AUTORIDAD DEL CANAL DE PANAMÁ

Feasibility Evaluation of a Tug Assisted Locks Vessel Positioning System

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Final Report and Appendix A

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1. EXECUTIVE SUMMARY

The vessel-positioning system is a key element necessary to determine the new Post Panamax lock size and will have a direct impact in the locks cost and the eventual locks alternative analysis.

One gap in the ongoing locks conceptual design studies has been identified as the lack of feasibility studies for alternatives to the existing locomotive ship positioning system. The only previous study available is a brainstorming-type study made by Texas A & M University, "Project to Identify and Evaluate Alternative Concepts for Vessel Positioning at the Locks", in June 1999, which evaluated concepts and presented six final concepts that would require further studies.

To address this situation, the Canal Capacity Projects Division made a proposal to the Maritime Operations Department to assemble a team consisting of Canal Pilots, Tug Masters and Locks engineers to travel to the Port of Antwerp to visit the largest Post Panamax locks in the world, Berendrecht and Zandvliet, to observe and evaluate their operations and how they position these vessels with the assistance of tugs.

The trip was made on October 19-26, 2002, and this report is the result of the team's observations and professional judgment in trying to determine the feasibility of using a tug assisted vessel-positioning system in the proposed Panama Canal Post Panamax locks.

Locks of one, two and three lifts were considered and from the operations standpoint; the single lift was discarded because of the line or wire angles from the top of the locks wall to the vessel, the double lift was estimated as borderline because of the same reason and the triple-lift lock was considered the most feasible and the one for which the different lockage procedures were developed.

Four scenarios were developed for two types of Post Panamax vessels: a container vessel and a Dry Bulk / Tanker vessel. The scenarios included: tug assisted tying up to one lock wall, 4th generation locomotives on just one wall, tug assisted tying up to one lock wall using a line-carrying vehicle, and tug assisted tying up in the middle of the chamber to both lock walls. Two more scenarios were developed for Panamax-Plus vessels (Panamax size with more than 12.04 m of draft) and an additional one for a multiple vessel lockage.

The lockage procedures and preliminary lockage times were developed by Canal Pilots, based on the observed times in Belgium and their professional judgment. Filling-and-emptying and tying-up times were introduced to establish the total lockage and relays lockage cycle times for the Post Panamax tug assisted options. They are summarized and compared to the locomotive scenario in the following table:

Container Vessels	**Lockage Time** (min)
Locomotives on one wall	148.7
Tug assisted tie-up to one wall	185.7
Tug assisted tie-up in the middle of the chamber	160.7
Tug assisted tie-up to one wall with LCV	165.7
Tug assisted tie-up in the middle of the chamber with LCV	140.7
Dry Bulk /Tanker Vessels	**Lockage Time** (min)
Locomotives on one wall	188.7
Tug assisted tie-up to one wall	220.7
Tug assisted tie-up in the middle of the chamber	195.7
Tug assisted tie-up to one wall with LCV	200.7
Tug assisted tie-up in the middle of the chamber with LCV	175.7
Container Vessels	**Lockage Cycle Time** (min)
Locomotives on one wall	102.8
Tug assisted tie-up to one wall	113.8
Tug assisted tie-up in the middle of the chamber	103.8
Tug assisted tie-up to one wall with LCV	93.8
Tug assisted tie-up in the middle of the chamber with LCV	83.8
Dry Bulk /Tanker Vessels	**Lockage Cycle Time** (min)
Locomotives on one wall	128.8
Tug assisted tie-up to one wall	133.8
Tug assisted tie-up in the middle of the chamber	123.8
Tug assisted tie-up to one wall with LCV	113.8
Tug assisted tie-up in the middle of the chamber with LCV	103.8

Table 1-1. Total Lockage and lockage cycle times for a three-lift lock for different types of Post Panamax vessels and modes of operating with tugs.

With a tug assisted vessel-positioning system some lock infrastructures are not required, such as the approach walls, towing tracks and conductor slots, track transformers and switchgears. Changes are needed because of the increased chamber dimensions for the gates, length of walls and water saving basins. Additional chamber fenders will probably be required.

Estimates of the infrastructure changes required by a tug-assisted system were made and compared to the assumed locomotive system requirements. Operations and maintenance, labor and materials annual costs were also developed for both options and considered for a 30-year life cycle using a discount rate factor of 12%. An optimistic unit price of \$3.0 million was assumed for a 4th generation locomotive and a consulted price of $ 5.6 million for the lock tugs. In this case, a difference of $***70.58 million*** is found in favor of the locomotive positioning system. The following tables summarizes the cost estimates:

Locomotive Positioning System (working similar to existing)	**USD in million**
Initial Infrastructure Investment	168.31
Initial Equipment Investment	60.00
Annual Operations, Materials and Maintenance for 30 years (includes additional purchase of locomotives for relays & Rio Indio)	147.26
Total Cost at Net Present Value @ discount rate factor of 12%	**375.57**
Tug Assisted Positioning System (using LCV)	
Initial Infrastructure Investment	203.25
Initial Equipment Investment	36.10
Annual Operations, Materials and Maintenance for 30 years (includes additional purchase of LCV for relays & Rio Indio)	206.80
Total Cost at Net Present Value @ discount rate factor of 12%	**446.15**

Table 1-2. Total Costs breakdown for the Locomotive and the Tug Assisted Vessel Positioning Systems in a lock with wider and longer chambers.

It is very important to note that for whatever vessel positioning system alternative is selected, new 50- to 60-ton bollard pull tugs will be necessary to assist shipping throughout the Canal's navigable channels. This will be especially true in the lock entrances, Gaillard Cut and possibly beyond, and the new bypass channel leading to the new Pacific lock structure. The number of these tugs that is required will be dependent on the expected amount of traffic derived from the ongoing Marketing studies. Since these new tugs are necessary, independent of the vessel positioning system selected for the locks, and will be used mainly outside the locks, their costs were not included as part of the economic evaluation.

The primary conclusion of this study is whether a tug assisted locks vessel-positioning system is feasible navigationally, technically and economically for the new Post Panamax locks and should be considered as one of the alternatives for decision-making analysis.

For the tugboat system to work safely and efficiently in the locks, the following conditions should be met:

A. The width of the proposed chamber should be 20 % wider than the beam of the design vessel, or at least 12.2 m (40 feet) more, to allow bow tugs to leave the chamber if they are not needed.

B. The length of the proposed chamber should be at least 100 m (328 feet) longer than the design vessel to allow maneuvering space for the bow tugs and the possibility of Panamax tandem lockages.

C. An under-the-keel clearance (UKC) of 3m (10 feet) is paramount in allowing these vessels to move through the locks in a timely manner.

D. The filling and emptying system of the locks should work in such a way that little or no turbulence, longitudinal or transverse forces are developed to allow safe tie-up to the walls or in the middle of the chamber. The hydrodynamic forces that would develop during water exchanges should not create a dangerous situation of parting mooring lines.

E. The Compact Lock tugs concept should be implemented to reduce the requirements on the ACP Post Panamax tug fleet.

It is our recommendation that the ACP should make a field test of this system in our existing locks with an actual transiting vessel proportioned to the Post Panamax chamber. This will confirm the safety of the operation, the system's behavior in multiple-lift locks and estimated lockage times. The results of this test can be introduced as an update or revision of this report, to enhance its thoroughness and documentation.

Locks Locomotives

Because of the large displacements of Post Panamax vessels, the existing locomotives will not provide adequate assistance to these vessels because of a lack of space for their proper positioning alongside the vessel at points where effective forces can be exerted. A team of transportation, electrical, mechanical and structural engineers should be contracted to develop a conceptual design for the 4th generation of towing locomotives. The technical and economical feasibility of the locomotives can then be properly evaluated, and a revisit of this report should be made, especially in the costs section where the $ 3.0 million / unit locomotive price was used.

Also, the previous ACP-developed, Post-Panamax Canal Capacity study should be revisited to introduce these new lockage time estimates and reevaluate the previously estimated capacity, especially for financial feasibility purposes.

2. LOCKAGE PROCEDURES FOR THE POST-PANAMAX LOCKS

2.1 Study Assumptions

Vessel Dimensions

For this project we are assuming two types of Post Panamax vessels. One will be a container vessel and the other a dry-bulk carrier/tanker, both with the following dimensions: overall length 385.7 meters (1265 feet); maximum beam 54.9 meters (180 feet) and maximum draft 15.2 meters (50 feet). It is assumed that container vessels in the following scenarios are equipped with operational bow and stern thrusters.

Spilling and Density Currents

It should be taken into consideration that the procedures we describe in this document are assuming that the sea gates should have been opened for a long enough period of time, so that the density currents experienced at the present sea entrances (spilling and mixing of fresh and salt water, which takes approximately forty minutes to dissipate), will be at its minimum level.

Vessel Lifting Process

The process of lifting a vessel from sea level to Gatún Lake level can physically be accomplished in one or more lifts. It entails a total lift of 25.9 to 26.7m (85 to 87.5 feet). For the following analysis we will assume that the typical freeboard of a loaded dry-bulker is 9.1m (30 feet) and the distance from the top of the wall to the water line of a full chamber is 2.1m (7 feet).

a. **One-Lift Lock**: If we consider a one-lift chamber, the distance from the top of the wall down to the main deck of the vessel can be almost 18m (60’) and the leads for the mooring lines or locomotive wires will be almost at ninety degree angles, making it impossible for the vessel to be held safely alongside the wall or in the middle of the chamber (with locomotives). An alternative could be the use of floating bollards recessed in the lock walls, but a safe and effective way of taking the vessel’s mooring lines to the floating bollards needs to be determined.

b. **Two-Lift Lock**: If we consider a two lift lock, the distance from the top of the wall down to the main deck of the vessel can be in the vicinity of 6m (20’) and the leads for the mooring lines or locomotive wires will be at such an angle that it will be very difficult to hold the vessel safely alongside the wall or in the middle of the chamber (with locomotives).

c. **Three-Lift Lock**: In the case of a three-lift lock, the distance from the top of the wall to the main deck of the vessel will be acceptable. The leads can either be upward or downward for the mooring lines or locomotive wires and they will be of such an angle that positive control can be maintained.

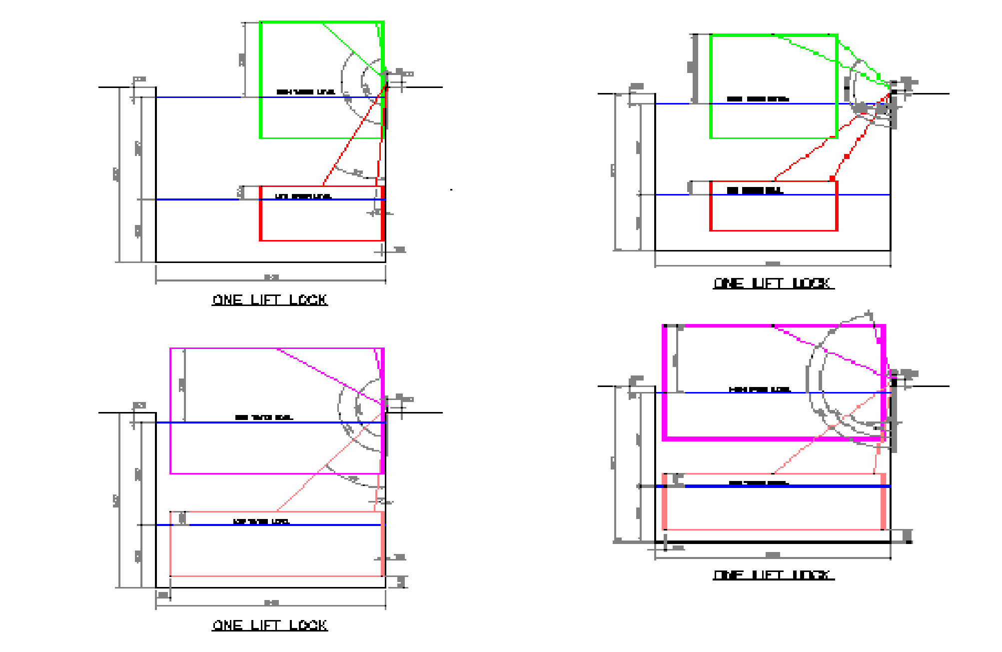

Figure 2-1. One-Lift Lock- Mooring lines or Locomotive wires angles. Panamax and Post Panamax vessels at High and low water. Vessels are also shown alongside the wall or in the middle of the chamber.

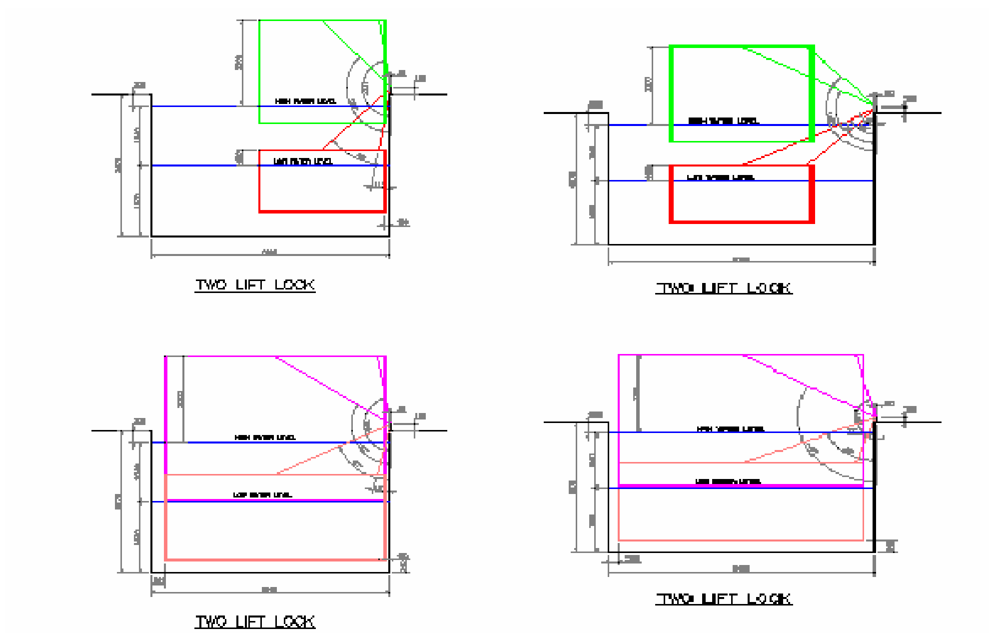

Figure 2-2. Two-Lift Lock- Mooring lines or Locomotive wires angles. Panamax and Post Panamax vessels at High and low water. Vessels are also shown alongside the wall or in the middle of the chamber.

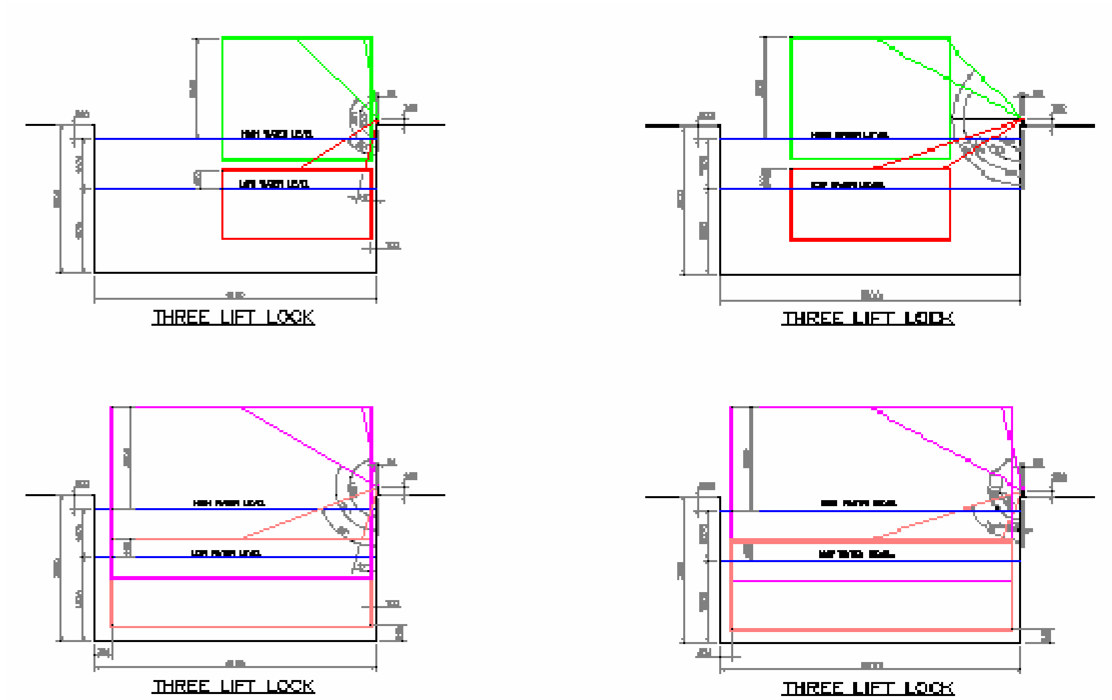

Figure 2-3. Three-Lift Lock- Mooring lines or Locomotive wires angles. Panamax and Post Panamax vessels at High and low water. Vessels are also shown alongside the wall or in the middle of the chamber.

2.2 First Scenario– Post-Panamax Vessels – Tug Assisted tying up to one wall

According to our assumptions, a three-lift lock with similar chamber dimensions to Berendrecht (500 x 68 x 18.3 meters) is required to be able to have a lockage of a vessel with the design dimensions chosen for the ACP studies. The rule of thumb would be to have the width of the chamber 20% wider than the beam of the design vessel (or at least 12.1 m or 40 feet, which is the approximate width of a tug), similar to the design criteria used in Belgium. This lock system has no approach wall, fenders, locomotives or alternative mooring gears located on the walls other than bollards.

2.2.1 Lockage of Container Vessels

These vessels will require the assistance of two omni-directional tugs, which should have a bollard pull between 50 and 60 tons. One tug will be used on the bow on a hawser and the other on the stern on a hawser. These tugs will remain with the vessel for the whole lockage procedure. We can foresee that at least one tug will be used by these vessels while proceeding through Gaillard Cut and probably beyond.

The approach to the locks will be considered to begin roughly three ship lengths away from the knuckle. At this time the vessel's speed will be about three knots. Considering an average speed of two knots, it will take this vessel approximately 20 minutes to arrive at the locks. Upon arriving at the locks, this vessel should be making a speed around one knot. Considering the length of the chamber, it will take this type of vessel approximately ten minutes to get inside the first chamber and an additional ten minutes to be fully moored alongside the wall. This vessel will be using four lines to secure to the wall, one head line and one spring line on the bow, and one stern line and one spring line on the stern. This arrangement is possible if there is little or no turbulence during the process of drawing water into the chamber. If there is any significant turbulence during this process, some other means of positioning the vessel alongside the wall or on the middle of the chamber should be considered.

Once the water level of both chambers is equalized and the forward gates are fully recessed, the process of moving the vessel to the next chamber is basically an undocking maneuver, moving ahead approximately 457.2m (1500 feet) and once again mooring alongside the wall with the assistance of the accompanying tugs. This process will normally take between 25 and 30 minutes and is repeated twice during the whole lockage procedure taking the vessel up to Gatun Lake.

Upon reaching the upper chamber, the vessel will be moved with the assistance of the two tugs out into Gatún Lake where one of the assisting tugs will remain with the vessel. This process will normally take between 15 and 20 minutes.

A rough estimate of the time required to move a Post Panamax container vessel in this scenario from three ship lengths off the knuckle to clearing into Gatún Lake is approximately two hours (2:00) plus the time it will take to fill each chamber and open and close the gates. Having a minimum under-keel-clearance of 3m (10') is paramount in allowing these vessels to move through the locks in a timely manner and without any other additional assistance.

2.2.2 Lockage of Dry Bulk Carriers / Tankers

These vessels will require the assistance of three omni-directional tugs (in some specific cases a fourth tug may be required), with a recommended bollard pull between 50 and 60 tons. Two tugs will be used on the bow on a hawser and the other(s) on the stern on a hawser. Two of these tugs will remain with the vessel for the whole lockage procedure. We can foresee that at least one tug will be used by these vessels while proceeding through Gaillard Cut and probably beyond.

The approach to the locks will be considered to begin roughly three ship lengths away from the knuckle. At this time the speed will be in the vicinity of three knots. Considering an average speed of 1.5 knots it will take this vessel approximately 25 minutes to arrive at the locks. Arriving at the locks this vessel should be making a speed in the vicinity of one knot. Considering the length of the chamber, it will take this type of vessel approximately fifteen minutes to get inside the chamber and an additional ten minutes to be fully moored alongside the wall. This vessel will be using four lines to secure to the wall, one head line and one spring line on the bow and one stern line and one spring line on the stern. This arrangement is possible if there is little or no turbulence during the process of drawing water into the chamber. If there is any significant turbulence during this process, some other means of positioning the vessel alongside the wall or in the middle of the chamber should be considered.

Once the water level of both chambers is equalized and the forward gates are fully recessed, the process of moving the vessel to the next chamber is basically an undocking maneuver, moving ahead approximately 457.2m (1500 feet) and once again mooring alongside the wall with the assistance of the accompanying tugs. This process will normally take approximately 40 minutes and is repeated twice during the whole lockage procedure taking the vessel up to Gatún Lake.

Upon reaching the upper chamber, the vessel will be moved with the assistance of the two tugs out into Gatun Lake where one of the assisting tugs will remain with the vessel. This process will normally take approximately 25 minutes.

A rough estimate of the time required to move a Post-Panamax dry bulk carrier or tanker from three ship-lengths off the knuckle to clearing into Gatun Lake is approximately two hours and thirty five minutes (2:35) plus the time it will take to fill each chamber and open and close the gates. Having a minimum under-keel clearance of 3m (10’) is paramount in allowing these vessels to move through the locks in a timely manner and without any other additional assistance.

2.3 Second Scenario– Post-Panamax Vessels – 4th Generation Locomotives working from one wall

This will be a lockage at a three-lift lock similar in chamber dimensions to Berendrecht (500 x 68 x 18.3 meters). This lock will have an approach wall, fenders and locomotives.   The approach wall shall have a usable length equivalent to 1.5 times the maximum length of projected vessel (385 m x 1.5 = 578 m or 1265 ft x 1.5 = 1895 ft). The fenders shall be “V” type or similar to those presently in use at Pedro Miguel Southeast approach wall.   Four locomotives with a bollard pull of 444,800 N (100,000 lbs.), two on the bow and two on the stern, are assumed to be used in the lockage on the center wall only.

2.3.1 Lockage of Container Vessels

These vessels will require the assistance of two omni-directional tugs, which should have a bollard pull between 50 and 60 tons. One tug will be used on the outboard bow and the other on the stern on a hawser or cut style. We can foresee that at least these vessels will use one of these tugs while proceeding through Gaillard Cut and probably beyond.

The approach to the locks will be considered to begin roughly three ship lengths away from the softnose.   At this time, the vessel’s speed will be in the vicinity of three knots. Considering an average speed of 2 knots, it will take this vessel approximately 20 minutes to arrive at the locks. Arriving at the locks, this vessel should be making a speed in the vicinity of 1.5 knots. The vessel will be landed on the approach wall, where locomotives will make it fast. The vessel will be kept alongside the wall, with the assistance of two tugs and four locomotives while proceeding inside the chamber. This vessel should take approximately fifteen minutes to proceed from the softnose to the knuckle. Considering the length of the chamber, it will take this type of vessel approximately twelve minutes to be in position inside the chamber. It is paramount to keep the vessel along side the wall during the filling of the chamber; therefore this process should be carried out with a minimum of effect on the vessel's position inside the chamber.

Once the water level of both chambers is equalized and the forward gates are fully recessed, the process of moving the vessel to the next chamber is basically to slide down the wall, with the assistance of four locomotives, exercising caution not to develop any considerable speed, until the ship is in position in the next chamber. These vessels can make good use of bow and stern thrusters, and no tugs should be necessary for this maneuver. This process will normally take approximately 12 minutes and is repeated twice during the whole lockage procedure taking the vessel up to Gatún Lake.

Upon reaching the upper chamber, the vessel will slide down to the approach wall where locomotives will be cast off. This process will take approximately 12 minutes.

A rough estimate of the time required to move a Post Panamax container vessel in this scenario from three ship lengths off of the softnose to clearing into Gatún Lake is approximately one hour and thirty five minutes (1:35), plus the time it will take to fill each chamber and open and close the gates. Having a minimum under-keel clearance of 3m (10') is paramount in allowing these vessels to move through the locks in a timely manner and without any other additional assistance.

2.3.2 Lockage of Dry Bulk Carriers / Tankers

These vessels will require the assistance of two omni-directional tugs with a recommended bollard pull between 50 and 60 tons. One tug will be used on the outboard bow and the other on the stern on a hawser or cut style. One tug will remain with the vessel for the whole lockage procedure to assist in stopping the vessel while moving into and from chamber to chamber. We foresee that at least one tug will remain with the vessel while proceeding through Gaillard Cut and probably beyond.

The approach to the locks will be considered to begin roughly three ship lengths away from the softnose. At this time the speed will be in the vicinity of 3 knots. Considering an average speed of 1.5 knots, it will take this vessel approximately 25 minutes to arrive at the locks. Arriving at the locks, this vessel should be making a speed in the vicinity of one knot. The vessel will be landed on the approach wall, where locomotives will be made fast. The vessel will be kept alongside the wall while proceeding inside the chamber with the assistance of two tugs and four locomotives. This vessel should take approximately 25 minutes to proceed from the softnose to the knuckle. Considering the length of the chamber, it will take this type of vessel approximately 15 minutes to be in position inside the chamber. It is paramount to keep the vessel alongside the wall during the filling of the chamber; therefore this process should be carried out with a minimum of effect on the vessel's position inside the chamber.

Once the water level of both chambers is equalized and the forward gates are fully recessed, the process of moving the vessel to the next chamber is basically to slide down the wall with the assistance of four locomotives, exercising caution not to develop any considerable speed, until the ship is in position in the next chamber. This process will normally take approximately 20 minutes and is repeated twice during the whole lockage procedure taking the vessel up to Gatún Lake.

Upon reaching the upper chamber, the vessel will slide down to the approach wall where locomotives will be cast off. This process will take approximately 18 minutes.

A rough estimate of the time required to move a Post-Panamax dry bulk carrier/ tanker from three ship lengths off of the softnose to clearing into Gatún Lake is approximately two hours (2:00) plus the time it will take to fill each chamber and open and close the gates. Having a minimum under-keel clearance of 3m (10') is paramount in allowing these vessels to move through the locks in a timely manner and without any other additional assistance.

2.4 Third Scenario– Post Panamax Vessels – Tug Assisted using a LCV and tying up to one wall

This will be a lockage at a three-lift lock similar in chamber dimensions to Berendrecht (500 x 68 x 18.3 meters). This lock will have no approach wall or locomotives, but will include a fender system inside the chamber. The fenders shall be "V" type or similar to those presently in use on the Pedro Miguel Southeast approach wall. It will employ a "Line Carrying Vehicle" (LCV) device that will assist in moving the vessel's mooring lines alongside the wall. This LCV device can be considered just a moving bollard and should be designed to withstand some inevitable tension from the vessel's mooring lines.

The lockage procedure using the LCV device, also known as the running bollard, will be similar to that described in Scenario One, with the only difference that the time it takes to moor the vessel inside the chamber, when in position, and while moving from chamber to chamber might be reduced by five minutes in each maneuver.

If we attempt to move the vessel from chamber to chamber by sliding it along the wall, the mooring lines will not be capable of withstanding the hydrodynamic forces that would develop, creating a dangerous situation if the mooring lines should break.

The only way to accomplish this maneuver and with some degree of risk is by using the procedure described in Scenario One in conjunction with having the lines slack while moving from chamber to chamber. There are inherent dangers in doing this procedure. First, the slack lines could be fouled in the propeller or thrusters. Second, the chaffing effect of having the slacked lines rubbing on the wall while moving the vessel approximately 457.2 m (1500 feet) in every chamber will considerably reduce the lines' breaking strength. Thus it is of extreme importance that the LCV is able to keep the mooring lines off the wall and, in coordination with the vessel's crew, also off the water.

2.5 Fourth Scenario– Post Panamax Vessels – Tug Assisted tying up in the middle of the chamber

This will be a lockage at a three-lift lock similar in chamber dimensions to Berendrecht (500 x 68 x 18.3 meters). This lock has no approach wall, fenders, locomotives or alternative mooring gears located on the walls, other than bollards. In this scenario we will position the vessel in the middle of the chamber with mooring lines off both sides of the vessel (similar to the procedure presently used for center chamber handline lockages).

2.5.1 Lockage of Container Vessels

These vessels will require the assistance of two omni-directional tugs, which should have a bollard pull between 50 and 60 tons. One tug will be used on the bow on a hawser and the other on the stern on a hawser or cut style. These tugs will remain with the vessel for the whole lockage procedure. We can foresee that at least one tug will be used by these vessels while proceeding through Gaillard Cut and probably beyond.

The approach to the locks will be considered to begin roughly three ship lengths away from the knuckle. At this time the speed will be in the vicinity of three knots. Considering an average speed of two knots, it will take this vessel approximately 20 minutes to arrive at the locks. Arriving at the locks, this vessel should be making a speed in the vicinity of one knot. Considering the length of the chamber it will take this type of vessel approximately ten minutes to get inside the chamber, and an additional ten minutes to be fully secured in the middle of the chamber. This vessel will be using four lines: two head lines, one off each bow; and two stern lines, one off each quarter.

The arrangement described above will only be possible if there is little or no turbulence during the process of drawing water into the chamber during an up-lockage, or a down-lockage. If there is any significant turbulence during this process, the lines from the vessel would not be capable of withstanding the strain of the forces acting on the vessel, with the more-than-likely end result of parting the lines. This will endanger the life and limb of deckhands on board the vessel as well as those on shore, and could also result in structural damage to the hull of the vessel and the lock walls. If the turbulence is of such magnitude that the vessel's movement cannot be avoided, then this procedure should be avoided at all costs, and some other method of positioning the vessel in the middle of the chamber should be evaluated.

Once the water level of both chambers is equalized and the forward gates are fully recessed, the process of moving to the next chamber is basically to move the vessel ahead approximately 457.2m (1500 feet) and once again secure it in the middle of the chamber. This process will normally take 20 minutes and is repeated twice during the whole lockage procedure taking the vessel up to Gatún Lake.

Upon reaching the upper chamber, the vessel will be moved with the assistance of the two tugs out into Gatún Lake where one of the assisting tugs will remain with the vessel. This process will normally take 15 minutes.

A rough estimate of the time required to move a Post-Panamax container vessel from three ship lengths off the knuckle to clearing into Gatún Lake is approximately one hour and thirty five minutes (1:35) plus the time it will take to fill each chamber and open and close the gates. Having a minimum under-keel clearance of 3m (10') is paramount in allowing these vessels to move through the locks in a timely manner and without any other additional assistance.

2.5.2 Lockage of Dry Bulk Carriers / Tankers

These vessels will require the assistance of three omni-directional tugs (in some specific cases a fourth tug may be required), with a recommended bollard pull between 50 and 60 tons. Two tugs will be used on the bow on a hawser and the other(s) on the stern on a hawser or one cut style. Two of these tugs will remain with the vessel for the whole lockage procedure. We can foresee that at least one tug will be used by these vessels while proceeding through Gaillard Cut and probably beyond.

The approach to the locks will be considered to begin roughly three ship lengths away from the knuckle. At this time the speed will be in the vicinity of three knots. Considering an average speed of 1.5 knots, it will take this vessel approximately 25 minutes to arrive at the locks. Arriving at the locks, this vessel should be making a speed in the vicinity of one knot. Considering the length of the chamber, it will take this type of vessel approximately fifteen minutes to get inside the chamber and an additional ten minutes to be fully secured in the middle of the chamber. This vessel will be using four lines: two head lines, one off each bow; and two stern lines, one off each quarter.

The arrangement described above will only be possible if there is little or no turbulence during the process of drawing water into the chamber in an up lockage, or during a down lockage. If there is any significant turbulence during this process, the lines from the vessel would not be capable of withstanding the strain of the forces acting on the vessel, with the more-than-likely end result of parting the lines. This will endanger the life and limb of deckhands on board the vessel as well as those ashore, and could result in structural damage to the hull of the vessel and the lock walls. If the turbulence is of such magnitude that the vessel's movement cannot be avoided, then this procedure should be avoided at all costs, and some other method of positioning the vessel in the middle of the chamber should be evaluated.

Once the water level of both chambers is equalized and the forward gates are fully recessed, the process of moving to the next chamber is basically to move the vessel ahead approximately 457.2m (1500 feet) and once again securing it in the middle of the chamber. This process will normally take approximately 30 minutes and is repeated twice during the whole lockage procedure taking the vessel up to Gatún Lake.

Upon reaching the upper chamber, the vessel will be moved with the assistance of the two tugs out into Gatún Lake, where one of the assisting tugs will remain with the vessel. This process will normally take approximately 20 minutes.

A rough estimate of the time required to move a Post-Panamax dry bulk carrier or tanker from three ship lengths off the knuckle to clearing into Gatún Lake is approximately two hours and 10 minutes (2:10) plus the time it will take to fill each chamber and open and close the gates. Having a minimum under-keel clearance of 3m (10') is paramount in allowing these vessels to move through the locks in a timely manner and without any other additional assistance.

2.6 Fifth Scenario– Panamax Plus Vessels – Tug Assisted tying up to one wall

This will be a lockage at a three-lift lock similar in chamber dimensions to Berendrecht (500 x 68 x 18.3 meters). This lock has no approach wall, fenders, locomotives or alternative mooring gears located on the walls other than bollards.

Vessel Dimensions

For this scenario we assume two types of vessels. One will be a container vessel with the following dimensions: overall length 294.1 m (965 feet); maximum beam 32.3 m (106 feet) and maximum draft 14.02 m (46 feet); and the other a dry-bulk carrier/tanker with the following dimensions: overall length 224.9 m (738 feet); maximum beam 32.3 m (106 feet) and maximum draft 14.02 m (46 feet). It is assumed that container vessels in the following scenarios are equipped with operational bow and stern thrusters.

2.6.1 Lockage of Container Vessels

These vessels will require the assistance of two omni-directional tugs, which should have a bollard pull between 50 and 60 tons. One tug will be used on the bow on a hawser and the other on the stern on a hawser or cut style. These tugs will remain with the vessel for the whole lockage procedure. We can foresee that at least one tug will be used by these vessels while proceeding through Gaillard Cut and probably beyond.

The approach to the locks will be considered to begin roughly three ship lengths away from the knuckle. At this time the speed will be in the vicinity of three knots. Considering an average speed of two knots, it will take this vessel approximately 15 minutes to arrive at the locks. Arriving at the locks, this vessel should be making a speed in the vicinity of 1.5 knots. Considering the length of the chamber, it will take this kind of vessel approximately 10 minutes to get inside the chamber and an additional 5 minutes to be fully moored alongside the wall. This vessel will be using four lines to secure to the wall: one head line and one spring line on the bow, and one stern line and one spring line on the stern. This arrangement is possible if there is little or no turbulence during the process of drawing water into the chamber. If there is any significant turbulence during this process, some other means of positioning the vessel alongside the wall or on the middle of the chamber should be considered.

Once the water level of both chambers is equalized and the forward gates are fully recessed, the process of moving the vessel to the next chamber is basically an undocking maneuver, moving ahead approximately 457.2m (1500 feet) and once again mooring alongside the wall. This process will normally take 20 minutes and is repeated twice during the whole lockage procedure taking the vessel up to Gatún Lake.

Upon reaching the upper chamber, the vessel will be moved with the assistance of the two tugs out into Gatún Lake where one of the assisting tugs will remain with the vessel. This process will normally take 10 minutes.

A rough estimate of the time required to move a Panamax-Plus container vessel from three ship lengths off of the knuckle to clearing into Gatún Lake is approximately one hour and twenty minutes (1:20), plus the time it will take to fill each chamber and open and close the gates. Having a minimum under-keel clearance of 3m (10') is paramount in allowing these vessels to move through the locks in a timely manner and without any other additional assistance.

2.6.2 Lockage of Dry Bulk Carriers / Tankers

These vessels will require the assistance of three omni-directional tugs with a recommended bollard pull between 50 and 60 tons. Two tugs will be used on the bow on a hawser and the other on the stern on a hawser or cut style. Two of these tugs will remain with the vessel for the whole lockage procedure. We can foresee that at least one tug will be used by these vessels while proceeding through Gaillard Cut and probably beyond.

The approach to the locks will be considered to begin approximately three ship lengths away from the knuckle. At this time the speed will be in the vicinity of three knots. Considering an average speed of 1.5 knots, it will take this vessel approximately 15 minutes to arrive at the locks. Arriving at the locks, this vessel should be making a speed in the vicinity of one knot. Considering the length of the chamber, it will take this type of vessel approximately 10 minutes to get inside the chamber and an additional 5 minutes to be fully moored alongside the wall. This vessel will be using four lines to secure to the wall: one head line and one spring line on the bow and one stern line and one spring line on the stern. This arrangement is possible if there is little or no turbulence during the process of drawing water into the chamber. If there is any significant turbulence during this process, some other means of positioning the vessel alongside the wall or in the middle of the chamber should be considered.

Once the water level of both chambers is equalized and the forward gates are fully recessed, the process of moving the vessel to the next chamber is basically an undocking maneuver, moving ahead approximately 457.2m (1500 feet) and once again mooring alongside the wall. This process will normally take approximately 25 minutes and is repeated twice during the whole lockage procedure taking the vessel up to Gatún Lake.

Upon reaching the upper chamber, the vessel will be moved with the assistance of the two tugs out into Gatún Lake, where one of the assisting tugs will remain with the vessel. This process will normally take approximately 15 minutes.

A rough estimate of the time required to move a Panamax dry bulk carrier or tanker from three ship lengths off the knuckle to clearing into Gatún Lake is approximately one hour and thirty five (1:35) minutes plus the time it will take to fill each chamber and open and close the gates. Having a minimum under-keel clearance of 3m (10’) is paramount in allowing these vessels to move through the locks in a timely manner and without any other additional assistance.

2.7 Sixth Scenario– Panamax Plus Tandems

This will be a lockage at a three-lift lock similar in chamber dimensions to Berendrecht (500 x 68 x 18.3 meters). This lock has no approach wall, fenders, locomotives or alternative mooring gears located on the walls other than bollards. For this scenario we will consider the possibility of tandem lockages, with both vessels moored to same wall maintaining a minimum distance of 15.24 m (50 feet) from the gates (fore and aft) and 22.86 m (75 feet) between vessels.

Vessel Dimensions

For this scenario we assume there is a tandem, two vessels of 213.4 m (700 feet) in length, 32.3 m (106 feet) in beam and up to 14.02 m (46 feet) in draft. These may be container vessels, dry bulk carriers or general cargo vessels.

2.7.1 Lockage Procedure

The lockage procedure will be similar to the one used in the fifth scenario with the estimated times, depending on the type of vessels involved in the tandem and the availability of tugs for all the vessels involved. The additional time that has to be included in this procedure is the time that the second vessel has to wait in order to proceed inside, move to the next chamber and clear the locks.

The first vessel will proceed inside the chamber using the same procedure described in scenario five. The second vessel will have to wait until the first vessel has entered the locks in order to start its approach. Keeping a safe distance of approximately three ship lengths from the vessel ahead will mean that the second vessel will enter locks approximately 20 minutes after the first one.

The movement between chambers could be expedited if both vessels had their own set of tugs. If this is not the case, there will be delays in releasing tugs from one vessel to assist the other and vice versa.

If both vessels have their own set of tugs, then the second vessel will probably have to wait until the first vessel is a safe distance away before casting off the lines and proceeding ahead into the next chamber. This will probably be 15 minutes after the first vessel has already started moving.

If there is only one set of tugs assigned to move the two vessels from chamber to chamber, then the second vessel will have to wait until the first one is secured alongside the wall and the tugs are released and are made fast to the second vessel in order to proceed. The time between releasing the tugs from the first piece to having the tugs made fast on the second piece is approximately 15 minutes.

Whenever the vessels are ready to clear the locks, the second vessel will have to wait until the first vessel is completely clear of the locks before casting off the lines and proceeding out into Gatún Lake.

A rough estimate of the time required to move two Panamax dry bulk carriers, if both vessels have their own set of tugs assigned to them, from three ship lengths off the knuckle to clearing into Gatún Lake is approximately two hours and forty minutes (2:40), plus the time it will take to fill each chamber and open and close the gates. If there is only one set of tugs to assist both vessels from chamber to chamber and out into Gatún Lake then an additional 50 minutes must be added to the above estimate. These times may be adjusted depending upon the combination of vessels involved in the tandem; normally, container vessels or vehicle carriers should take less time to accomplish these maneuvers. Having a minimum underwater keel clearance of 3m (10’) is paramount in allowing these vessels to move through the locks in a timely manner and without any other additional assistance.

2.8 Seventh Scenario– Multiple Vessels

This will be a lockage at a three-lift lock similar in chamber dimensions to Berendrecht (500 x 68 x 18.3 meters). This lock has no approach wall, fenders, locomotives or alternative mooring gears located on the walls other than bollards.

For this scenario we will consider different combination of vessels inside the chamber using both walls to moor the vessels alongside. A maximum combined beam limitation of 53.3 m (175 feet) will be the restriction for this scenario, leaving a minimum clearance of 13.7 m (45 feet) between vessels abeam of each other. A minimum distance of 15.2 m (50 feet) from the gates (fore and aft) and 22.9 m (75 feet) between vessels should be maintained.

Vessel Dimensions

For this scenario we will consider vessels of different sizes with the following maximum dimensions: 294.1 m (965 feet) overall length, 32.3 m (106 feet) extreme beam and deep draft of 14.02 m (46 feet). The maximum combined beam should not exceed 53.3 m (175 feet). The aggregate length of vessels should not exceed the usable length of the chamber, taking into consideration the distance of the vessels to the gates and between each other.

In this particular example we will use a dry bulk carrier 221 x 32.3 x 12.2 m (725 x 106 x 40 feet), a container vessel 183 x 28.9 x 10.9 m (600 x 95 x 36 feet), a general cargo vessel 160 x 22.9 x 9.8 m (525 x 75 x 32 feet) and a refrigerated cargo vessel 143.3 x 19.8 x 7.9 m (470 x 65 x 26 feet).

2.8.1 Lockage Procedure

The size of the vessels will determine the arrangement and order in which they are placed inside the chamber. For the mixture described above the order will be the following: first, the dry bulk carrier; second, the refrigerated cargo vessel; third, the container vessel and fourth, the general cargo vessel.

Preference should be given to the larger and heavier vessel to enter the chamber first. This will guarantee that the whole chamber is available for this vessel to safely maneuver inside the chamber. The second vessel proceeding in should be the one that will be moored abeam of the larger vessel on the opposite wall. The third vessel proceeding in should be the second largest, guaranteeing that the whole width of the chamber is available for this vessel to safely maneuver inside. The fourth vessel proceeding in should be the one moored abeam of the second largest vessel.

The lockage procedure for the dry bulk carrier and the container vessel will be a combination of the procedures explained in scenarios five and six.

The smaller vessels in this lockage, the general cargo and the refrigerated cargo, will require the assistance of two omni-directional tugs with a recommended bollard pull between 30 and 40 tons. One tug will be used on the bow on a hawser and the other on the stern on a hawser. If any of these vessels is equipped with bow or stern thrusters, the amount of tugs needed to assist could be adjusted.

Description of the procedure for the two smaller vessels: The approach to the locks will be considered to begin approximately three ship lengths away from the knuckle. At this time the vessel's speed will be in the vicinity of three knots. Considering an average speed of 1.5 knots, it will take this vessel approximately 10 minutes to arrive at the locks. Arriving at the locks, this vessel should be making a speed in the vicinity of one knot. Considering the length of the chamber, it will take this type of vessel approximately 10 minutes to get inside the chamber and an additional 5 minutes to be fully moored alongside the wall. This vessel will be using four lines to secure to the wall: one headline and one spring line on the bow and one stern line and one spring line on the stern. This arrangement is possible if there is little or no turbulence during the process of drawing water into the chamber. If there is any significant turbulence during this process, some other means of positioning the vessel alongside the wall should be considered. It is assumed that only two tugs will be locking with the vessels to assist in moving to the following chambers and out into Gatún Lake.

Once the water level of both chambers is equalized and the forward gates are fully recessed, the vessels will proceed into the next chamber in the same order that they entered the first chamber.

The process of moving the smaller vessels to the next chamber is basically an undocking maneuver, moving ahead approximately 457.2m (1500 feet) and once again mooring alongside the wall, with the assistance of the same amount of tugs that were used while proceeding inside the chamber. This process will normally take approximately 18 minutes for each of the smaller vessels and is repeated twice during the whole lockage procedure taking the vessels up to Gatún Lake.

Upon reaching the upper chamber, the smaller vessels will be moved with the assistance of one tug out into Gatún Lake and they will proceed ahead of the larger vessels. This process will normally take approximately 10 minutes per small vessel. It is assumed that there are at least two more tugs available at Gatún Lake level since the two larger vessels will be in need of tug assistance through Gaillard Cut.

A rough estimate of the time required to move the combination of vessels described in this scenario from three ship lengths off the knuckle to clearing into Gatún Lake is approximately six hours (6:00) plus the time it will take to fill each chamber, open and close the gates. Having a minimum underwater keel clearance of 3 m (ten feet) is paramount in allowing these vessels to move through the locks in a timely manner and without any other additional assistance.

2.9 Tugs Assistance

2.9.1 Lockage Procedures

Tug operations for ship assist in areas surrounding the Post Panamax locks of Berendrecht and Zandvliet in Belgium, are slightly different to the practice in the Panama Canal. While in the port of Antwerp the use of the indirect towing mode is a regular practice, in the Panama Canal the basic mode of ship assist is the push and pull mode.

Vessels approaching the locks will require tug assistance to ensure a safe and expeditious lockage. This could be accomplished mainly with the use of two tugs, one on the bow and one on the stern. In some cases, depending on the wind or climate conditions and the vessels characteristics (engine power, availability of bow or stern thrusters) it might be necessary to use one or two additional tugs. It is recommended that the tug on the bow send its hawser through the center chock of the vessel; that is, in line with the stem (Figure 2-4 & 2-5). This will enable the tug on the bow to pull to either side as requested by the pilot for effective assistance to the vessel. Under this scenario, the tugs must be highly maneuverable to achieve the desired effectiveness. The tug on the stern could make up on the vessel's recessed bit, if available, or with a hawser (Figure 2-6).

Figure 2-4. Bow tug using hawser line through center chock.

Figure 2-5. Bow tug using hawser line through center chock.

Figure 2-6. **Stern tug using hawser line through center chock.**

If the tugs are required to assist vessels moving from one chamber to another, the choice of length and width of the chambers must take this into consideration for appropriate maneuvering space. If the new locks are built as a one-lift lock, at least 12.2 m (40 feet) of width clearance is needed for the tugs to exit the chamber in those circumstances were there is no need for the tug to make the lockage with the vessel (Figure 2-7 & 2-8).

Figure 2-7. **Bow tug exiting the chamber after docking maneuver is complete.**

Figure 2-8. **Tug entering chamber to assist vessel during the exiting maneuver.**

2.9.2 Tugs Resources

The tug assistance in and out of the locks for Post Panamax vessels, if required, will demand the assignment of our most powerful tugs; these are those with a bollard pull of 55 tons.

Vessels navigating in the Schelde River in Belgium are assisted by any of the 15 river tugs owned and managed by **U**nie Van **R**edding–En **S**leepdiesnst (U.R.S.) tugs company, and vessels in the Port of Antwerp are assisted by any of the 22 dock tugs (all Voith drives with bollard pulls in the range of 28 to 55 tons) owned and managed by the Port Authority tug company.

U.R.S. tug fleet is composed of A.S.D., Voith and Combi-tugs (Figure 2-9 & 2-10) with bollard pulls in the range of 37 to 55 tons.

Figure 2-9. Voith propulsion tug entering chamber to assist vessel.

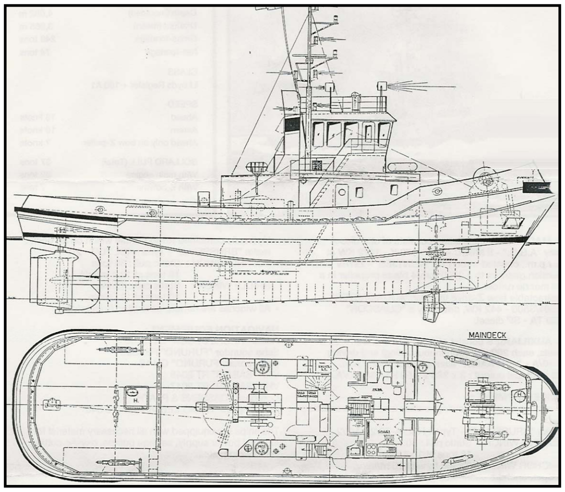

Figure 2-10. **Voith propulsion type tug.**

For future Panama Canal Tug Operations, based on observed operations in the Port of Antwerp, ASD tugs with a bollard pull of 55 tons will be suitable for proper ship assistance. It is important to consider that if the operation procedure for assisting Post Panamax vessels on the bow will be by sending tug lines through the bow center chock of the assisted vessel, our next generation of tugs not only needs to be powerful and highly maneuverable but also have all-around visibility.

The design of future A.S.D. tugs must enable the tug Master to tow from the bow (Figure 2-11) or stern of the tug.

Figure 2-11. **Tug towing Post Panamax container vessel from its bow.**

The total number of tugs for operations in the new lane of Post Panamax locks will depend on several factors. Among them are the number of ships to be assisted and the lock infrastructure (one, two or three lifts). The scenario, which requires the least amount of tugs, is the option of building a one-lift lock with consideration of adequate dimensions as previously mentioned.

In a one lift lock working in the alternate mode, which is the only way for such a lock to be scheduled without an enormous use of water and diminished capacity, three tugs might be desirable for these operations; two tugs assisting the vessel into the locks, while the following vessel is assisted by one tug and waits for another one to be released from the vessel ahead. If the alignment favors maneuverability, two tugs could safely assist the vessels into the locks.

If locks with more than one lift are constructed, it is recommended to introduce the concept of the "lock tugs". This is, having tugs (one for a double lift lock, two for a triple-lift lock) in the locks working at the bow of the vessel and assisting them to move from chamber to chamber.

In all scenarios, vessels requiring tug assist out of the locks could receive the assigned tug from the next navigable area or, based on logistics needs, tugs could proceed in the lockage with the vessel.

The length and beam of the tugs becomes more relevant if we will be using them to assist vessels in the locks. It is recommended to consider the feasibility of using a "Compact tug" (Figure 2-12) for future canal operations. These tugs are 24 m in length and 11 m in beam (ACP 55-ton tugs are 30.8m in length x 11.1m in beam). Recent studies presented by Robert Allan LTD. to the towing industry, have revealed that the Compact tug can safely provide up to 65 tons of bollard pull. A crew of three could also man these tugs.

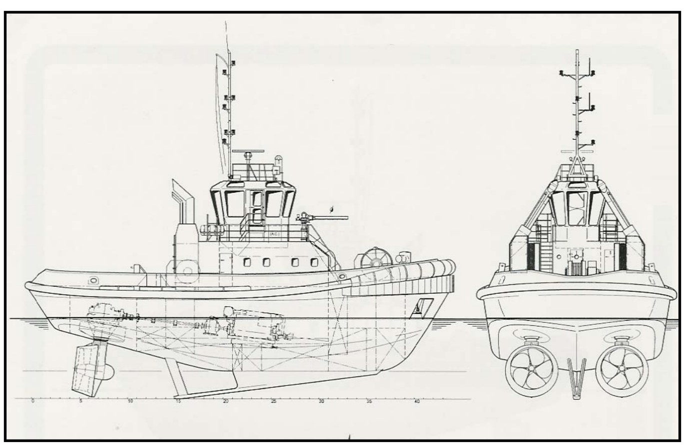

Figure 2-12. Proposed "Compact" tug to be used exclusively in future lockage operations.

Presently, we have the possibility of obtaining tugs "off the shelf" in the tug building market. The benefits are mainly a significant reduction of the total initial investment and a short delivery time (three months as per Damen Shipyard representatives).

3. OPERATIONAL CAPACITY OF THE NEW LOCKS

3.1 Lockage Times

One of the most relevant issues that could determine the feasibility of using tugs as a vessel positioning system in the new Post Panamax locks will be its impact on the locks capacity to transit ships. The locks capacity is determined by the filling and emptying times plus the time required for the various ships movements (lock approach, chamber entrance, chamber to chamber displacement and lock exit) and it is also dependant on the number of lock lifts.

During the Evaluation Team visit to the Post Panamax locks of the Port of Antwerp, times of all the vessels boarded were logged and are presented in the following tables. The filling and emptying times for the different possible locks configurations will be added, taken from the respective draft reports submitted by the Consorcio Post Panamax (CPP) for locks of one and three lifts and the US Corps of Engineers (USACE) for a two lift lock. Using this method, estimates for Post-Panamax and Panamax vessels are presented for all three possible lock configurations.

Note: Since no approach walls are used in these locks, an estimate of 1300 m from the knuckle area or 3.4 ship lengths was used to locate the approach starting point used to establish the arrival times.

A. Lock: **Berendrecht** - 68 m wide x 500 m long
Ship Name: **Ormond** Ship Type: Post Panamax Dry Bulker
DWT: 114,025 tons LOA: 299.8 m
Beam: 47.2 m Draft: 13.8 m
Tugs Used: 2; 1 in the bow and 1 astern
Maneuver experienced: Exiting the lock to dock in the inner Right bank

Times:

Ship Position	Time	Maneuver	Total Time (min)
Untie start	06.35	Untying	5.0
Untie finish	06:40	Exit Chamber	22.0
Clear	07:02		

Table 3-1-1. Times recorded for the vessel "Ormond".

B. Lock: **Berendrecht** - 68 m wide x 500 m long
Ship Name: **CSK Unity** Ship Type: Panamax Dry Bulker
DWT: 68,519 tons LOA: 224 m
Beam: 32.2 m 110
Draft: F-9.54 m; M- 9.69 m; A-9.94 m

Tugs Used: 3; 2 in the bow and 1 astern
Maneuver experienced: Entering the lock from the River Schelde, 90° turn with cross currents

Times:

Ship Position	Time	Speed (knots)	Maneuver	Total Time (min)
Approach start	14:15	5.0	Approach	9.0
Enter	14:24	1.8	Enter Chamber	4.0
Inside chamber	14:28	1.4		
Tie-up start	14:32	-		
Tie-up finish	14:35	-	Tie-up and Ready for water	5.0
Along the wall	14:37	-		

Table 3-1-2. Times recorded for the vessel "CSK Unity".

C. Lock: **Terneuzen** – 40 m wide x 290 m long
Ship Name: **Hilal 1** Ship Type: Dry Bulker
Beam: 26.07 m LOA: 185.37 m
Draft: 11.0 m
Tugs Used: 3; 2 in the bow and 1 astern
Maneuver experienced: Entering the lock from the River Schelde, 90° turn with cross currents. Windy conditions. Limited width available (38 m). Similar conditions to the design ship entering into the proposed new locks.

Times:

Ship Position	Time	Maneuver	Total Time (min)
Approach start	15:04	Approach	8.0
Enter	15:12	Enter Chamber	3.0
Inside chamber	15:15		
Tie-up start	15:17		
Tie-up finish	15:21	Tie-up and Ready for water	6.0
Along the wall	15:23		

Table 3-1-3. Times recorded for the vessel "Hilal 1".

D. Lock: **Zandvliet** – 57 m wide x 500 m long
Ship Name: **Republicca di Venezia** Ship Type: Car Carrier
Beam: 30.4 m LOA: 213.22 m
Draft: 8.3 m
Thrusters: Bow 1200KW & stern 900 KW
Tugs Used: 2; 1 in the bow and 1 astern
Maneuver experienced: Entering the lock from the inner Right bank docks doing a 90° turn. Very windy conditions. Nighttime.

Times:

Ship Position	Time	Maneuver	Total Time (min)
Arrival	21:57	Approach	13.0
Enter	22:10	Enter Chamber	5.0
Inside	22:15		
Tie-up start	22:14		
Tie-up finish	22:19	Tie-up and Ready for water	7.0
Along the wall	22:21		

Table 3-1-4. Times recorded for the vessel "Republicca di Venezia".

From the Draft Reports of the Post Panamax Locks Concept Design Studies underway, we take the following filling and emptying times:

Number of Lifts & basins	Designer	F/E times range (min)	Average F/E time (min)
One-lift, 6 basins	CPP	33 to 37	35
Two-lifts, 2 basins/lift	COE	13.2 to 15.1	14.2
Three-lifts, 3 basins/lift	CPP	12.4 to 15.3	13.9

Table 3-1-5. Filling and Emptying Times taken from Conceptual Design studies.

Considering that *no approach walls are required* when handling the vessels only with tugs, the approach maneuver is estimated as starting 1150 m or approximately 3.0 ship lengths from the lock entrance. Using the available information, the resulting Lockage times would be:

A. **Single Lift Lock - Container Vessels**

Maneuver times (min)	Tie-up Alongside of Wall	Tie-up Middle of Chamber	Tie-up Alongside of Wall
	Panamax Plus	Post Panamax	Post Panamax
Approach	15.0	20.0	20.0
Entering Chamber	10.0	10.0	10.0
Tie-up	5.0	10.0	10.0
Gate Closing	5.0	5.0	5.0
Filling or Emptying	35.0	35.0	35.0
Gate Opening	5.0	5.0	5.0
Untying	5.0	5.0	5.0
Exiting	5.0	10.0	15.0
Total Lockage Time	**85.0**	100.0	105.0
Pedro Miguel Locks Total Lockage Time (inc. locomotives return)	**80**		

Table 3-1-6. Estimated Lockage Times for Container vessels in a one-lift Post-Panamax lock.

B. Single Lift Lock – Dry Bulk Carrier / Tanker Vessels

Maneuver times (min)	Tie-up Alongside of Wall	Tie-up Middle of Chamber	Tie-up Alongside of Wall
	Panamax Plus	Post Panamax	Post Panamax
Approach	15.0	25.0	25.0
Entering Chamber	10.0	15.0	15.0
Tie-up	5.0	10.0	10.0
Gate Closing	5.0	5.0	5.0
Filling or Emptying	35.0	35.0	35.0
Gate Opening	5.0	5.0	5.0
Untying	5.0	5.0	5.0
Exiting	10.0	15.0	20.0
Total Lockage Time	**90.0**	115.0	120.0
Pedro Miguel Locks Total Lockage Time (inc. locomotives return)	**80**		

Table 3-1-7. Estimated Lockage Times for Dry Bulker / Tanker vessels in a one-lift Post-Panamax lock.

C. Double Lift Lock- Container Vessels

Maneuver times (min)	Tie-up Alongside of Wall	Tie-up Middle of Chamber	Tie-up Alongside of Wall
	Panamax	Post Panamax	Post Panamax
Approach	15.0	20.0	20.0
Entering Chamber	10.0	10.0	10.0
Tie-up	5.0	10.0	10.0
Gate Closing	5.0	5.0	5.0
Filling or Emptying	14.2	14.2	14.2
Gate Opening	5.0	5.0	5.0
Untying	5.0	5.0	5.0
Chamber to Chamber	10.0	10.0	20.0
Gate Closing	5.0	5.0	5.0
Tie-up	5.0	5.0	5.0
Filling or Emptying	14.2	14.2	14.2
Gate Opening	5.0	5.0	5.0
Untying	5.0	5.0	5.0
Exiting	5.0	10.0	15.0
Total Lockage Time	**108.4**	123.4	138.4
Lockage Cycle Time	**98.4**	108.4	118.4
Miraflores Locks Total Lockage Time	**95**		
Miraflores Locks Lockage Cycle Time	**70**		

Table 3-1-8. Estimated Lockage Times for Container vessels in a two-lift Post-Panamax lock.

D. **Double Lift Lock– Dry Bulk Carrier / Tanker Vessels**

Maneuver times (min)	Tie-up Alongside of Wall	Tie-up Middle of Chamber	Tie-up Alongside of Wall
	Panamax	Post Panamax	Post Panamax
Approach	15.0	25.0	25.0
Entering Chamber	10.0	15.0	15.0
Tie-up	5.0	10.0	10.0
Gate Closing	5.0	5.0	5.0
Filling or Emptying	14.2	14.2	14.2
Gate Opening	5.0	5.0	5.0
Untying	5.0	5.0	5.0
Chamber to Chamber	15.0	20.0	30.0
Gate Closing	5.0	5.0	5.0
Tie-up	5.0	5.0	5.0
Filling or Emptying	14.2	14.2	14.2
Gate Opening	5.0	5.0	5.0
Untying	5.0	5.0	5.0
Exiting	10.0	15.0	20.0
Total Lockage Time	**118.4**	148.4	163.4
Lockage Cycle Time	**103.4**	128.4	138.4
Miraflores Locks Total Lockage Time	**95**		
Miraflores Locks Lockage Cycle Time	**70**		

Table 3-1-9. Estimated Lockage Times for Dry Bulker / Tanker vessels in a two-lift Post-Panamax lock.

E. Triple Lift Lock- Container Vessels

Maneuver times (min)	Tie-up Alongside of Wall	Tie-up Middle of Chamber	Tie-up Alongside of Wall
	Panamax	Post Panamax	Post Panamax
Approach	15.0	20.0	20.0
Entering Chamber	10.0	10.0	10.0
Tie-up	5.0	10.0	10.0
Gate Closing	4.0	4.0	4.0
Filling or Emptying	13.9	13.9	13.9
Gate Opening	4.0	4.0	4.0
Untying	5.0	5.0	5.0
Chamber to Chamber	10.0	10.0	20.0
Gate Closing	4.0	4.0	4.0
Tie-up	5.0	5.0	5.0
Filling or Emptying	13.9	13.9	13.9
Gate Opening	4.0	4.0	4.0
Untying	5.0	5.0	5.0
Chamber to Chamber	10.0	10.0	20.0
Gate Closing	4.0	4.0	4.0
Tie-up	5.0	5.0	5.0
Filling or Emptying	13.9	13.9	13.9
Gate Opening	4.0	4.0	4.0
Untying	5.0	5.0	5.0
Exiting	5.0	10.0	15.0
Total Lockage Time	**145.7**	**160.7**	**185.7**
Lockage Cycle Time	**93.8**	**103.8**	**113.8**
Existing Panama Locks Total Lockage Time	**130**		
Existing Panama Locks Lockage Cycle Time	**80**		

Table 3-1-10. Estimated Lockage Times for Container vessels in a three-lift Post-Panamax lock.

F. Triple Lift Lock– Dry Bulk Carrier / Tanker Vessels

Maneuver times (min)	Tie-up Alongside of Wall	Tie-up Middle of Chamber	Tie-up Alongside of Wall
	Panamax	Post Panamax	Post Panamax
Approach	15.0	25.0	25.0
Entering Chamber	10.0	15.0	15.0
Tie-up	5.0	10.0	10.0
Gate Closing	4.0	4.0	4.0
Filling or Emptying	13.9	13.9	13.9
Gate Opening	4.0	4.0	4.0
Untying	5.0	5.0	5.0
Chamber to Chamber	15.0	20.0	30.0
Gate Closing	4.0	4.0	4.0
Tie-up	5.0	5.0	5.0
Filling or Emptying	13.9	13.9	13.9
Gate Opening	4.0	4.0	4.0
Untying	5.0	5.0	5.0
Chamber to Chamber	15.0	20.0	30.0
Gate Closing	4.0	4.0	4.0
Tie-up	5.0	5.0	5.0
Filling or Emptying	13.9	13.9	13.9
Gate Opening	4.0	4.0	4.0
Untying	5.0	5.0	5.0
Exiting	10.0	15.0	20.0
Total Lockage Time	**160.7**	**195.7**	**220.7**
Lockage Cycle Time	**98.8**	**123.8**	**133.8**
Existing Panama Locks Total Lockage Time	**130**		
Existing Panama Locks Lockage Cycle Time	**80**		

Table 3-1-11. Estimated Lockage Times for Dry Bulker / Tanker vessels in a three-lift Post-Panamax lock.

3.1.1 Ship's Line-Carrying Vehicle Alternative

The estimated lockage times for Panamax vessels in the new Post-Panamax locks are very similar to the existing Marine Traffic Control standard transit times for Panamax vessels used in the existing locks. But if we consider that the filling and emptying times of the Post Panamax locks are greater because of the additional time required by the water saving basins, it is evident that providing enough width and under-keel clearance to the vessels in the chambers would drastically reduce the maneuvering times through the locks, compensating for time lost for the filling and emptying of the chambers and basins.
If we desire to further reduce the maneuvering times, the only area where some improvement could be made is in the handling of the ship's lines, specifically the tying and untying of lines to the wall on every level.

It is the Team's idea that a ship's line-carrying vehicle can be introduced into the lockage process in order to eliminate several tie-up operations, the number of which would be dependent on the number of lifts. This vehicle could move on rubber tires or on a rail, and it would only be required to carry the lines from one level to the next without exerting any force or tension on the lines; therefore, no major structural design is required, as opposed to the case of a towing locomotive system. If this is the case, the ship's lines are brought to the wall only once and reeled back up to the ship only once. The net effect on the lockage times for double- and triple-lift locks would be:

Double Lift Lock **Container vessels**	Tie-up Alongside of Wall	Tie-up Middle of Chamber	Tie-up Alongside of Wall
	Panamax	Post Panamax	Post Panamax
Total Lockage Time	108.4	123.4	138.4
Lockage Cycle Time	98.4	108.4	118.4
Total Lockage Time with Line Vehicle	98.4	113.4	128.4
Lockage Cycle Time with Line Vehicle	88.4	98.4	108.4
Triple Lift Lock **Container vessels**	Panamax	Post Panamax	Post Panamax
Total Lockage Time	145.7	160.7	185.7
Lockage Cycle Time	93.8	103.8	113.8
Total Lockage Time with Line Vehicle	125.7	140.7	165.7
Lockage Cycle Time with Line Vehicle	73.8	83.8	93.8

Table 3-1-12. Estimated Lockage Times for Container vessels in a two- and three-lift Post Panamax lock with the use of an LCV.

Double Lift Lock Dry Bulker/Tanker vessels	Panamax	Post Panamax	Post Panamax
Total Lockage Time	118.4	148.4	163.4
Lockage Cycle Time	103.4	128.4	138.4
Total Lockage Time with Line Vehicle	108.4	138.4	153.4
Lockage Cycle Time with Line Vehicle	93.4	118.4	128.4
Triple Lift Lock Dry Bulker/Tanker vessels	Panamax	Post Panamax	Post Panamax
Total Lockage Time	160.7	195.7	220.7
Lockage Cycle Time	98.8	123.8	133.8
Total Lockage Time with Line Vehicle	140.7	175.7	200.7
Lockage Cycle Time with Line Vehicle	78.8	103.8	113.8

Table 3-1-13. Estimated Lockage Times for Dry Bulker / Tanker vessels in a two- and three-lift Post Panamax lock with the use of an LCV.

This line-carrying vehicle could be similar in construction to a combination of the *Integrated Robot Winch* and *Traveling Bit* concepts developed by Texas A & M University in their study for the "Project to Identify and Evaluate Alternative Concepts for Vessel Positioning at the Locks", of June 1999 (Program Study ING-04.02). The main difference would be that it does not need to be designed to withstand braking, towing and centering forces such as the ones presented in the study because the vehicle's only purpose is to carry the ship's heavy mooring lines from one level to the next, where the vessel will be tied up again by linehandlers at a fixed bit in the wall. This procedure will be similar to the one currently used for center chamber hand-line procedures where the locks linehandlers carry the lines from one level to the next and then position the lines in the mooring bits located in the lock walls.

4. CAPITAL, OPERATIONAL AND MAINTENANCE COSTS

4.1 Capital Costs for a Tugboat Assisted Positioning System

4.1.1 Locks

As mentioned in Section 2 – Lockage Procedures for the Post Panamax Locks, one of the principal assumptions made regarding the chamber dimensions is that, in order to be able to transit Post Panamax vessels with the dimensions of the chosen design ship through the new locks, the chamber's width and length has to be similar to those of Berendrecht lock, which has a width of 68 m (223 feet) and a length of 500 m (1640 feet).

If this is the case, the presently assumed design chamber (61 m x 457.2m) must be modified. This modification requires a cost increase of the gates; lock walls, because of the increase in length; excavation volumes; and water saving basins, because of the additional area. We will assume that the filling and emptying culverts and conduits have enough capacity to handle the additional water volume without significant time increases. The cost for the additional lengths of fiber optic cables and electric power cables is also insignificant.

Even though some of the major component costs will increase, it is also true that other components will not be required, thus partly compensating these cost increases. The components that would not be needed are the approach walls, locomotives, locomotive tracks and conductor slot, turntables or switching devices, the track feeding transformer rooms and the locomotive repair buildings.

These cost increases will be described for the three-lift option, based on CPP's costs for a Pacific lock, which should be the most expensive. These costs will also be used for the Atlantic lock since no reliable information is yet available, an assuming that it is very possible that costs for the Atlantic lock may actually be less. A description of these costs is provided in the following sections:

4.1.1.1 Rolling Gates

The rolling gates will remain the same height, but their width and length will have to be greater. A 7 m increase in length represents approximately a $[(68/61)^2]$ = 24% increase in steel volume, which will correspond to a 24% increase in cost.

If we use CPP's gate price of $ 199.14 million for the 8 rolling gates, the new price will be $ 246.94 million. This represents an ***additional $ 47.79 million for the larger rolling gates***.

4.1.1.2 Lock walls

The length of the chambers needs to be increased by 42.8 m. We will use CPP's costs for a 30 m segment, multiplied by 1.5 to represent a 45 m difference per chamber.

If CPP's total cost for the RCC + RC lock walls is $ 107.69 million which represents sixty-six 30-m segments, then each segment averages $ 1.63 million. This multiplied by 1.5 equals $ 2.45 million. Since 3 additional 45-m segments are required (one for each chamber) the ***total <u>additional</u> cost for the lock walls would be $ 7.34 million***.

4.1.1.3 Additional Excavation Volumes

The length of each chamber has to be increased by approximately 45 m and the width by 7 m, while the height of the chambers remains the same. So the increase of the overburden, La Boca formation and basalt excavations will be proportional to these increases in area.

Overburden excavation

The new overburden excavation volume is the result of three 500-m-long chambers with a width of 68 m. This results in a total volume of 4.54 million m^3 with a unit price of $ 3.50; the new cost is $ 15.89 million.

La Boca excavation

The new La Boca formation excavation volume is the result of one 500 m long chamber with a width of 68 m. This results in a total volume of 1.99 million m^3 with a unit price of $ 4.75; the new cost is $ 9.48 million.

Basalt excavation

The new Basalt rock excavation overburden volume is the result of adding two 500-m-long chambers with a width of 68 m. This results in a volume of 4.54 million m^3 with a unit price of $ 6.00; the new cost is $ 27.25 million.

New total cost

The new total excavation cost is $ 52.62 million, compared to CPP's excavation cost of $ 38.87 million, represents ***an additional excavation cost of $ 13.75 million***.

4.1.1.4 Water saving basins walls

Since the area of the lock chamber is increased, the area of the water saving basins also needs to be increased proportionally to maintain the same percentage of water savings. In this case, the excavation volume and the length of the four walls that form a basin need to be increased, but with no major structural change in the design. If this is correct, a proportional increase will be applied to the original CPP water saving basins cost.

Area increase, (68 x 500) / (61 x 457.2) = 1.22 or 22%. If CPP's costs, including the excavation, for the 9 basins are of $ 118.17 million, the new cost will be $ 144.17 million. ***The net additional cost for the larger water saving basins is $ 25.99 million***.

4.1.1.5 Lock chamber V type fenders

A continuous fender protection of the chamber walls is accomplished by installing Metso –Trellex V- type fenders similar to the ones installed in the southeast approach wall of Pedro Miguel locks.

If 1500 m of fenders are installed to line all three chambers, and the unit ACP price of these fenders is $ 2,247 per meter, then the ***required cost for the fender system is $ 3.37 million,*** if we line one wall and ***$ 6.74 million if we line both walls.***

4.1.2 Tugs

The concept of having Compact Lock Tugs was discussed in section 2.9.2 – Tugs Resources. These 11-m -beam and 24-m-long omni-directional tugs with a bollard pull of 65 tons would be specially constructed to assist vessels inside the lock chambers. Their estimated price is$5,600,000 per unit.

To adequately handle vessels in a three-lift lock, a minimum of two tugs is needed per structure. For certain bulk carriers and tankers, it may be necessary to have an additional tug available to be able to have two of them assist in the bow. When this situation occurs in relay operations, scheduling has to be arranged so that a container vessel follows this bulk carrier or tanker so that the additional bow tug can be released and used elsewhere. The stern tug would always be a regular Post-Panamax tug that would be part of the regular fleet, since it will be the one that will continue assisting the vessel in its transit through Gaillard Cut and probably beyond.

The total cost of Compact Lock Tugs will be $ 33.60 million. Resulting from 3 tugs per lock structure.

4.2 Capital Costs for a Locomotive Positioning System

4.2.1 Locks

The components that would not be needed and represent savings in a tugboat assisted positioning system are the approach walls, locomotive tracks and conductor slot and switching devices, the track-feeding transformer rooms and the locomotive repair facilities.

The additional costs for a locomotive positioning system compared to a lock that uses a tugboat positioning system will be described for the three-lift option, which should be the most expensive, based on CPP's costs for a Pacific lock and Canal Capacity Projects Division (IPCE) estimates. These costs will also be used for the Atlantic lock since no reliable information is yet available, with the understanding that it is very possible that for the Atlantic lock they may actually be less. A description of these costs is provided in the following sections:

4.2.1.1 Approach walls

With a tug-based vessel positioning system the evaluating team has determined that no approach wall at the locks entrances will be required. A locomotive positioning system requires approach walls.

Using CPP's costs, having approach walls represents $ 50.28 million if we average the cost of the RCC + RC and RC options. By adding the required 1157 m of V-type fenders the cost is increased by $ 2.6 million which adds up to ***a total cost of $ 52.88 million.***

4.2.1.2 Locomotive Tracks, Conductor Slot and Switching Devices

IPCE (C. George, Locks Team) made an estimate of the costs to furnish and install the necessary hardware to have the CPP three-lift lock fitted with a locomotive track system, switching devices and its required electrical conductor slot. Based on the existing Panama Canal system, an upgrade of the structural elements was necessary to accommodate the heavier and more powerful locomotives that will be required.

The estimated cost for a locomotive track for all three chambers and two approach walls is $ 15.65 million, which includes fabrication and labor.

The estimated cost for the required return track for merry-go-round operations is $ 7.99 million, which includes fabrication and labor.

The estimated cost for 4 total crossovers or switching devices is $4.93 million, which includes fabrication and labor.

The total costs for these items will represent $ 28.57 million.

4.2.1.3 Locomotive Repair Facilities

IPCE (C. George, Locks Team) made an estimate of the costs of the required locomotives repair facilities. These facilities consist of a steel framed building, a repair pit for two locomotives, two 5-ton overhead cranes and the required track and conductor slot to access the building. ***The costs would be $801,100 for two of these facilities,*** one on each lock wall.

4.2.1.4 Transformer rooms for Locomotive Towing and Return Tracks

Using a conservative approach to establish the locations of the track transformer rooms for a three-lift Post-Panamax lock with 500-m long chambers and two, 578-m long approach walls results in placing a transformer room approximately every 250 m. Considering the higher loads the 4th generation locomotives will demand, 16 track-feeding transformer rooms will be required, 7 rooms in the shorter wall and 9 rooms in the other, longer wall. In every room, two 750 Kva transformers will be needed, with a price tag of $16,000 per transformer, if we use the USACE price. These 16 track transformer rooms (32 transformers) represent a cost of $ 512,000.

Each track transformer room needs low voltage switchgear with its corresponding busses, breakers, monitors and protection. At USACE's price of $ 84,000 per switchgear, the 16 needed would represent costs of $ 1.34 million.

Also we should include the power cable to feed the conductor slot from the track breakers. We estimate 100 m of 500 MCM power cable for each of the transformers (3 lines of 33.3 m, going from the load side of the breaker to the A and C phase copper rails and the B-phase track rail). Using USACE's price of $18.70 /m ($5.70 / ft.) the costs in track power cables total $ 59,840.

The total cost for these items will represent $ 1.92 million.

4.2.2 Fourth Generation of Towing Locomotives

The existing 3rd generation of towing locomotives recently acquired from the Mitsubishi Corporation at $ 2,100,000 per unit are designed to handle vessels of up to 70,000 DWT. Up to 8 units are required to safely handle a vessel of Panamax size, all of them with a maximum cable line pull of 155,680 N / cable (two 35,000 lbs./ cable). For a Post-Panamax lock with a design vessel of up to 140,000 DWT, locomotives with at least 444,800 N (100,000 lbs.) of line pull per locomotive will be assumed. This requires a definite change in the present locomotive design to accommodate for the additional pulling force, within a reasonable wire rope diameter, that can be handled efficiently by the humans assigned to line handler duties.

A rather optimistic price tag of $ 3 million has been assumed in this study for the new 4th generation of towing locomotives, even though some research and development will be required before being able to produce these machines.

For maximum throughput and efficiency at a single lane lock, relay operations, working in a semi-convoy mode, will be required, the same principle of operation used today. To be able to handle two vessels at the same time in separate lock chambers with an empty chamber in between, two sets of 4 towing locomotives are needed, if scenario two of this report is used. However, two sets of 8 towing locomotives are needed if the operations are going to be the same as today, having the locomotives work from both walls. If we add the necessary spare machines plus the catastrophic replacement machine, a total of 10 towing locomotives will be needed per three-lift lock structure for scenario two, and 20 towing locomotives will be needed per three-lift lock structure for operations identical to the existing one. ***The total cost for this item will represent a minimum of $ 30 up to a maximum $ 60 million per lock.***

4.3 Comparative Capital Costs Table

Capital Costs for two three-lift lock structures (Pac. & Atl.): Tugboat Assisted Positioning System	**USD ($) in million**
Rolling gates (16 ea)	95.59
Lock walls	14.68
Additional excavation volumes	27.50
Additional length and excavation for water saving basins	51.99
V- type fenders to line chamber walls	13.48
Lock Tugs (6 ea)	33.60
Total Capital Costs	**$236.85**
Capital Costs for two three -lift lock structures (Pac. & Atl.): Locomotive Positioning System	
Approach walls (4 ea.) that include V-type fendering	105.76
Towing and return tracks, conductor slot and switching devices	57.12
Repair Facilities (4 ea.)	1.60
Track Transformers and Switchgear	3.83
4th Generation Towing Locomotives (40 ea.); relay or MGR operations	120.00
Total Capital Costs	**$288.31**

Table 4-3-1. Comparative Capital Costs analysis of the required infrastructure for a tug-assisted versus a locomotive-based Vessel Positioning system.

4.4 Operational Costs

4.4.1 Water Consumption Comparison

The water intake at a Post-Panamax three-lift lock with the required dimensions (68 x 500 m) for lockages with tugs assistance only, would be 22% (68 x 500 x H / 61 x 457 x H) greater than the intake of a lock using the conceptual design dimensions (61 x 457 m). In other words, for a complete ocean-to-ocean transit, the water consumption is 22% greater than the consumption of the conceptual design lock.

If an average lift of 8.67 m is used, the additional average consumption per lock structure would be 21,235 m^3 [(68x 500 x 8.67 x 0.4)- (61x 457 x 8.67 x 0.4)], in the case of using 3 water saving basins per level to save 60 % of the water intake. For a complete transit, the additional average water consumption would be 42,470 m^3 or 0.22 of one existing Canal lockage.

To date, ACP has not determined a price for raw water. Until that is established, no direct cost can be associated with the additional water consumption of a wider and longer Post-Panamax lock. What would be done is to insert a water project in the 30-year economic analysis at a point where the additional water per lockage will demand the water input from the new reservoir. If this is the case, we would introduce the Rio Indio project (cost **$230.00 million)** in the 8th year of operation for the tug-assisted system and in the 11th year of operation for the locomotive system. This is when we estimate that the water project should be started in order to comply with an expected Post-Panamax lockage demand of 11 lockages / day, which is the point where an additional water source will be required.

4.4.2 Locks Crewing

A basic assumption made is that the majority of Post-Panamax traffic will be handled during daylight hours and the rest of the day Panamax-Plus vessels will use the new locks. This condition leads to another assumption that the existing locks could have a reduction in Panamax traffic levels leading to possibly operating one of the existing lanes only for 16 hours. In this case, part of the operating personnel will be reassigned to the new lock. If the case is that no Panamax-Plus traffic is expected in the midnight shift, and in order to save water, the new locks will only work 16 hours and the locks operations personnel will be used in the existing locks. Another assumption is that all locks will be controlled from a single Control Center, reducing the necessity of an additional Control House Operator.

For a tug assisted vessel positioning system, during every 8-hour shift, a lock operations crew will consist of the following personnel:

- 1 Lockmaster
- 1 Tie-up Bosun
- 12 Linehandlers

This way vessels can be handled in the middle of the chamber and /or vessels tied up as tandems to one wall or both walls.

If relay operations are required, then an 8-hour shift lock operations crew will consist of the following personnel:

- 2 Lockmasters
- 1 Tie-up Bosun
- 24 Linehandlers

This way vessels can be handled in the middle of the chamber and /or vessels tied up as tandems to one wall or both walls.

The required crews for 24-hour operations in the new Post Panamax locks (Atlantic & Pacific structures) will represent the following operational costs:

Normal Operations	**Dollars ($)**
3 crews, 24 hours per structure	2,903,978
Relay Operations	
6 crews, 24 hours per structure	5,433,423

Table 4-4-1. Total Operations Crews Cost

The complete description is presented in Appendix A, Costs Tables, Table A-2, “Alternativa de Manejo con Remolcadores y Transporte de Soga”.

4.4.3 Tugs Crewing

With the Compact Lock Tug alternative selected, the tugs will require 3-person crews. Consisting of a Tug Captain, a Tug Engineer and a seaman. If 6 crews were needed per 8-hour shift, a total of 28 crews would be sufficient to provide 3-tugs-per-lock service during 16 hours and 2-tugs-per-lock service for the remaining 8 hours when the Panamax-Plus vessels are assumed to be transiting.

Using ACP FY 2002 data, found in Appendix A, Table A-3 “MRRT- Costos de Operación y Mantenimiento”, the operational costs for a 22-tug fleet, indicate that the average annual operation cost per tug is of $ 1,691,667. Using this as reference, if 6 operational tugs are required at the Post Panamax locks, the ***annual operational cost for the Lock Tugs will be $ 10.15 million***.

4.5 Maintenance Costs

4.5.1 Locks Maintenance

For the tug assisted vessel positioning system alternative, the Post Panamax maintenance work force will consist of administrative and electromechanical personnel of different grades and responsibilities. Jobs range from supervisors, crane operators, and electricians, to machinists, etc. A complete listing and description is presented in Appendix A, Costs Tables, Table A-2, “Alternativa de Manejo con Remolcadores y Transporte de Soga” (Tugboat Maneuvering and Towing Alternative). These costs are independent of normal or relay operations. If the alternative of using an LCV is implemented, ***the total annual maintenance labor costs for both structures is $ 3.02 million.***

4.5.2 Tugs Maintenance

Tug maintenance costs include fuel, mooring lines, rubber fenders, engine parts and repairs as well as larger scheduled or emergency repairs at the Cristobal Industrial Division shipyard. The average maintenance cost per tug is taken from Appendix A, Table A-3 “MRRT- Costos de Operación y Mantenimiento” (Operation and Maintenance Costs) and is $ 532,233. For the six ***Lock-Tug fleet, the annual maintenance cost is $ 3.19 million.***

5. COMPARATIVE ANALYSIS WITH A LOCOMOTIVE SYSTEM

5.1 Feasibility of the Existing Locomotive

The evaluating team has serious doubts that the existing locomotives will be able to handle the larger Post Panamax vessels, especially in the towing and braking modes. The Canal pilots have estimated that at least 4 locomotives with a line pull of 444,800 N (100,000 lbs.) are required to safely handle a 140,000 DWT vessel from just one wall. Most of the maneuvering will be to center and hold the vessel while it moves from one chamber to the other. Some minor braking and towing will be required because the vessel's own engine will be the primary driver.

It is the team's opinion that no locomotive system will be effective in a one-lift lock because of the extreme angles that the cables would be forced to form between the vessel's hull and the locomotives when the vessel is at the lowest water level (sea level) and the locomotives are, at a minimum, 26 m (85ft) above the vessel on top of the locks wall. Even a tug-assisted tying up operation of the vessel to the wall will be difficult, impractical and unsafe. **From the operational point of view this alternative should not even be considered.**

For a two-lift lock structure, the potential use of locomotives is almost borderline. Although the problems are less evident, the 13 to 16 m height difference between low water and the top of wall, demand that the locomotives should be able to provide the required forces at different angles on its horizontal and vertical components. For a tug-assisted operation the lift heights are going to present an operational problem, too. **From the operational point of view, this alternative should only be considered in the case that the three-lift option fails.**

The evaluating team considers that the existing locomotives are not feasible for a Post-Panamax lock working at today's lockage speeds. In addition, the requirements and feasibility of a 4th generation locomotive that could effectively and efficiently handle Post-Panamax vessels in a three-lift lock (and maybe in a two-lift lock) should be studied to determine their costs and technical merits.

5.2 Lock Infrastructure Costs

Using the information developed in section 4 - Capital, Operational and Maintenance Costs, sub sections 4.1, 4.2 and 4.3, the following two tables are modifications of Table 4.3.1 and only include the additional lock infrastructure costs.

Tug Assisted VPS Capital Costs for two 3-lift lock structures	$ USD in million
Rolling gates (16 ea)	95.59
Lock walls	14.68
Additional excavation volumes	27.50
Additional length and excavation for water saving basins	51.99
V- type fenders to line chamber walls	13.48
Total Capital Additional Costs	**$203.25**

Table 5-2-1. Capital Costs breakdown of the required additional infrastructure for a tug assisted Vessel Positioning system.

Locomotive VPS Capital Costs for two 3-lift lock structures	**USD in million**
Approach walls (4 ea.) that include V-type fendering	105.76
Towing and return tracks, conductor slot and switching devices	57.12
Repair Facilities (4 ea.)	1.60
Track Transformers and Switchgear	3.83
Total Capital additional Costs	**168.31**

Table 5-2-2. Capital Costs breakdown of the required additional infrastructure for a locomotive Vessel Positioning system.

From these tables it becomes evident that, if only the additional infrastructure costs are accounted for, the locomotive vessel-positioning alternative is economically more attractive because it requires an additional investment of $ 168.31 million over the estimated, conceptual design cost for a three-lift structure that would use a tugboat-assisted vessel positioning system. It represents a savings of $ 34.94 million when compared to the additional infrastructure needed for a tug-assisted vessel positioning system for a three-lift Post Panamax lock when the width of the locks is increased to 68 m and the length to 500 m. We should point out that the locomotive infrastructure cost was not included in the cost estimates received with the Locks Conceptual Design studies.

Maintenance costs for the lock infrastructure differ drastically between both alternatives. The only maintenance requirements for the tug assisted option will be the replacement of the V-type fenders when they are knocked off the walls. An eventual decision to eliminate them, as was done in Berendrecht Lock, could be made, eliminating this cost item.

Meanwhile, for the locomotive system an assumption is made that no major maintenance of the track rails and conductor slots will be required in 30 years, so their costly repairs or replacement would not affect that much.

5.3 Locomotives and Tugs Costs

For a relay operation in a single lane of a three-lift lock, twenty (20) fourth generation towing locomotives are required, as discussed in section 4, 4.2.2 Fourth Generation Towing Locomotives. For both structures to operate the same way as today's locks, 40 locomotives will be needed. At an assumed optimistic price tag of $ 3 million per unit, ***the total initial investment for the purchase of the new locomotives is at least $ 60 million, with another $ 60 million investment required when relay or merry-go-round (MGR) operations are needed***.

The annual operations and maintenance labor costs for this alternative, using two lock structures, add up to $ 14.25 million for relay operations that are similar to the existing locks and ***$ 13.02 million for relay operations under scenario two***. For normal operations similar to the existing operations, the costs is $ 9.26 and $ 8.64 million under scenario two, as presented in Appendix A, Costs Tables, Table A-1, “Alternativa de Manejo con Locomotoras”. ***The annual materials cost is estimated at $ 30,000 / month per lock structure for a total of $ 720,000***.

If the Compact Lock Tug alternative is adopted, as discussed in section 2, 2.9.2 Tugs Resources, for a three-lift Post Panamax lock, two lock tugs are needed per structure. If we add one tug for the more difficult bulk carriers and tankers that require two tugs on the bow, a total of 6 Compact Lock tugs are required. With a price tag of $ 5.6 million per tug, ***the total initial investment for the purchase of the Compact Lock Tugs is $ 33.60 million.*** For the two-lift lock alternative, a total of only four of these special tugs are needed with an ***initial investment of $ 22.40 million***.

If the LCV option is implemented, an additional assumed investment ($ 250,000 per LCV) of ***$ 5.0 million is required for twenty LCVs*** for the two lock structures and relay operations. Their purchase will also be spaced, similar to the locomotives, to a point in time when relay operations are needed.

The annual locks operations and maintenance labor costs for this alternative add up to $ 8.45 million for relay operations and ***$ 5.92 million for normal operations*** for the two lock structures, as presented in Appendix A, Costs Tables, Table A-2, “Alternativa de Manejo con Remolcadores y Transporte de Soga”. An ***additional materials cost was estimated at $ 60,000 per year*** if the LCV option is implemented.

The annual tug operations and maintenance labor costs for this alternative add up to $13.34 million for relay operations for the two lock structures, as presented in section 4, 4.4.3 Tugs Crewing and 4.5.2 Tugs Maintenance.

From these tables, it becomes evident that from an initial equipment investment point of view, the Compact Lock Tugs vessel positioning option is economically more attractive because it requires an initial investment of $ 33,600,000 for a three-lift structure. It represents a savings of $ 26.4 million when compared to the locomotive vessel positioning system initial investment for a three-lift Post-Panamax lock working similarly to the existing locks.

When the annual operations, materials and maintenance costs, along with the Rio Indio water project, are included over a 30-year span, at a ***discount rate factor of 12 %,*** then the life cycle costs are **$ 70.58 million**, in favor of the Locomotive vessel-positioning alternative. The complete economic analysis breakdown is presented in Appendix A, Costs Tables, Table A-4, “Cost Analysis at a Discount Rate Factor of 12%”.

Locomotive Positioning System (operating similar to the existing system)	**$ USD in million**
Initial Infrastructure Investment	168.31
Initial Equipment Investment	60.00
Annual Operations, Materials and Maintenance for 30 years (includes additional purchase of locomotives for relays & Rio Indio)	147.26
Total Cost at Net Present Value	**375.57**
Tug Assisted Positioning System (using LCV)	
Initial Infrastructure Investment	203.25
Initial Equipment Investment	36.10
Annual Operations, Materials and Maintenance for 30 years (includes additional purchase of LCV for relays & Rio Indio)	206.80
Total Cost at Net Present Value	**446.15**

Table 5-3-1. Total Costs breakdown for the Locomotive and the Tug Assisted Vessel Positioning Systems in a lock with wider and longer chambers.

It is very important to note that for whichever vessel positioning system alternative is selected, new 50 to 60 ton bollard pull tugs will be necessary to assist shipping throughout the Canal's navigable channels. This will be especially true in the lock entrances, Gaillard Cut and possibly beyond, and the new bypass channel leading to the new Pacific lock structure. The number of these tugs that is required will be dependant on the expected amount of traffic derived from the ongoing marketing studies. Since these new tugs are necessary, independent of the vessel positioning system selected for the locks, and will be used mainly outside the locks, their costs are not and should not be included as part of the economical feasibility evaluation of the different lock vessel positioning alternatives. But their cost has to be kept in mind when the investment cost for the expansion program is eventually totaled.

5.4 Lockage Times

In section 2 - Lockage Procedures for the Post Panamax Locks, estimated lockage times were derived for different operating scenarios independent of the locks filling and emptying times and the gates opening and closing times. In section 3 – Operational Capacity of the New Locks, the locks filling and emptying times and the gates opening and closing times were added and estimate of total lockage and lockage cycle times were made for one-, two- and three-lift locks.

Since the cost comparisons were based on a three-lift lock, determined as the most feasible from the operations standpoint, the lockage times comparison will use the same basic lock structure with the added value that under relay operations, the three-lift lock will be the structure with the lowest lockage cycle times and the best throughput.

The following summary table contains the total lockage times for five different operation modes for the two types of Post Panamax vessels considered:

locomotives on one wall, tug assisted tie-up to one wall, tug assisted tie-up in the middle of the chamber, tug assisted tie-up to one wall with LCV, tug assisted tie-up in the middle of the chamber with LCV.

Container Vessels	**Lockage Time** (min)
Locomotives on one wall	148.7
Tug assisted tie-up to one wall	185.7
Tug assisted tie-up in the middle of the chamber	160.7
Tug assisted tie-up to one wall with LCV	165.7
Tug assisted tie-up in the middle of the chamber with LCV	140.7
Dry Bulk /Tanker Vessels	**Lockage Time** (min)
Locomotives on one wall	188.7
Tug assisted tie-up to one wall	220.7
Tug assisted tie-up in the middle of the chamber	195.7
Tug assisted tie-up to one wall with LCV	200.7
Tug assisted tie-up in the middle of the chamber with LCV	175.7

Table 5-4-1. Lockage times for a three-lift lock for different types of Post Panamax vessels and modes of operating with tugs.

The following summary table contains the lockage cycle times for five different operation modes for the two considered types of Post Panamax vessels: locomotives on one wall, tug assisted tie-up to one wall, tug assisted tie-up in the middle of the chamber, tug assisted tie-up to one wall with LCV, tug assisted tie-up in the middle of the chamber with LCV.

Container Vessels	**Lockage Cycle Time** (min)
Locomotives on one wall	102.8
Tug assisted tie-up to one wall	113.8
Tug assisted tie-up in the middle of the chamber	103.8
Tug assisted tie-up to one wall with LCV	93.8
Tug assisted tie-up in the middle of the chamber with LCV	83.8
Dry Bulk /Tanker Vessels	**Lockage Cycle Time** (min)
Locomotives on one wall	128.8
Tug assisted tie-up to one wall	133.8
Tug assisted tie-up in the middle of the chamber	123.8
Tug assisted tie-up to one wall with LCV	113.8
Tug assisted tie-up in the middle of the chamber with LCV	103.8

Table 5-4-2. Lockage cycle times for relay operations in a three-lift lock for different types of Post Panamax vessels and modes of operating with tugs.

It is reasonable to believe that in the future, the single-lane Post-Panamax locks will eventually be working at full capacity. Relay operations, although improbable at first, will become a necessity. Selecting, a vessel positioning system now that will be reliable, safe and efficient and at the same time produce the biggest lockage throughput is a necessity. From Tables 5-4-1 and 5-4-2 it is evident that a tug assisted system tying up in the middle of the chamber will be the most efficient. Safety will become an issue that will have to be resolved with an adequate design of the locks filling and emptying system that must provide filling with little or no turbulence, longitudinal or transverse forces for this tie-up mode to work. The effectiveness of such filling and emptying system will only be demonstrated when the scale model tests are conducted. These tests also must include testing of the behavior of a model design vessel in the locks.

6. RECOMMENDATIONS

a. After the Evaluating team visited the Port of Antwerp and with the hands on experience with the tug assisted vessel-positioning system used there, several scenarios were developed that seem feasible for a Post Panamax lock. It is our recommendation that the ACP should make field tests of this system in our existing locks. A transiting vessel with dimensions in our chambers proportioned to the design vessel dimensions in a Post Panamax chamber should be selected. Several things need to be confirmed, especially the safety of the operation, how the system behaves in multiple-lift locks and whether the estimated lockage times are reasonable for both the tie-up to one wall and in the middle of the chamber options. The results of this test can be introduced as an update or revision of this report, to enhance its thoroughness and documentation.

b. Although towing locomotives are not recommended for a one-lift lock and may be marginally feasible for a two-lift lock, they are believed to be a feasible vessel-positioning alternative for a three-lift lock structure. Because of the large displacements the Post Panamax vessels have, the existing ACP locomotives will not provide adequate assistance to these vessels because of a lack of space for their proper positioning alongside the vessel in points where effective forces can be exerted. A team of transportation, electrical, mechanical and structural engineers should be contracted to develop a conceptual design for the 4th generation of towing locomotives. Doubts exist about the diameter and weight of the required windlass cable and how safely and efficiently ACP personnel would be able to handle it. The loads imposed on the walls and track structures are also an issue. With a locks conceptual design and price tag on hand, the technical and economical feasibility of the locomotives can be properly evaluated, and then a revisit to this report should be made, especially in the costs section where the $ 3.0 million / unit locomotive price was assumed.

c. If at a later date a decision is made to implement a tug assisted vessel-positioning system in the new locks, the ACP Maritime Training computer simulators need to be updated and our Pilot and Tug Masters force should be trained locally and / or abroad to be prepared for the new locks vessel-positioning system implementation.

d. The previously developed, Post-Panamax Canal Capacity study (by ACP), should be revisited to introduce these new lockage time estimates and reevaluate the estimated capacity, especially for financial feasibility purposes.

7. CONCLUSIONS

a. A tug assisted locks-vessel-positioning system is feasible for the new Post Panamax locks and should be considered as one of the alternatives for analysis.

b. This system will work safely and efficiently, if the following conditions are met:

   i. The width of the proposed chamber should be 20 % wider than the beam of the design vessel or at least 12.2 m (40 feet) more, to allow bow tugs to leave the chamber if they are not needed.

   ii. The length of the proposed chamber should be at least 100 m (328 feet) longer than the design vessel to allow maneuvering space for the bow tugs and the possibility of Panamax tandem lockages.

   iii. An under-keel clearance (UKC) of 3m (10 feet) is paramount in allowing these vessels to move through the locks in a timely manner.

   iv. The locks filling and emptying system should work in such a way that little or no turbulence, longitudinal or transverse forces are developed, in order to allow safe tie-up to the walls or in the middle of the chamber. The hydrodynamic forces that would develop should not create a dangerous situation of parting mooring lines.

   v. The Compact Lock tugs concept should be implemented to reduce the requirements on the ACP Post-Panamax tugboat fleet.

c. If it becomes possible to tie up in the middle of the chambers or to just one wall and a Line Carrying Vehicle (LCV) is used to move the mooring lines from chamber to chamber, eliminating the need to tie and untie in every level, this tug assisted option will have a higher locks throughput (8 to 13 minutes less in the lockage cycle time depending on the type of vessel) than a locomotive option working from just one wall.

d. With a tug assisted vessel-positioning system, some lock infrastructures are not required, such as the approach walls, towing tracks and conductor slots, track transformers and switchgears. Changes are needed because of the increased chamber dimensions to the gates, length of walls and water saving basins. Additional chamber fenders will probably be required.

e. Assuming a $ 3.0 million locomotive unit price and a $ 5.6 million lock-tug unit price, the infrastructure investments and the respective annual operations and maintenance labor and materials costs for relay operations at both three-lift structures for a 30-year life cycle, the result is that the respective additional net present value costs at a **discount rate factor of 12 %** that are needed to implement a vessel-positioning system are ***$ 375.57 million for a locomotive system*** working from both walls as in the existing locks and ***$ 446.15 million for a tug system using LCVs***. The net difference is ***$ 70.58 million in favor of the locomotive vessel positioning system***.

8. REFERENCES

1. Diseño Conceptual de las Esclusas Post Panamax, 3 STEPS LOCK SYSTEM- Task 4- Draft Final Report, Consorcio Post Panamax (CPP), 15 September 2002.

2. Panama Canal Concept Design, Atlantic Locks Structure, Third Lane, Main Report (draft), Two-Lift Design, US Army Corps of Engineers, 25 October 2002.

3. Project to Identify and Evaluate Alternative Concepts for Vessel Positioning at the Locks, Texas A & M University, June 1999

APPENDIX A

TERCER JUEGO DE ESCLUSAS ALTERNATIVA POST PANAMAX Y PANAMAX																			
ALTERNATIVA DE MANEJO CON LOCOMOTORAS																			
	Primeros 20 años										Despues de 20 años								
Crafts	Adm.	Loco	M&V	Aux	T&P	UW	Ohl	Totales	Costo Unit.	Costo	Adm.	Loco	M&V	Aux	T&P	UW	Ohl	Totales	Costo
Maint. Inspectors MG-11	2							2	53,316.82	106,633.64	2							2	106,633.64
Supply Clerk NM-03								0	20,441.51	0.00								0	0.00
Eq. Maint. Sup. MS11								0	68,458.67	0.00		1						1	68,458.67
Electromec. Lider ML11		2	2	1	1			6	58,645.59	351,873.54		2	2	1	1			6	351,873.54
Electromecanicos MG11		5	5	1				11	53,316.82	586,485.02		10	5	1				16	853,069.12
Ind Eq Mech MG-10			2	1	2			5	51,132.89	255,664.45			2	1	2			5	255,664.45
Trabaj.Electromec.MG08		3	3	2	2			10	24,023.14	240,231.40		6	3	2	2			13	312,300.82
Crane Oper MG-11							1	1	53,316.82	53,316.82								0	0.00
Rigger MG-10								0	51,132.89	0.00								0	0.00
Rigg Wrkr MG-07								0	20,266.80	0.00								0	0.00
Electrician MG-10					3			3	51,132.89	153,398.67					3			3	153,398.67
Trabajador Elect.MG08					2			2	24,023.14	48,046.28					2			2	48,046.28
Maint. Mech.MG10			1	1				2	51,132.89	102,265.78			1	1				2	102,265.78
Trabajador Mech.MG08			1	1				2	24,023.14	48,046.28			1	1				2	48,046.28
Mech. / Buzo MG10								0	71,586.05	0.00								0	0.00
Tender MG05								0	36,282.22	0.00								0	0.00
Sub Totales	2	10	14	7	10	0	1	44		1,945,961.88	2	19	14	7	10	0	0	52	2,299,757.25
	Cuadrilla		Proyección		int	vac	tot		Costo Unit.	Costo	Cuadrilla		Proyección		int	vac	tot		Costo
Contramaestre MS11 / CHO FN08	1		4.2		4	0.5	5.0		68,458.67	342,293.35	2		8.4		8	1.1	9.0		616,128.03
Bosun MS05	1		4.2		4	0.0	4.0		29,701.34	118,805.36	1		4.2		4	0.0	4.0		118,805.36
Pasacables MG-04	12		50.4		50	6.7	57.0		17,384.02	990,889.14	24		100.8		101	13.6	114.0		1,981,778.28
LLO's MG-09	8		33.6		34	4.6	38.0		32,380.28	1,230,450.64	16		67.2		67	9.0	76.0		2,460,901.28
Sub Total										2,682,438.49									5,177,612.95
Costo por Esclusa por año										4,628,400.37	**Costo por Esclusa por año**								7,477,370.20

Table A-1. Alternativa de Manejo con Locomotoras

TERCER JUEGO DE ESCLUSAS ALTERNATIVA POST PANAMAX Y PANAMAX																			
ALTERNATIVA DE MANEJO CON REMOLCADORES Y TRANSPORTE DE SOGAS																			
	Primeros 20 años										Despues de 20 años								
Crafts	Adm.	Loco	M&V	Aux	T&P	UW	Ohl	Totales	Costo Unit.	Costo	Adm.	Loco	M&V	Aux	T&P	UW	Ohl	Totales	Costo
Maint. Inspectors MG-11	2							2	53,316.82	106,633.64	2							2	106,633.64
Supply Clerk NM-03	1							1	20,441.51	20,441.51	1							1	20,441.51
Eq. Maint. Sup. MS11								0	68,458.67	0.00								0	0.00
Electromec. Lider ML11			2	1	1			4	58,645.59	234,582.36			2	1	1			4	234,582.36
Electromecanicos MG11			5	2				7	53,316.82	373,217.74			5	3				8	426,534.56
Ind Eq Mech MG-10			2	1	2			5	51,132.89	255,664.45			2	1	2			5	255,664.45
Trabaj.Electromec.MG08			3	2	2			7	24,023.14	168,161.98			3	3	2			8	192,185.12
Crane Oper MG-11								0	53,316.82	0.00								0	0.00
Rigger MG-10								0	51,132.89	0.00								0	0.00
Rigg Wrkr MG-07								0	20,266.80	0.00								0	0.00
Electrician MG-10					3			3	51,132.89	153,398.67					3			3	153,398.67
Trabajador Elect.MG08					2			2	24,023.14	48,046.28					2			2	48,046.28
Maint. Mech.MG10			1	1				2	51,132.89	102,265.78			1	1				2	102,265.78
Trabajador Mech.MG08			1	1				2	24,023.14	48,046.28			1	1				2	48,046.28
Mech. / Buzo MG10								0	71,586.05	0.00								0	0.00
Tender MG05								0	36,282.22	0.00								0	0.00
Sub Totales	3	0	14	8	10	0	0	35		1,510,458.69	3	0	14	10	10	0	0	37	1,587,798.65
	Cuadrilla		Proyeccion		int	vac	tot		Costo Unit.	Costo	Cuadrilla		Proyeccion		int	vac	tot		Costo
Contramaestre MS11 / CHO FN08	1		4.2		4	0.5	5.0		68,458.67	342,293.35	2		8.4		8	1.1	9.0		616,128.03
Bosun MS05	1		4.2		4	0.0	4.0		29,701.34	118,805.36	1		4.2		4	0.0	4.0		118,805.36
Pasacables MG-04	12		50.4		50	6.7	57.0		17,384.02	990,889.14	24		100.8		101	13.6	114.0		1,981,778.28
LLO's MG-09	0		0.0		0	0.0	0.0		32,380.28	0.00	0		0.0		0	0.0	0.0		0.00
Sub Total										1,451,987.85									2,716,711.67
Costo por Esclusa por año										2,962,446.54	**Costo por Esclusa por año**								4,304,510.32

Table A-2. Alternativa de Manejo con Remolcadores y Transporte de Sogas

	AF2000	AF2001	AF2002	variación AF-01 VS AF-02	% de cambio
Costos de Operación de Remolcadores (función 300003)	$ 28,896,974.14	$ 29,395,623.05	$37,216,682.54	$ 7,821,059.49	27%
Costos de Mantenimiento de Remolcadores (función 300002)	$ 6,527,251.45	$ 7,637,897.83	$11,709,121.14	$ 4,071,223.31	53%
Tot Costos MRRT (300000)	32,993,683.31	41,383,048.80	51,800,813.05	$10,417,764.25	25%
Ingresos MRRT (300000)	$ 52,984,867.98	$ 55,329,308.02	$67,248,948.54	$11,919,640.52	22%
Utilidad MRRT (300000)	$ 19,991,184.67	$ 13,946,259.22	$15,448,135.49	$ 1,501,876.27	11%

Las variaciones en el costo de operación se deben a: En el 2000 aparecieron por primera vez algunos servicios corporativos, los mismos fueron aumentando en el 2001 y luego en el 2002 aparecieron todas las unidades de negociones ejecutoras. La variación se hace mayor en el 2002 porque también aparece la cuenta de costo indirecto corporativo (costos de las funciones que son overhead).	La cuenta de inventario también va en aumento del 2000 ($545K), 2001 ($823K), al 2002 ($996K). Otra de las cuentas que aumenta significativamente es la de depreciación que va de 2000 (2,325K), 2001 ($2,994K) al 2002 ($3,357) esto se debe a la llegada de los nuevos remolcadores.	**Las variaciones en el costo de mantenimiento se deben a:** Los servicios corporativos, principalmente los de la División Industrial, que aumentaron del 2000 ($3,333), 2001 ($5,558K), al 2002 ($8,453K). Inclusión de nuevas tarifas para el 2002.

Table A-3. **MRRT- Costos de Operación y Mantenimiento**

Cost Analysis at a Discount Rate Factor of 12 %

Tug Assited Positioning System using a LCV — 2003 costs in million USD	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
		4 lockages				8 lockages						12 lockages																			
Infrastructure Investment for 2 lock structures																															
Rolling gates (size increase)	95.59																														
Additional excavation	27.50																														
Lock walls	14.68																														
Additional excavation & length of WSBs	51.99																														
V-type fenders on chamber walls	13.48																														
Water supply projects (Rio Indio @ 9th lockage)									230.00																						
Sub total	203.25								92.89																						
Equipment Investment																															
Lock Tugs (6 total)	33.60																														
LCV (20 total)	2.50					2.50																									
Sub total	36.10					1.42																									
Annual Operations (Relay 3 crews)	0.00	13.05	13.05	13.05	13.05	15.58	15.58	15.58	15.584	15.58	15.58	15.584	15.58	15.58	15.58	15.58	15.58	15.58	15.58	15.58	15.58	15.58	15.58	15.58	15.58	15.58	15.58	15.58	15.58	15.58	15.58
Annual Materials (if LCVs are used)	0.00	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
Annual Maintenance (includes tugs & lock maint.)	0.00	6.21	6.21	6.21	6.21	6.21	6.21	6.21	6.21	6.21	6.21	6.21	6.21	6.21	6.21	6.21	6.21	6.21	6.21	6.21	6.37	6.37	6.37	6.37	6.37	6.37	6.37	6.37	6.37	6.37	6.37
Sub total	0.00	19.33	19.33	19.33	19.33	21.86	21.86	21.86	21.856	21.86	21.86	21.856	21.86	21.86	21.86	21.86	21.86	21.86	21.86	21.86	22.01	22.01	22.01	22.01	22.01	22.01	22.01	22.01	22.01	22.01	22.01
Totals	239.35	19.33	19.33	19.33	19.33	23.27	21.86	21.86	114.75	21.86	21.86	21.86	21.86	21.86	21.86	21.86	21.86	21.86	21.86	21.86	22.01	22.01	22.01	22.01	22.01	22.01	22.01	22.01	22.01	22.01	22.01
Net Present Value	239.35	17.26	15.41	13.76	12.28	13.21	11.07	9.89	46.35	7.88	7.04	6.28	5.61	5.01	4.47	3.99	3.57	3.18	2.84	2.54	2.28	2.04	1.82	1.62	1.45	1.29	1.16	1.03	0.92	0.82	0.73
Total Net Present Value	**446.15**																														

Locomotive Positioning System	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
Infrastructure Investment for 2 lock structures																															
Approach walls (578 m each)	105.76																														
Locomotives Tracks, conductor slot & switching devices	57.12																														
Locomotive repair facilities	1.60																														
Track Transformers & Switchgears	3.83																														
Water supply projects (as needed)												230.00																			
Sub total	168.30											66.12																			
Equipment Investment																															
Locomotives (normal operation, 20 total)	60.00																														
Locomotives (MGR operation, 40 total)						60.00																									
Sub total	60.00					34.05																									
Annual Operations (Normal operations crews)	0.00	5.36	5.36	5.36	5.36																										
(Relay operations crews)	0.00					10.35	10.35	10.35	10.354	10.35	10.35	10.354	10.35	10.35	10.35	10.35	10.35	10.35	10.35	10.35	10.35	10.35	10.35	10.35	10.35	10.35	10.35	10.35	10.35	10.35	10.35
Annual Materials	0.00	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72	0.72
Annual Maintenance (normal oper. Locos & lock maint.)	0.00	3.892	3.892	3.892	3.892																										
(Relay operations lock & locos maint.crews)						4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598	4.598
Sub total	0.00	9.98	9.98	9.98	9.98	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67
Totals	228.30	9.98	9.98	9.98	9.98	49.72	15.67	15.67	15.67	15.67	15.67	81.79	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67	15.67
Net Present Value	228.30	8.91	7.95	7.10	6.34	28.21	7.94	7.09	6.33	5.65	5.05	23.51	4.02	3.59	3.21	2.86	2.56	2.28	2.04	1.82	1.62	1.45	1.30	1.16	1.03	0.92	0.82	0.73	0.66	0.59	0.52
Total Net Present Value @ 12%	**375.57**																														
Tugs vs Locos NPV difference in cost	**70.58**																														

Table A-4. Cost Analysis at a Discount Rate Factor of 12 %.