effect of reducing 3 knots of speed through water also approximately halved bank effects. For speeds above 10 knots, the 1m tide case saw the design vessel UKC reduce to zero, so no results were reported.

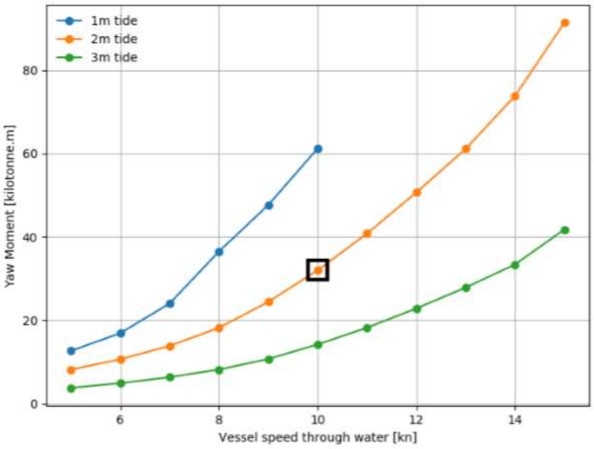

Figure 10 Bank generated yaw moment for varied vessel speed and varied water levels. Base case highlighted in black.

As tidal stream directly affects a vessel's speed through water, the effect of a head tidal stream (i.e., a tidal stream flowing counter to the vessel's course) on bank effects can be directly mitigated by reducing a vessel's speed by the equivalent amount.

As shown, speed and UKC are important contributors to the magnitude of bank effect, but this is dependent on the proximity to the channel boundary on one side of the vessel compared to the other. It is the imbalance in forces that causes the yawing moment on the vessel, which is of most concern. The magnitude of yawing moment is dependent on factors such as speed through water and UKC, but the presence of yawing moment is dependent on vessel position off the channel centreline, or an unequal bank profile.

Another factor highlighted as a contributor to bank effects is the presence of cross-channel currents. These have the potential to cause vessels to move off the channel centreline and closer to one bank or the other.

5.1 Discussion

The results from the SimFlex simulations demonstrated that the key contributors to bank effects are:

- Vessel speed through water
- Vessel UKC
- The presence of cross currents

Wind forcing can have a secondary impact on bank effects, but its effect is much lower than the key contributors above.

If the vessel maintains a centreline track, then the above contributors are not significant as the bank effects tend to balance out. However, once a vessel has deviated from the centreline, these contributors begin to have a cumulative effect.

6. Conclusions

Analysis of AIS vessel positions have shown that instances of vessels approaching the channel boundaries did not strongly correlate with any prevailing environmental conditions investigated, namely: tide rate of change, wind force on vessel, or vessel UKC. Currents could not be investigated in detail due to a lack of measured data.

Vessel speed through the water did have a relationship with transit clearance, with faster transits seemingly more likely to experience lower minimum transit clearance. However, the relationship with speed was not definitive, and there may be other considerations, such as human factors/operation reasons for those cases where vessels approach the channel boundaries.

Approximately 1 in 4 transits derived from AIS has an instance of the vessel approaching within 10m of the channel boundary, with a small number of vessels having exceeded the channel boundary at some point in the transit. It is noted that AIS data may be subject to errors; the accuracy of the AIS data used in the study has not been confirmed.

The simulator desktop study has shown that the key factors with the potential to cause bank effects for vessels off the channel centreline in the Port Adelaide channel are UKC, vessel speed, and the presence of cross currents. For the tidal range in the Port Adelaide channel, the simulator analysis showed that for each meter of extra UKC, the yawing moment generated is roughly halved.

A reduction in vessel speed will also reduce the magnitude of bank effects significantly, with the benefits of reducing a set amount of speed increasing at higher speeds.

These key factors also increase in magnitude based on how far off the channel centreline the vessel is. A vessel keeping to the channel centre line, under any environmental conditions, will experience low bank effects. It is when it approaches the bank, which could initially be for operational reasons, that the key factors described above can cause increased bank effects.

Overall, this analysis did not identify clear environmental correlation in vessels approaching the channel bounds.

It is likely that vessels that have approached the banks have done so for some operational reason and have then experienced problematic bank effects, regardless of the environmental conditions prevailing at the time.

To better identify the cause of bank effects, instances where the vessels have approached the bank for operational reasons should be investigated and the vessel response to the bank analysed in these situations to determine the prevailing environmental conditions, disregarding transits that did not approach the bank.

This could involve more detailed analysis using PPU, VDR and pilot transit notes on events where the vessel approached the bank, and may help identify common causes of these events

7. References

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