COMISIÓN EJECUTIVA PORTUARIA AUTONOMA
REPUBLIC OF EL SALVADOR

FINAL REPORT
FOR
SPECIAL TECHNICAL ASSISTANCE
FOR
MAINTENANCE DREDGING
OF
THE PORT OF LA UNIÓN
IN THE REPUBLIC OF EL SALVADOR
(SUMMARY)

June 2014

JAPAN INTERNATIONAL COOPERATION AGENCY

ECOH CORPORATION

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Abbreviations Table

ALMOB	Automatic Light Mixture Overboard
C.D.L.	Chart Datum Level
CA4	Four Central American countries:El Salvador, Guatemala, Honduras and Nicaragua
CA5	Five Central American countries:El Salvador, Guatemala, Honduras, Nicaragua and Costa Rica
CEPA	Comisión Ejecutiva Portuaria Autónoma or Executive Autonomous Port Commission of the Republic of El Salvador
CNR	National Registration Center of the Republic of El Salvador
COCATRAM	Comisión Centroamericana de Transporte Marítimo (The Central American Commission on Maritime Transport)
CPN	Comision Portuaria Nacional Guatemala (Guatemala National Port Commission)
D.L.	Datum Level
ECOH	Environmental Consultants for Ocean and Human
EPN	Empresa Portuaria Nacional (Nicaragua National Port Company)
EPQ	Empresa Portuaria Quetzal (Quetzal Port Company)
GPS	Global Positioning System
GVD	Geodetic Vertical Datum
JBIC	Japan Bank for International Cooperation
JICA	Japan International Cooperation Agency
JSCE	Japan Society of Civil Engineers
LMOB	Lean Mixture Overboard
LOA	Length overall
MLIT	Ministry of Land, Infrastructure, Transport and Tourism
MLLW	Mean Low Low Water
MLW	Mean Low Water
MSL	Mean Sea Level
NAD27	North American Datum of 1927
NOAA	National Oceanic and Atmospheric Administration United States Department of Commerce
OCDI	The Overseas Coastal area Development Institute
OD	Origin-Destination
PIANC	World Association of Waterborne Transport Infrastructure
SAPI	Study on Special Assistance for Project Implementation
SIECA	La Secretaría de Integración Económica Centroamericana (The Secretariat of Central American Economic Integration)
TDS	Tons Dry Solid
TOR	Terms of Reference
TSHD	Trailing Suction Hopper Dredger
TSS	Total Suspension Solid
UNCTAD	United Nations Conference on Trade and Development
USA	United States of America

USDA	U.S. Department of Agriculture
VBA	Visual Basic for Applications
WGS84	World Geodetic System 1984
WID	Water Injection Dredging

Executive Summary

Executive Summary

Chapter 1 Introduction

The Republic of El Salvador decided to develop the new port in the Department of La Union, and requested the Japanese Government to prepare a master plan for the port construction and to carry out a feasibility study. The latter responded to the request by executing the feasibility study of La Union Port through JICA during October 1997 to December 1998. Following the feasibility study, the detailed design was made during July 2001 to January 2003. The project of constructing La Union Port began in April 2005, and construction of the civil engineering works was completed in December 2008 (see Figure 1.1).

While capital dredging of the access channel of 22.3 km long was progressing in 2007, it was observed a large quantity of siltation in the Inner and Outer channels and the harbor basin. Because the siltation might endanger the smooth operation of the port, the government of El Salvador and Japan discussed on the necessity of study on the fast siltation in July, 2008, and they agreed upon to start the Special Assistance for Project Implementation for La union Port Development Project (hereinafter referred to as "SAPI"). The SAPI Study was undertaken by JICA and executed during November 2008 to November 2009 (see Figure 1.1).

The SAPI Study clarified that the siltation is caused by slow movement of fluid mud toward a deeper seabed. Owing to the limited quantity of bathymetric time-series data and a relatively short duration of the study, however, it was difficult to predict the siltation volume with a high accuracy for making reliable estimate of the volume of maintenance dredging.

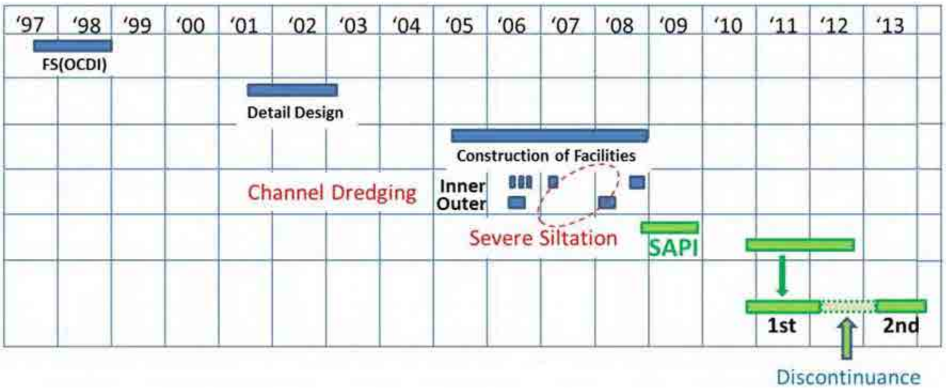

Figure 1.1 History of La Union Port

To make the port function properly as a deep sea port, dredging method as well as cost is a vital issue in financial viability and a key factor for successful terminal operation. Hence, CEPA again requested JICA to provide an effective and efficient maintenance dredging plan. According to a result of discussion between JICA and CEPA, JICA commenced the 1st Term Study in January 2011 and conducted a series of bathymetric survey and analysis for about one year and four months up to May 2012.

The survey and analysis have proved that detailed analysis of future shipping service, detailed demand forecast, and the data of trial dredging are inevitable for making valid maintenance dredging plan. Hence, JICA and CEPA discussed again and agreed to revise the TOR of Special Technical Assistance for Maintenance Dredging of the Port of La Union before the commencement of the 2nd Term Study. In the 2nd Term Study, not only the engineering issue but also the economic issue is included in the study scope to analyze technically/financially and economically optimum channel depths at present and in the future. After about one year suspension of study, the 2nd Term Study resumed on April, 2013.

The 1st Term Study and the 2nd Term Study have the following three purposes:
(1) To prepare data, information and analysis utilized by CEPA to formulate an effective and efficient maintenance dredging plan of the Port.
(2) To transfer technology to cope with the siltation in the channel and basin.
(3) To assist CEPA to prepare dredging plan based on the collected data and analysis.

The 2nd Term Study Team consists of two sub-teams, that is to say, the Engineering Team and the Economic Team. In order to properly implement the 2nd Term Study, the Project Support Domestic Committee has been established in JICA Headquarters to support and give advices to the Engineering Team from an academic and technical view point.

Chapter 2 Technology Transfer

In the 1st Term Study, the technical training of CEPA personals was carried out in Japan from 21 November to 9 December, 2011. Two trainees participated in the training program and studied on operation and management of dredging works, methodology of bathymetric survey and astronomical tide prediction, and so on.

In the 2nd Term Study, the Engineering Team has transferred the technology to the counterparts and participants through the twelve times of lectures, exercises, discussion and on-the-job training. The technology transferred contains the matters concerning the bathymetric survey, the prediction of tide level, the tide level correction, the mechanism and the processes of siltation, the rake-dredging, the empirical prediction models for siltation, the monitoring plan of siltation, the influence of the Semicircular Island and the types of dredging vessel, and so on.

The Economic Team has transferred the technology to the counterparts and participants through sixteen lectures and discussions. The technology transferred includes matters concerning the Vessel Calling Model, the present state of container shipping in Central America, the tariff of La Union Port and neighboring countries, the expected ship waiting time by tidal change in La Union Port, the navigable time of the channel by using tidal advantage, the connection between industrial development of the region surrounding the port and port planning and promotion, and so on.

The workshop on “Special Technical Assistance for Maintenance Dredging of the Port of La Union in the Republic of El Salvador” was held in CEPA Headquarter on 27 August, 2013. Numbers of participants were 17 from the El Salvador (CEPA) side, 4 from the Japanese side, 7 from the JICA Study Team and 4 from the JICA El Salvador Office.

Chapter 3 Field Survey and Results

The field survey such as bathymetric survey and mud sampling were conducted in the 1st Term Study.

The bathymetric survey was repeated three times in February 2011, August 2011 and January 2012. A preliminary analysis was made with the data obtained. La Union Port has an access channel with total length of 22.3 km and had been dredged to a depth of D.L.-14 m. At present, however, the entire passage has been filled to almost the original elevation and the depth when it was completed has not been maintained.

From the analysis of mud sampled at about two years after capital dredging, it is confirmed that fluid mud layer, the wet density of which is less than 1,200 kg/m^3, is formed with the height of about 0.5m in Outer channel and about 1.0 m in Inner channel.

The fluid mud layer in the channel continues in existence for relatively long period. This indicates a possibility to reduce maintenance dredging volume by making a maintenance dredging plan taking the fluid mud layer into account.

Judging from the Team's experience in the field, it is considered that the echo sounder of 200 kHz in frequency detects the top surface of the fluid mud layer. Therefore, the depth navigable for vessels is considered to be deeper than the depth measured by the echo sounder of 200 kHz, due to the thickness of the fluid mud layer.

Chapter 4 Analysis of Siltation Process and Prediction Models

At first, an empirical prediction model is formulated with an exponential function based on the bathymetric data.

Next, a process and a mechanism of siltation in the channel are revealed through the analysis of bathymetric data. According to the result of analysis, the original exponential model has been improved to be a new model, which is named as a modified Exponential Model.

Moreover, it is shown that a rapid siltation occurs just after the dredging within several months. By taking into account a possibility that the rapid siltation does not occur during a period of maintenance dredging, a second prediction model has been newly established, which is called a Linear Model.

At present, there is a discrepancy in the volumes of siltation predicted by the modified Exponential Model and the Linear Model. The volume of siltation predicted by the former is usually equal or greater than that of the latter. Since the latter model is formulated based on a unverified hypothesis, we must refrain from the use of it until the hypothesis is verified with the bathymetric data.

Chapter 5 Estimation of Dredging Volume and Cost

By using two prediction models formulated in Chapter 4, the volume of maintenance dredging will be estimated in Chapter 5.

At present, the harbor basin, Inner channel and Outer channel have been filled to almost the original elevation. The basin and channel need to be re-dredged at first. The total volume of the re-dredging for six target navigation depths of 9 to 14 m varying by 1 m is estimated based on the latest survey result in July 2013. The estimated re-dredging volume by depths is summarized in Table 5.1.

Table 5.1 Estimated re-dredging volume (units: 1000 m^3)

Depth (m)	Outer Ch.	Inner Ch.	Basin	Total
9.0	0	895	0	895
10.0	25	1,535	59	1,619

11.0	404	2,215	344	2,964
12.0	1,161	2,936	798	4,895
13.0	2,284	3,696	1,471	7,452
14.0	3,882	4,496	2,186	10,565

The maintenance dredging volume is calculated for six levels of the target depth: i.e., 9, 10, 11, 12, 13, and 14m. The cycle time, or the time interval of successive maintenance dredging, is set at 3, 4, 6, or 12 months. The volume of maintenance dredging at a specified cycle time and a target depth is estimated by applying the Modified Exponential Model and the Linear Model. In the calculation, the fluid mud thickness is taken into account. The result of estimation is shown in Figure 5.7.

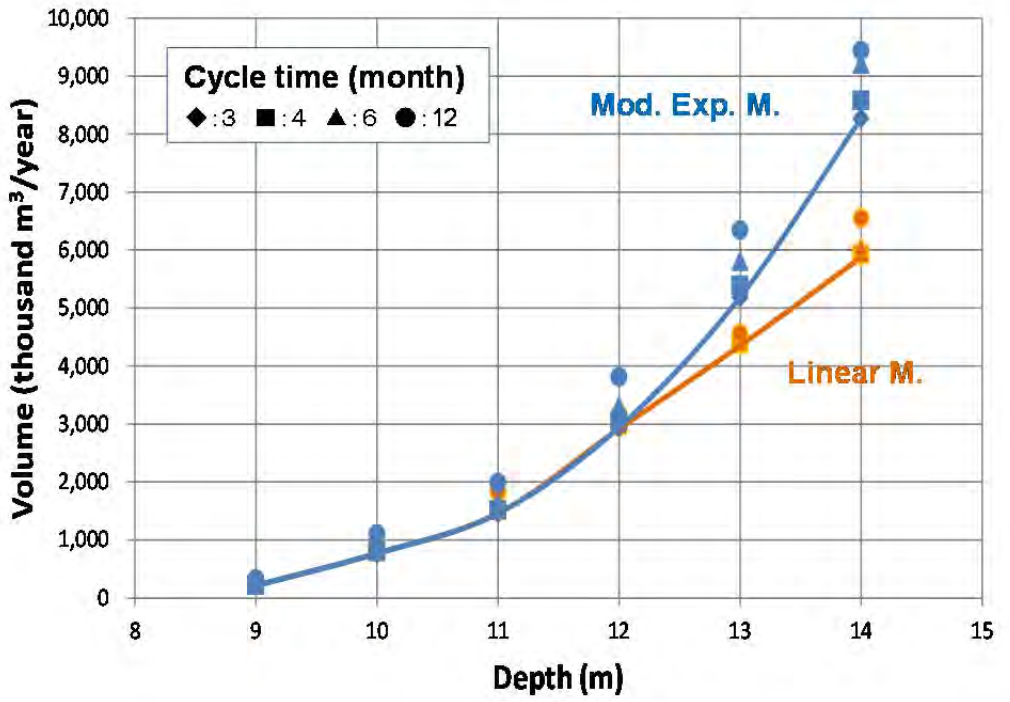

Figure 5.7 Maintenance Dredging Volume by Depths

TSHD (Trailing Suction Hopper Dredger) is regarded appropriate for the re-dredging and the maintenance dredging in La Union Port, because TSHD has the lowest impact on "other vessels traffic" with the highest "productivity" and "cost efficiency" among four types of dredger.

The dredging cost by own dredger is estimated smaller than contract base because the indirect cost is estimated cheaper than by contract base while direct costs are similar. Indirect cost of contract base includes mobilization cost, insurance cost, costs related with contingency and so on. On the contrary, indirect cost of dredging by own dredger include only mobilization, insurance cost and contingency as other cost is difficult to estimate. However, it is not appropriate to discuss about the dredging framework only with a comparison of dredging costs by contract base and own dredger, for the following reasons.

If CEPA owns a dredger, CEPA would have to bear considerable cost more than the cost estimation. And, dredging works could not be functioned without long experience and the accumulation of know-how. Aside from the cost, CEPA would have to handle training and education for dredger's crew.

Furthermore, accurate prediction of the siltation volume is necessary to design the size or capacity of the dredger before its procurement. But prediction models of siltation volume developed in this report is not reliable enough and necessary to be revised through monitoring of channel siltation for a certain period.

In addition to above, in case of change of target channel depth, the flexible response is extremely difficult if CEPA owns its dredger. This problem will remain unchanged for future as well.

Judging from the above all, "dredging by contract base" for the channel maintenance dredging for a certain period is strongly recommended.

Chapter 6 Proposal of Monitoring Plan

The two models established in Chapter 4 are based on the bathymetric data which is not necessarily enough in quality and quantity. More the Linear Model is standing on the unverified hypothesis. The monitoring of the channel depth by bathymetric survey is the only method for improving the precision of prediction and for enhancing the applicability of the Linear Model to the maintenance dredging. This is the first purpose of monitoring. The second one is to confirm the phenomenon of rapid siltation just after the dredging.

The monitoring plan is set up, subject to the condition that the bathymetric survey will be conducted by CEPA themselves with their own equipment.

For the first purpose, the bathymetric survey should be conducted immediately before and just after the re-dredging in the basin and the access channel. After that, the bathymetric survey shall be repeated with the time interval of two months, or one month if possible. For the second purpose, the bathymetric survey must be conducted just after the re-dredging. After that, it is recommended that the survey is repeated at an interval of two weeks for several months. The bathymetric survey must be usually conducted with the two acoustic signals of 38 kHz and 200 kHz to have the data on the thickness of fluid mud.

The record of dredging and the record of vessels which enter into and leave from the port must be collected at the same time.

Chapter 7 Reviews of Demand Forecast Model and Market Allocation Model developed by CEPA

In this chapter, the calculation method for projecting the growth rate of container volume from CA4 (El Salvador, Guatemala, Honduras and Nicaragua) and developing the market allocation model is shown.

"Port demand Study of La Union" carried out by CEPA consists of three parts:

1. Projected growth rate of container volume to and from CA4
2. Development of market allocation model
3. Projected market allocation for La Union Port

Chapter 8 Vessel Calling Model

The main purpose of Chapter 8 is to describe the vessel calling model which will be used to conduct the financial and economic analysis of La Union Port.

For that purpose, the current status of Salvadoran ports (8.1) as well as other major ports in other Central American countries (8.2) is summarized. The main focus is put on economic aspects because they are key for underpinning the model development, but the physical condition of each port is also described because it affects the capacity of cargo handling. In particular, the physical condition of Acajutla Port is crucial because the present and future limitation of its handling capacity is considered to directly influence the future container cargo throughput in La Union Port.

The strategy of maritime container shipping companies in the Pacific Coast of Central America is also examined prior to establishing the model (8.3). It is examined by two approaches; the first approach is to develop the liner shipping network of each company from the containership movement database. The second approach is to conduct interviews with shipping companies and other stakeholders.

The latter part of this chapter focuses on the vessel calling model. First, an outline of the model is described (8.4). After that, each component of the model is described; i.e., behavior of shipping companies, container cargo assignment model, and input data for the vessel calling model.

The maritime container shipping network of regular services operated by each company is vital to understanding the behavior of shipping companies (8.5). It is structured from the containership movement database by extracting 28 worldwide and local companies and 163 ports of the world.

The container cargo assignment model is the core element of the vessel calling model (8.6). The container cargo assignment model is an application of stochastic network assignment model on the intermodal shipping network of international container cargo, based on the generalized cost including both monetary cost and shipping time.

Preparing the input data is also important for the vessel calling model (8.7). Container cargo shipping demand (container cargo OD) between each port or region of the world is one of the most important data items. It is estimated from container cargo OD between countries and various statistics and information on regional economy, trade, and cargo handling in ports. The other necessary data is information on the shipping network including physical distance and shipping cost in the land, port, and maritime links. The information on the cost and time in border-crossing on land is also included.

The last section (8.8) of Chapter 8 summarizes the calculation results of the container cargo assignment model. After the description of the calculation procedure and unknown parameter estimation, the calculation results are examined from the viewpoint of the model reproducibility by several benchmarks such as container cargo throughput, share by partner countries, export and import port in CA4 countries, shares by shipping company, and estimated volume shipped by each liner service. Also, the sensitivity of the model to estimated unknown parameters is also examined.

As a result, the container cargo assignment model well describes the actual container cargo shipping market in CA4 countries and reasonably behaves against the change of the model input.

Chapter 9 Vessel Calls to La Union Port and Economic Analysis

Chapter 9 mainly focuses on the output of the vessel calling model.

The first part of the chapter describes the present status of navigation channel and rules in La Union Port, followed by a proposal for a new navigation rule (9.1). The "expected waiting time" is calculated based on the new rule as well as on the existing rule. It is found that the existing rule may be effective under the current situation that a small ship navigates a shallow channel, but when the channel is deepened and ships of various sizes are expected to call the new rule needs to be introduced.

Many calculation scenarios on the future liner shipping network are prepared for each channel depth in La Union Port in 2020 and 2030, and several feasible scenarios for each depth in both years are selected based on certain criteria (9.2). Figure 9.8 and Figure 9.9 show the container cargo throughput in La Union Port in 2020 and 2030, estimated by the vessel calling model based on each feasible scenario with the depth of navigation channel. In the figure, the results in both 1) modification scenarios of existing feeder and way-port service network with -9m to -12m channel depth and 2) additional vessel-calling scenarios as a transshipment hub with -12m to -14m channel depth are shown. The figures show that the container cargo throughput in La Union Port increases as the depth of navigation channel increases.

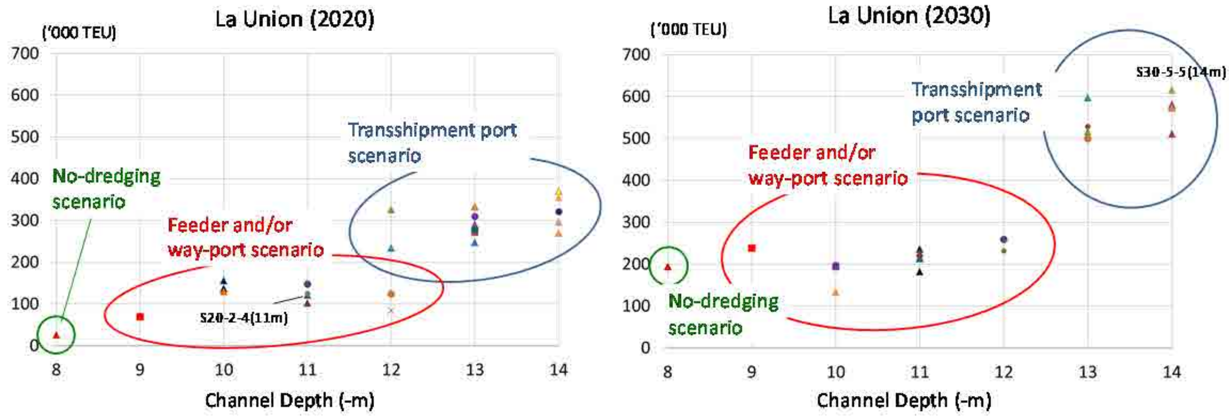

Figure 9.8 & 9.9 Container cargo throughput for each feasible scenario in port of La Union in 2020 and 2030

Based on the container cargo throughput and other outputs estimated in the model, net income (which is acquired by subtracting the expected revenue from port and handling charges by expenditure such as container operation cost except for the dredging cost) from container business of La Union Port, net income from container business of Salvadoran port sector (sum of Acajutla and La Union Port), and net benefit for Salvadoran economy of the dredging project in La Union Port (difference of the sum of the net incomes of the ports of La Union and Acajutla and shipping cost of Salvadoran import/export cargo for dredging scenarios from those of the no-dredging scenario) are estimated and compared with the dredging cost by channel depth (9.3). From the financial aspect for La Union Port, if the tariff of La Union Port is kept at the present level, the net income will be always less than the dredging cost for each channel depth (see Figure 9.14 and Figure 9.15).

However, if the tariff of La Union Port is increased, the net income (except for the dredging cost) may be larger than the dredging cost in the scenario that the expected net income is maximized by channel depth (9.4, see Figure 9.20 and Figure 9.24). It implies a need to increase the tariff in

La Union Port to keep a sound financial condition. However, this could weaken the competitiveness of the port against neighboring ports resulting in a decrease in the amount of containers handled. The level of the tariff will be a crucial issue when the shipping market becomes more liberalized such as when the barriers at national borders are removed (9.2.3(3)).

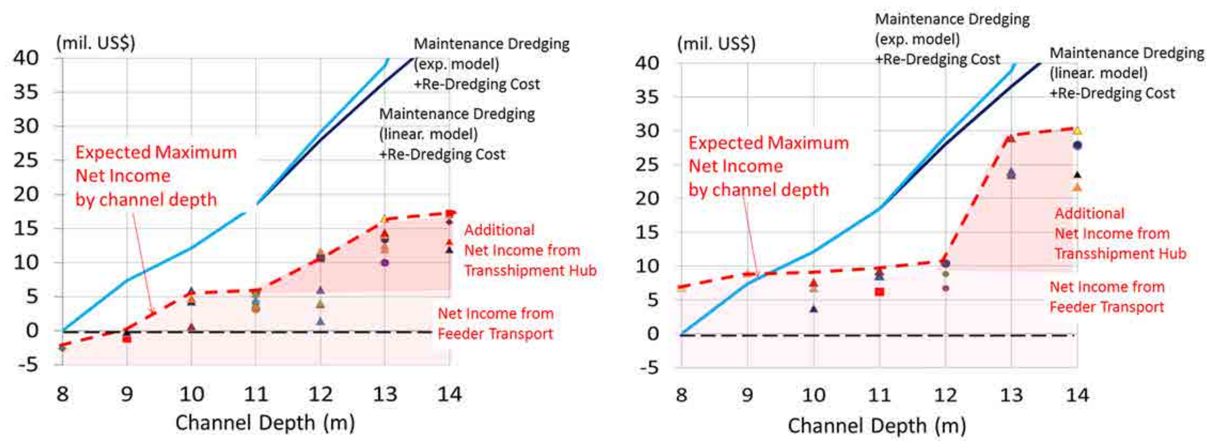

Figure 9.14 & 9.15 Estimated net income and dredging cost by channel depth in La Union Port (left: 2020; right: 2030)

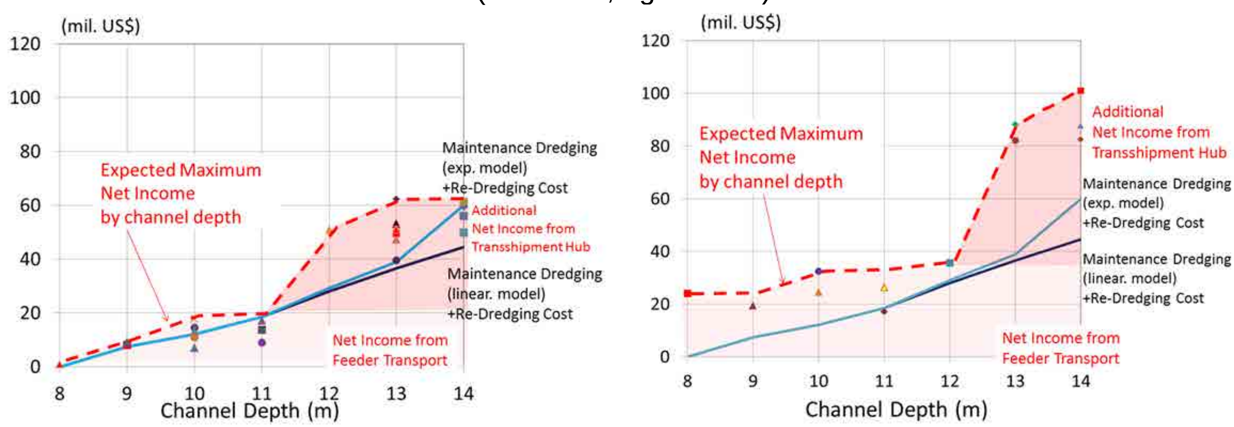

Figure 9.20 & 9.21 Estimated net income in case of the tariff increase and dredging cost by channel depth in La Union Port (left: 2020; right: 2030)

The other important point in the simulations of the chapter is that the scenarios on the future liner shipping network are prepared not only for modification of the existing feeder and way-port network, but also for calling by vessels of the trunk route. Some of these "transshipment hub" scenarios for La Union Port are considered to be feasible as already shown in Figure 9.8 and Figure 9.9; in addition, if the transshipment hub is realized, it will be very beneficial to the economy of El Salvador. However, an important point to keep in mind is that simply deepening the channel by dredging does not guarantee that the port will become a transshipment hub. To become a transshipment hub, considerable efforts to attract the vessels of the trunk line would need to be made.

The last finding is that regional development in the eastern El Salvador would contribute to increasing the amount of container cargo as well as the revenue in La Union Port (9.2.3(3)2) and 9.4.4). As originally planned, the integrated development of La Union Port with the hinterland in the eastern area of El Salvador is also one of important keys for the future development of La Union Port.

Chapter 10 Optimal Dredging Plan Considering Time-Series Changes on Demand and Costs

In Chapter 10, a methodology of the time series analysis considering each year's income, benefit and dredging cost is introduced.

Also, example results of calculation are shown in order to contribute to the discussion on the timing of investment for dredging. The calculation results on optimal year and net benefit for each combination of target depth after the first and second re-dredging and each type of dredging after increasing the tariff in La Union Port are shown. The calculation is based on many assumptions (e.g., re-dredging is allowed only twice and the second re-dredging must be carried out precisely ten years after the first dredging); in addition, a limited number of example results are shown based on the liner service network to generate the expected maximum net benefit in each channel depth is considered.

The example results imply that the best strategy to maximize the net benefit is to purchase a dredger for annual maintenance dredging within a few years and maintain a channel depth of around -12m or -13m, although there is a significant risk because this strategy will only be successful if the transshipment hub" scenario is realized. On the other hand, the second best strategy with relatively smaller risk is that the first re-dredging for a depth of around -10m is conducted with a contracted dredger and the second re-dredging for a depth of -13m. This kind of "step-wise" strategy is very useful for avoiding huge financial risks.

Chapter 11 Conclusions and Recommendations

Major findings of the study and recommendations are summarized on the following items;

11.1 Conclusions

(1) Present state of siltation in the access channel
(2) Thickness of fluid mud layer
(3) Mechanism of siltation and prediction models foe water depth in the channel
(4) Volume of re-dredging
(5) Volume of maintenance dredging
(6) Appropriate dredging method
(7) Vessel calling model
(8) Financial and economic analysis of La Union Port and policy simulation
(9) Optimal dredging plan considering time-series changes
(10) Navigation rule of access channel

11.2 Recommendations

(1) Applicability of a empirically formulated prediction model
(2) Applicability of the Linear Model
(3) Appropriate dredging framework
(4) Necessity of monitoring channel depth
(5) Use of dual frequencies of echo sounder
(6) Tariff setting
(7) Transshipment hub scenario
(8) Regional development in eastern El Salvador
(9) Importance of step-wise investment plan for dredging to avoid huge financial risks
(10) Necessity of new navigation rules for access channel of La Union Port

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Chapter 1 Introduction

1.1 Overview of Development of La Union Port

1.1.1 Development of La Union Port

The economic structure of the Republic of El Salvador depends strongly on foreign trade, and a major of its freight distribution is a marine transportation, which plays a significant role on the development of the country. However, Acajutla Port which is a only one international trade port in the country is directly exposed to the full energy of the Pacific Ocean. Because of this natural condition, there is a limit on the capacity of freight handling, especially for containers. There was no enough facility in El Salvador which could manage the increasing of seaborne traffic and a global trend of containerizing freight transportation.

The Department of La Union, which is the easternmost Department of Republic of El Salvador, is bordered with Honduras and Nicaragua across the Gulf of Fonseca. A port named Cutuco had been developed at the western waterfront of the Gulf of Fonseca at the distance of about 25 km from the entrance of the Gulf. The port handled 236 thousands ton of cargo in 1975, but the trade dwindled considerably during the civil war time late 1980s and early 1990s. The Department of La Union had been lagging in economy in comparison with other departments.

After the cease of the civil war, the Republic of El Salvador decided to develop the new port in the Department of La Union, which had an objective of stimulating economical and industrial development through the port activity in the Department of La Union. And also the new port is expected to function as a hub port of container ships along the Pacific coast of the Central American continent.

The Government of El Salvador requested the Japanese Government to prepare a master plan for the port expansion and to carry out a feasibility study for the short-term facility installation plan. The latter responded to the request by executing the feasibility study of La Union Port through Japan International Cooperation Agency (hereinafter referred to as “JICA”) during October 1997 to December 1998 and presenting the final report. Following the feasibility study, the detailed design was made during July 2001 to January 2003. The name of port was changed from Cutuco to La Union with a slight location shift of the wharf area.

The project of constructing La Union Port began in April 2005 with a total cost of about 21,400 million Japanese yen among which 11,233 million Japanese yen was provided by the Japan Bank for International Cooperation (hereinafter referred to as “JBIC”) as the low-interest loan, and construction of the civil engineering works was completed in December 2008.

The history of La Union Port mentioned above is shown in Figure 1.1.

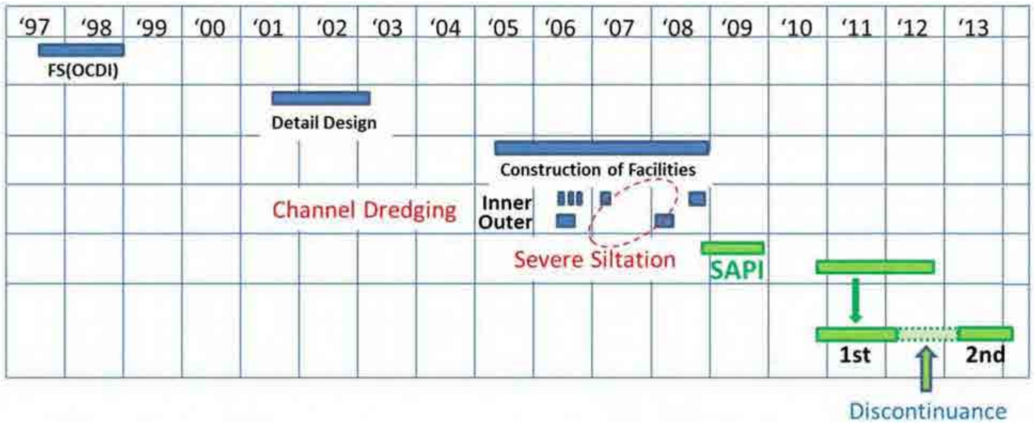


Figure 1.1 History of La Union Port

1.1.2 Harbor Facilities of La Union Port

La Union Port has been designed for Post-Panamax container ships, bulk carriers of 50,000 DWT, and passenger ships of 25,000 DWT classes.

The access channel of 22.3 km long is divided into the inner and outer parts by the narrow waterway between Cape Chiquirin and Zacatillo Island (see Figure 1.2). The Inner channel is about 5.0 km long and the Outer channel is 17.3 km long. When the dredging works completed in 2008, the Inner channel had the width of 140 m at the bottom and the water depth of 14m, while the Outer channel had the width of 137 m and the water depth of 14.5m. About 4.5 km of the Inner channel were cut through the water area shallower than 10 m with the shallowest portion of about 6 m. The length of the outer channel pass through the area shallower than 10 m is about 1.5 km; the shallowest depth is about 9 m. The side slope is designed with a gradient of 1 on 5. However, the entire passage has been filled in by siltation, and the depth when it was completed has not been maintained.

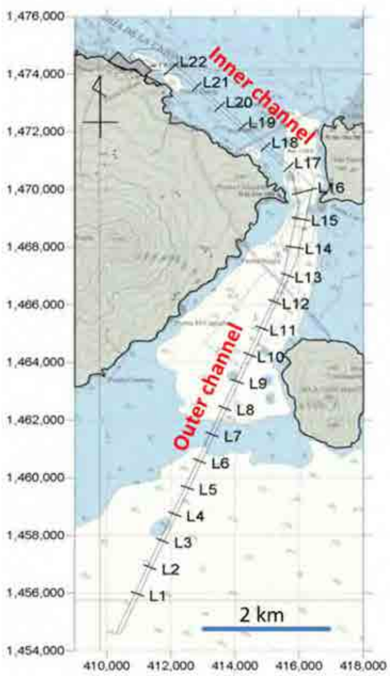


Figure 1.2 Access channel of La Union Port

1.2 Recognition of Siltation Problem in La Union Port and Commencement of SAPI Study

When La Union Port was under construction toward its completion at the end of November 2008, it was observed a large quantity of siltation in the Inner and Outer channels and the harbor basin, based on the bathymetric surveys performed during the execution of the dredging works (see Figure 1.1). The volume of siltation from April 2007 up to January 2008 is calculated as listed in Table 1.1. The volume of sedimentation in the harbor basin and access channel had been predicted in the Detailed Design Report (2002) and they are also listed in Table 1.1. Actual siltation was 4 to 8 times the prediction as of early 2008.

Table 1.1 Volume of siltation deposited from April 2007 to January 2008 in comparison with prediction at the time of Detailed Design Study in 2002

Name	Area (m^2)	Volume (m^3)	
		Obs.	Pred.
Harbor basin	657,000	158,000	478,000
Inner channel	626,000	1,973,000	453,000
Outer channel	1,660,000	2,389,000	312,000
Total	2,943,000	4,521,000	1,243,000

Since the cause of unexpectedly fast siltation was not identified, it was not possible to estimate the future siltation volume, nor to find an adequate measure. Then, a scrutiny of fast siltation became an acute task.

The JBIC and the Comisión Ejecutive Portuaria Autónoma (hereinafter referred to as "CEPA") discussed on the necessity of study on the fast siltation in July, 2008, and they agreed upon to start the Special Assistance for Project Implementation for the Port of La Union Development Project (hereinafter referred to as "SAPI"). The SAPI Study was undertaken by JICA and executed during November 2008 to November 2009 (see Figure 1.1).

1.3 Result of SAPI Study

The major results concerning with the siltation problem are cited from the Report of SAPI.

1.3.1 The Gulf of Fonseca and Mechanism of Siltation

The Gulf of Fonseca is about 65 km wide and 45 km long, having an area of about 3,200 km^2. Mud in the Gulf of Fonseca has come from the suspended sediments during floods from many rivers. Sediments of bed load are mostly caught by mangrove swamps at the head of the Gulf. Suspended sediments of silt and clay are diffused with flood discharge and uniformly spread over the whole bay areas with a thickness of 0.2 to 1.2m.

In the area around the Inner channel, most of the seabed is covered with silt and mud except for a few locations. The median diameter varies from 0.013 to 0.034 mm excluding the sites with local fine sand.

In the area outside the Outer channel, sediment on the bottom contains the fine sand of 30% to 50%.

Within the channel, however, sand content is few with a median diameter of 0.02 to 0.04 mm. Little sand content along the outer channel indicates that sand does not move into the channel, but silt and mud are brought into the channel. This supports the concept on siltation mechanism that a thin layer of fluid mud on the sea bottom creeps down into a deeper section by gravity. Movement continues as long as there is an elevation difference on the surface of fluid mud between the seabed inside and outside the channel.

1.3.2 Establishment of prediction formulae for siltation speed and channel depth

A trend analysis of the temporal variation of the mean channel depth at traverse survey lines has enabled to establish an empirical prediction formula for siltation speed as a function of difference in the depths inside and outside the channel, and the time elapsed from completion of capital dredging.

Another prediction formula for estimation of channel depth in future has also been derived from the siltation speed formula. This formula has been validated with the records of previous bathymetric survey results. By utilizing this formula, it was predicted that the siltation volume in the access channel with the depth of 14 m would be 10 million cubic meters per year.

1.4 Objectives and Major Works of this Study

To make the port function properly as a deep sea port, dredging method as well as cost is a vital issue in financial viability and a key factor for successful terminal operation either in the contingent stage of operation or in the stage of concession. Hence, CEPA requested JICA to provide an effective and efficient maintenance dredging plan.

According to a result of discussion between JICA and CEPA on 28 April, 2010, JICA commenced the 1st Term Study in January 2011 and conducted a series of bathymetric survey and analysis for about one year and four months up to May 2012. The 1st Term Study had the following two purposes:

(1) To prepare an effective and efficient channel maintenance plan to make La Union Port function properly as a deep sea port.
(2) To transfer technology to cope with the siltation in the channel and basin and to assist CEPA to review/revise the prepared dredging plan based on the bathymetric monitoring data.

The survey and analysis have proved that detailed analysis of future shipping service, detailed demand forecast, and the data of trial dredging are inevitable for making valid maintenance dredging plan. Hence, JICA and CEPA discussed and agreed to revise the TOR of Special Technical Assistance for Maintenance Dredging of the Port of La Union before the commencement of the 2nd Term Study, which has done on 31 October, 2012. In the 2nd Term Study, not only the engineering issue but also the economic issue is included in the study scope to analyze technically/financially and economically optimum channel depths at present and in the future.

The 2nd Term Study has the following three purposes:

(1) To prepare data, information and analysis utilized by CEPA to formulate an effective and efficient maintenance dredging plan of the Port.
(2) To transfer technology to cope with the siltation in the channel and basin.
(3) To assist CEPA to prepare dredging plan based on the collected data and analysis.

1.5 Engineers concerned and Chronologies of Study

1.5.1 Engineers concerned

(1) Project Support Committee in Japan

In order to properly implement the project on "Special Technical Assistance for Maintenance Dredging of the Port of La Union in the Republic of El Salvador", the Project Support Domestic Committee has been established in the Economic Infrastructure Department, JICA Headquarters. The committee, which consists of specialists on the siltation and dredging, evaluates items with respect to the issues related to siltation in the channel and the dredging method, and gives advice to the director of department, from an academic and technical view point.

(2) Study Team

The first term Study Team consists of engineers mainly from ECOH Corporation, Japan.

The second term Study Team can be divided into two sub-teams, that is to say, the engineering team and the economic team. The former consists of engineers mainly from ECOH Corporation, which is in charge of siltation problem and dredging plan in the channel. The latter is consists of engineers from OCDI, Japan, which is in charge of demand forecast and economic analysis of the port.

(3) Counterparts

For two counterparts in the first term Study listed in Table 1.2, the technical training was carried out in Japan.

In the second term Study, CEPA named 11 engineers as the counterparts, being 3 for the engineering team and 8 for the economic team, which are listed in Table 1.3.

Table 1.2 Counterparts in the first term Study

Name	Affiliation
Mr. Mario Orantes	Navigation Aids
Mr. Abelino Cruz	Chief of Maintenance Department

Table 1.3 Counterparts in the second term Study

	Name	Affiliation
Engineering Team	Mr. Andrés Abelino Cruz	Maintenance Manager, La Union Port
	Mr. Carlos Alejandro Molina Paz	Bathymetry and Dredging Specialist, La Union Port
	Ms. Egly Tatiana Chacón	Bathymetry and Dredging Specialist, La Union Port
Economic Team	Mr. Carlos Federico Paredes	Concessions Department, Advisor to the President
	Mr. Julio Romero	Concessions Department
	Ms. Patricia Callejas	Concessions Department
	Ms. Marta Eugenia Canales	Concessions Department
	Ms. Andrea Castillo	Presidency
	Mr. Alan Castillo	Concessions Department
	Mr. Juan Carlos Martinez	Concessions Department
	Mr. Damian Reyes	Market Analysis Division

(4) JICA Experts dispatched to CEPA

JICA experts dispatched to CEPA are Dr. Hidefumi IKEDA in the first term Study and Mr. Takashi KADONO in the second term Study.

1.5.2 Chronologies of Study

The chronologies of the first and the second term Studies are as follows;

[First term study] from January, 2011 to May, 2012

First on-site works	25 January to 21 February, 2011
Second on-site works	15 August to 6 September, 2011
Third on-site works	15 January to 6 February, 2012

[Second term study] from April, 2013 to April, 2014

First on-site works	10 April to 5 May, 2013
Second on-site works	11 August to 1 September, 2013
Third on-site works	04 to 15 December, 2013

Project Support Domestic Committee

First PSDC	1 April, 2013
Second PSDC	9 August, 2013
Third PSDC	19 November, 2013

1.6 Composition and Abstract of Chapters in the Report

In Chapter 2, the technical training of two counterparts in Japan, contents of technology transfer in the second term Study and a workshop held on 27 August, 2013 are explained.

In Chapter 3, the field survey such as bathymetric survey and mud sampling conducted in the first term Study is explained with its results.

In Chapter 4, at first, an empirical prediction model was formulated with an exponential function based on the bathymetric data. Next, a process and a mechanism of siltation in the channel are revealed through the analysis of bathymetric data. According to the result of analysis, the original exponential model has been improved to be a new model, which is named as a modified Exponential Model. Moreover, it is shown that a rapid siltation occurs just after the dredging within several months. By taking into account a possibility that the rapid siltation does not occur during a period of maintenance dredging, a second prediction model has been newly established, which is called a Linear Model. The applicability of these models is discussed.

In Chapter 5, the volumes of re-dredging and a maintenance dredging are estimated. The volume of maintenance dredging is estimated for each target depth by two prediction models formulated in Chapter 4. In a consideration for dredging method, a Self-propelling Trailing Suction Hopper Dredger (TSHD) is selected after the comparison of four types of dredging method. The dredging cost of re-dredging is estimated for the dredging of contract base, and those of maintenance dredging are estimated for both the contract base and the own dredger by CEPA.

In Chapter 6, contents and a method of monitoring on siltation in the channel and the basin are examined, which will be carried out just after the re-dredging and during the maintenance dredging. The purpose of monitoring are to verify an appropriateness of siltation volumes predicted by two models and to confirm the phenomenon of rapid siltation just after the re-dredging.

In Chapter 7, the calculation method for projecting the growth rate of container volume from CA4 (El Salvador, Guatemala, Honduras and Nicaragua) and developing the market allocation model is shown.

The main purpose of Chapter 8 is to describe a vessel calling model for financial and economic analysis of La Union Port. Before describing the model structure, the current status of Salvadoran ports as well as other major ports in Central American (CA5) countries is summarized mainly from the economic viewpoint but also focusing on their physical conditions. Also, a strategy of shipping operators (maritime container shipping companies) in the Pacific Coast of Central America is examined from the liner shipping network of each operator and its change as well as interview surveys to operators and other stakeholders. Then an outline of the vessel calling model is described, followed by a description on every component of the model including behavior of shipping companies, container cargo assignment model, and input data. Finally, calculation results of the container cargo assignment model are examined from the viewpoint of the model reproducibility by several benchmarks. The sensitivity of the model to the estimated unknown parameters is also examined.

Chapter 9 mainly focuses on the output of the vessel calling model. However, the first part of the chapter describes the present status of navigation channel and rule in La Union Port, followed by a proposal of new navigation rule. After that, according to a lot of scenarios on the future liner shipping network which are prepared for each channel depth in La Union Port, the vessel calling model is calculated to estimate the future container cargo throughput and other outputs. From the model output, net income (except for the dredging cost) from container business of La Union Port, net income from container business of Salvadoran port sector (sum of Acajutla Port and La Union Port), and net benefit for Salvadoran economy of the dredging project in La Union Port are estimated and compared with the dredging cost by channel depth. The model calculation as well as financial and economic analysis as mentioned above is also conducted in the cases that each related policy such as tariff increase of La Union Port, regional development in the eastern El Salvador, and decrease of the barrier at national border is implemented.

Chapter 10 shows a methodology of the time series analysis considering each year’s income, benefit and dredging cost. Also, example results of calculation are shown, in order to contribute to the discussion on the timing of investment for dredging.

In Chapter 11, major findings of the study and recommendations are summarized.

Chapter 2　Technology Transfer

Chapter 2 Technology Transfer

2.1 Execution for Technical Training of CEPA Personals in Japan

The technical training of CEPA personals was carried out in Japan from 21 November to 9 December, 2011. Two trainees, that is to say Mr. Cruz Fuentes Andrés Abelino and Mr. Orantes Montiagudo Mario René, participated in the training program and studied on operation and management of dredging works, methodology of bathymetric survey and astronomical tide prediction, and so on (see Photo 2.1).

Photo 2.1 Exercise on MLITT's dredger, Kaisho Maru

2.2 Technology Transfer to Counterparts

2.2.1 Technology Transfer in the Field of Engineering

(1) Explanation of the Inception Report in the Second Term Study on 16 April, 2013

The Inception Report which contains the purposes and methods of the second term Study was explained to five participants in La Union Port. They understood the contents well.

(2) Inspection of rake-dredging and confirmation of CEPA's tide correction, on 17 April, 2013

The Engineering Team got the information about the rake-dredging through the interview and the discussion with five participants. The counterpart explained about their method of tide correction. The team pointed out that their method was not appropriate.

(3) Joint bathymetric survey practice on 19 April, 2013

In the field, five participants explained the Team on the items related to the bathymetric survey such as an installation of echo sounder, a calibration of measured water depth, operation of surveying vessel, a recording of sounding data and so on (see Photo 2.2). It was confirmed that their method of bathymetric surveying was correct and appropriate, and their skill have been good.

Photo 2.2 Setting of recording device for bathymetric survey

(4) Explanation on the Soft-ware program for the prediction of tide level in La Union Port, on 22 April, 2013

A basic concept of tide correction was transferred to five participants. And also, a soft-ware program for the prediction of tide level in La Union Port, which is absolutely necessary for tide correction, has been provided to them with a detailed explanation.

(5) Joint bathymetric survey and a practice of tide correction on 21 August, 2013

The Joint Bathymetric survey of the engineering Team and six counterparts was carried out. The bathymetric data obtained was used for practice of tide correction, in which the provided soft-ware program was effectively utilized.

(6) Explanation of siltation process in the channel on 22 August, 2013

A result of analysis on the siltation process in the access channel of La Union Port was explained to three counterparts. The Team and the counterparts discussed on the phenomena of siltation, which gave a basic knowledge to the counterparts for understanding the prediction models of siltation.

(7) Joint bathymetric survey on 23 August, 2013

In the Inner channel, a longitudinal bathymetric survey was conducted under the joint of the Team and three participants.

(8) Modification of prediction model for siltation in La Union Port on 6 December, 2013

The engineering Team explained to five counterparts about the modified Exponential Model and newly formulated Linear Model. The counterparts could understand the applicability of these models.

(9) Explanation of the monitoring plan on siltation after re-dredging on 6 December, 2013

As a result of technology transfer, five participants deepened their understanding of the importance of monitoring for improving the prediction model.

(10) On the influence of Semicircle Island to the environment around it, on 9 December, 2013

CEPA has a plan to construct the Semicircular Island in order to reduce the volume of siltation. The effects of semicircular Island they expect are an alternate dumping site for dredged mud and reduction of siltation volume. The team explained a result of consideration concerning to this issue to five participants.

(11) Calculation method of siltation volume and Nautical depth of navigation, on 10 December, 2013

Five participants understood the calculation method of siltation volume by applying two prediction models.

(12) Introduction of various dredgers, on 12 December, 2013

Various types of dredger were introduced (see Photo 2.3). Thirteen counterparts were attended this lecture.

Photo 2.3 Atmosphere of presentation

2.2.2 Technology Transfer in the Field of Economic

(1) Explanation of the Inception Report on 16 April, 2013

At the beginning of the second term Study, the economic team explained the Inception Report. Seven participants of CEPA economic team were able to deepen their understanding of the central aim of this survey.

(2) Method of calculating CEPA model, on 26 April, 2013

The economic team confirmed the methodology used in the Future demand forecast and Market allocation conducted by CEPA. The participants were six.

Photo 2.4 Presentation by a member of the economic team

(3) Estimated result of Vessel Calling Model on 27 June, 2013 (by Skype meeting)

The economic team gave a summary of the estimated results obtained from the Vessel Calling Model. CEPA economic team confirmed what was outputted, and five participants were able to deepen their understanding of the model.

Photo 2.5 Skype meeting

(4) Outline of the Vessel Calling Model & Estimated results, on 11 July, 2013 (by Skype meeting)

The economic team gave an outline of the Vessel Calling Model and obtained from the Model. Four participants were able to deepen their understanding of the model.

(5) Estimated result of Vessel Calling Model, on 18 July, 2013 (by Skype meeting)

The economic team explained a summary of the estimated result obtained from the Vessel Calling Model. CEPA economic team was able to deepen their understanding of the model. A number of participants are four.

(6) Fundamentals of Vessel Calling Model, on 9 August, 2013 (by Skype meeting)

The economic team explained the traffic assignment model which is one of the fundamental components of the Vessel Calling Model. CEPA economic team practiced with the model, and was able to deepen their understanding of the model. A number of participants are four.

(7) Vessel Calling Model & Estimated results, on 15 August, 2013

The economic team explained how the Vessel Calling Model had been adjusted to better suit the Central American region. Five participants from CEPA economic team were able to deepen their understanding of the model.

(8) Container Service along Pacific Coast on CA5, on 16 August, 2013

The economic team explained the present state of container shipping along the Pacific Coast in CA5. Four participants from CEPA economic team were able to understand that the routes and frequency of container service could change depending on the strategy of shipping companies in Central America.

(9) Tariff of La Union port, on 25 August, 2013

The economic team explained the tariff of La Union port and neighboring countries. CEPA economic team was able to deepen their understanding of the tariff.

(10) Estimated an expecting ship waiting time in La Union Port, on 28 August, 2013

The economic team explained the estimated an expecting ship waiting time by tidal change in La Union port. Three participants from CEPA economic team were able to understand that the navigable time of the channel could be expanded by using tidal advantage.

(11) Channel Navigation by using Tidal Advantage, on 6 December, 2013

The economic team explained the navigable time of the channel by using tidal advantage. Four participants from CEPA economic team were able to deepen their understanding of the method used to calculate navigable time.

(12) Regional/Industrial Development and Port Planning and Promotion, on 9 December, 2013

The economic team explained the connection between industrial development of region surrounding the port and port planning and promotion. Five participants from CEPA economic team were able to deepen the understanding of the significance of port policy.

(13) Method of calculating Financial & Economic analysis and Summary of Draft Final Report, on 12 December, 2013

The economic team explained the method of calculating Financial & Economic analysis, and summary of Draft Final Report. Five participants from CEPA economic team were able to deepen the understanding about analysis and summary of DFR.

2.3 Workshop

The workshop on “Special Technical Assistance for Maintenance Dredging of the Port of La Union in the Republic of El Salvador” was held at the CEPA Headquarter on 27 August, 2013. The program of workshop, titles of presentations and presenters are listed in Table 2.1. Among them, Dr. K. Murakami and Dr. Y. Nakagawa are the members of Project Support Domestic Committee established in JICA Headquarters, Japan. Photo 2.6 shows an atmosphere of workshop, in which persons in CEPA side were occupying on the left side as one faces the screen of projector.

Table 2.1 Program of workshop, titles of presentations and presenters

START		12:00
0. Lunch	Invited by CEPA in order to enhance awareness of participants and presenters	12:00-12:30
1. Welcome Speech	By Mr. A. ARENE, President of CEPA	12:30-12-35
2. Opening Address	By Mr. T. KAWAKAMI, JICA HQ	12:35-12:40

3. Interim Report on Engineering Issues By Dr. N.ONO, ECOH 12:40-13:20
4. Interim Report on Economic Issues By Dr. R.SHIBASAKI, OCDI 13:20-14:00
5. Port Promotion examples in Japan By Mr. M.KIHARA, MLIT 14:00-14:30
< Coffee break>
6. Field Study on maintenance dredging in the access channel of Banjarmashin Port, Indonesia By Dr. K.MURAKAMI, TCU 14:45-15:15
7. Harbor siltation and countermeasures in Japan By Dr. Y.NAKAGAWA, PARI 15:15-15:45
8. Case study of analysis of bathymetric data By Dr. K.KATO, ECOH 15:45-16:05
9. Regional development and port By Mr. T.SHISHIDO, OCDI 16:05-16:25
10. Closing Remarks by Mr. T.KADONO, JICA Expert 16:25-16:30
CLOSE 16:30


Photo 2.6 Workshop held in CEPA Headquarters

Chapter 3 Field Survey and Results

Chapter 3 Field Survey and Results

3.1 Bathymetric Survey

3.1.1 Survey lines of bathymetric survey

La Union Port has an access channel with total length of 22.3 km and had been dredged to a depth of DL.-14 m.

The bathymetric survey was conducted along the survey lines shown in Figure 3.1 and Figure 3.2. The bathymetric survey was repeated three times in the first term study, that is to say, during the period from 31 January to 2 February 2011, that from 19 to 22 August 2011, and that from 19 to 21 January 2012.

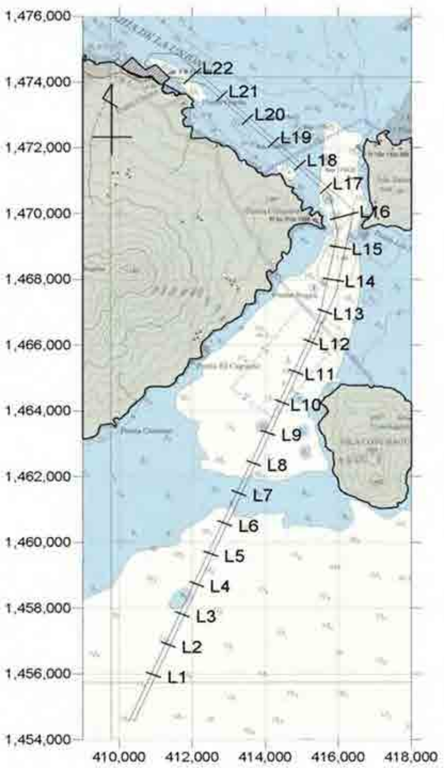


Figure 3.1 Bathymetric survey lines of access channel

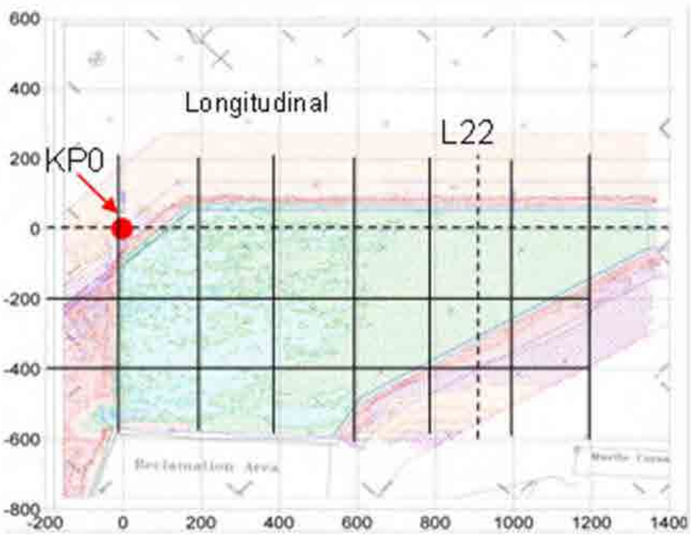


Figure 3.2 Bathymetric survey lines in harbor basin

3.1.2 Mean depth of access channel and harbor basin

The surveyed water depths over the bottom width of navigation channel (about 140 m) were averaged to yield the mean channel depth. Figure 3.3 shows the variation of the mean water depth along the harbor basin and access channel in comparison with the previous survey results which were obtained in August 2008, December 2008, and June 2009. The mean depth at the completion of capital dredging is also shown with the marks of black closed circles. The mean depths just after capital dredging are measured in April 2008 for the Outer channel and in December 2008 for the Inner channel.

In the Outer channel, siltation since June 2009 is slight and locally depression is also seen in KP13 and KP14. On the other hand, siltation in the inner channel is heavy and the channel depth at the locations of KP3.00 to KP4.00 is about 7.5 m.

At present, the entire passage has been filled to almost the original elevation and the depth when it was completed has not been maintained.

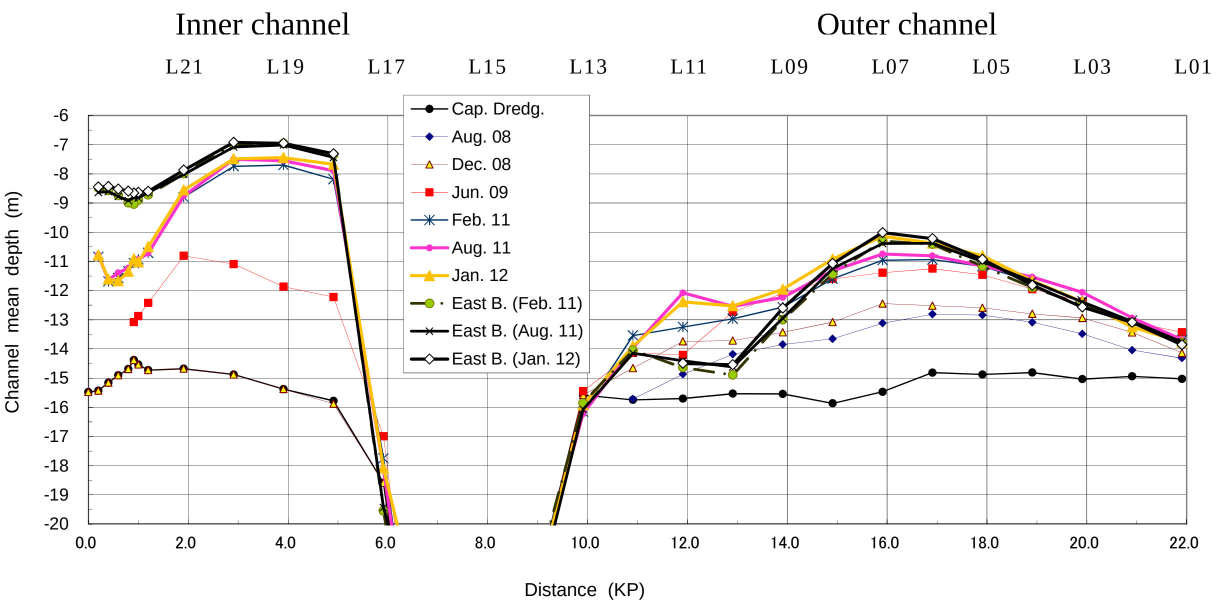


Figure 3.3 Variation of mean depth of the access channel

3.1.3 Difference between depth measurements with 38 and 200 kHz sonic waves

The dual frequency bathymetric survey in June 2009 during the SAPI Study indicated a certain difference between the water depth measured with the sonic waves of 38 kHz and 200 kHz, as shown in Figure 3.4, which are reproduced from the Final Report of SAPI Study (2009). The depth difference was regarded as representative of fluid mud layer which had not been consolidated yet after the completion of capital dredging in late December 2008.

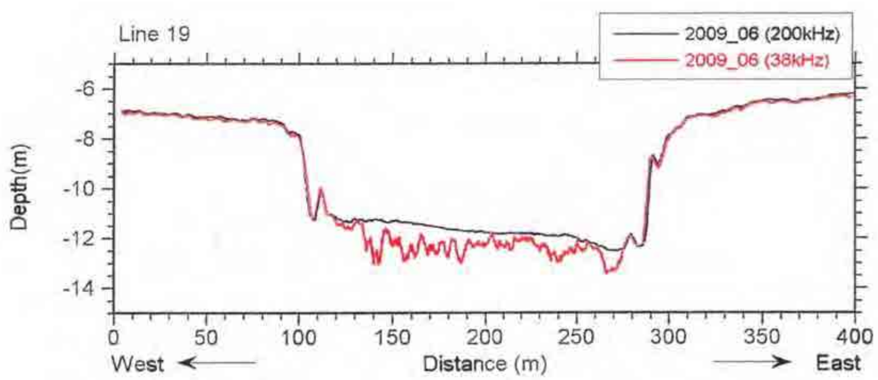


Figure 3.4 Transversal channel profiles with the acoustic signals of 38 kHz and 200kHz at L19 (SAPI, 2009)

There have been many arguments on the acoustic response of fluid mud layer to the low and high frequency sonic waves, but no quantitative conclusion has been obtained yet. Vertical mud sampling conducted during a period from 7 to 9 February, 2011, indicates the surface density of fluid mud layer is around 1.05 g/cm^3. Judging from the Team's experience in the SAPI and the present Project, the threshold density for activating the response of 38 kHz sonic waves seems to be around 1.05 g/cm^3, while the threshold density for the 200 kHz sonic waves seems to be around 1.03 g/cm^3 which is just above the seawater density with inclusion of turbid mud particles.

When maintenance dredging is undertaken, siltation process will take place immediately. During the early stage of siltation, there may be some difference in the acoustic response of the seabed with the sonic waves of 38 kHz and 200 kHz.

3.2 Seabed Mud Conditions

3.2.1 Sites and methodology of mud sampling

During the First On-site Works, mud sampling was made at five locations listed in Table 3.1. The sites A and B are located outside the basin and channel, while the sites C, D, and E are located inside the basin and channel. The site locations are shown in Figure 3.5.

Table 3.1 Locations of mud sampling sites.

No	KP (km)	*y* (m)	Approx. depth of mud surface layer (m)		Remarks
			As meas.	Ref. to DL	
A	0.20	+200	-8.7	-8.5	Outside basin
B	2.92	+200	-6.9	-6.7	Outside channel
C	0.20	0	-13.7	-13.5	Inside basin
D	2.92	0	-7.8	-7.6	Inside channel
E	15.91	0	-11.6	-11.4	Inside channel

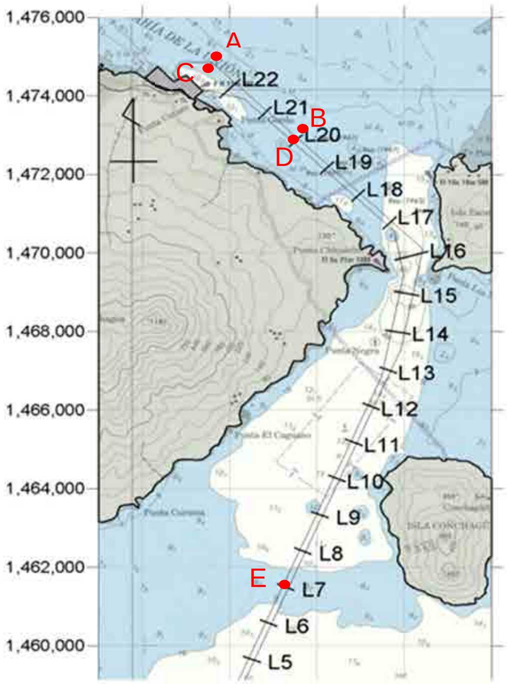


Figure 3.5 Location of sampling sites

At each site, a pair of 1ong polyvinyl-chloride pipe (1.5 m) and a short polyvinyl-chloride pipe (0.5 m) was vertically inserted into the mud layer by a pair of divers. The mud sampling was intended to catch the surface layer of fluid mud. The pipes were cut into sections of 0.3 m long on board (see Figure 3.6). The wet density of fluid mud was calculated with the weight of mud contained in the pipe by dividing it by the pipe's capacity.

(a) Cutting off the 0th and 1st sections.

(b) Splitting the 2nd and 3rd sections.

(c) Splitting the 3rd and 4th sections.

Figure 3.6 Cutting a sampling pipe into sections of 0.3 m long

3.2.2 Description of sampled mud and vertical density profile of mud layer

The mud content in each section was measured for its wet density, and then it was poured into a plastic bag with tight sealing (Ziplock) for later shipment to Japan. The pictures of mud samples placed in plastic bags are shown in Figure 3.7.

The measured wet density of mud layer is plotted against the mean depth of sampled layer below the seabed in Figure 3.8 for outside and inside the channel. Mud on the bank outside the channel has been left undisturbed for many years and well consolidated by its own weight. The trend of density change suggests that the mud wet density will exceed 1.4 g/cm^3 at the level of 0.7 m below the seabed.

On the other hand, the density of mud deposited inside the channel is low and its increase with depth is slow, as shown in Figure 3.8. The site D at the location of KP2.9 has a silted mud layer of about 7 m as indicated in Figure 3.3. The mud layer has been deposited in the past 2 years and it is still under the process of consolidation. The depth of threshold density (1.2 g/cm^3) would be nearly 2 m below the seabed.

(a) Mud sample from Site D
(2nd Section)

(b) Mud sample from Site D
(4th Section)

(c) Mud sample from Site B
(2nd Section)

(d) Mud sample from Site B
(4th Section)

Figure 3.7 Photographs of mud sample with its density

Around the site C at the location of KP0.20, the thickness of silted mud layer is about 4.5 m as seen in Figure 3.3. Around the site E at the location of KP15.91, the thickness of silted mud layer is also about 4.5 m, but the deposition since June 2009 is only 0.5 m thick. The thinner mud layer in the sites C and E than the site D may be the reason of the increase of mud wet density with the depth faster than that in the latter.

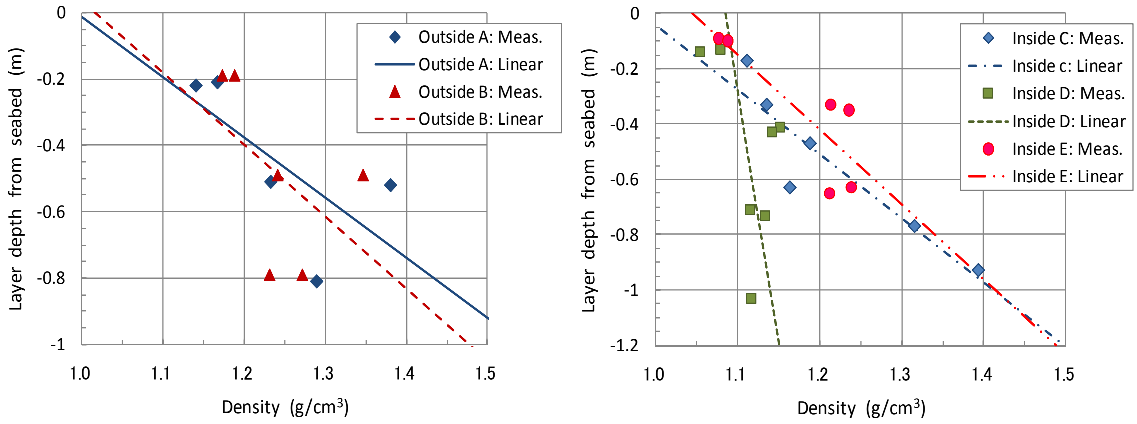


Figure 3.8 Vertical profile of mud wet density outside the channel (Left) and that inside the channel (Right)

3.2.3 Physical properties of sampled mud

The 40 mud samples were transported to Japan and detailed soil tests were commissioned to OYO CORPORATION. The wet density and moisture content were measured for all the samples, but other soil characteristics were investigated for the vertically mixed samples at respective sites because the mud properties are considered invariant to the depth.

The test results of the soil characteristics are listed in Table 3.2. These five samples represent the mud on the surface layer of 1.0 m below the seabed. The sample from the site D has the grain diameter much smaller than those at other sites and the higher plasticity index. It might have been caused by rapid inflow of fluid mud owing to a large depth difference there between the inside and outside of the channel.

Table 3.2 Soil characteristics at five sampling sites

Sampling site	Soil grain density ρ_s (g/cm^3)	Median diameter d_{50} (mm)	75% upper diameter d_{75} (mm)	Liquid limit w_L (%)	Plastic limit w_L (%)	Plasticity index I_P	Organic content c_0 (%)	Ignition loss L_i (%)
A	2.640	0.002	0.014	111.6	33.9	77.7	4.69	13.4
B	2.648	0.006	0.042	103.7	34.0	69.7	5.20	12.9
C	2.672	0.003	0.040	105.7	33.0	72.7	4.39	13.2
D	2.626	0.001	0.008	132.4	39.0	93.4	5.14	15.1
E	2.636	0.005	0.028	113.3	34.3	79.0	4.78	14.0

3.2.4 Numerical prediction of density profile change by means of mud consolidation process

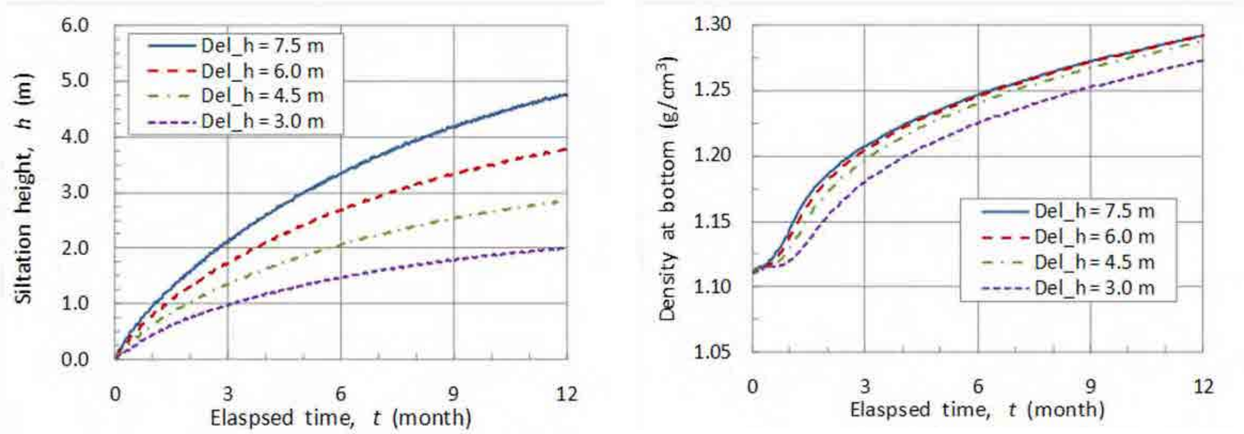
Fluid mud deposited in the basin and channel is a mixture of fine mud particles and sea water. Its initial density is somewhere between 1.05 to 1.10 g/cm^3. As time elapses, mud particles congregate together and their contact builds a 3D skeleton structure of mud particles. The weight of individual mud particles works as the load to the skeleton and squeezes out the water contained within the skeleton. Then the mud particle skeleton shrinks and the fluid mud wet density increases. This is the initial stage of mud consolidation.

Computation of mud consolidation process is made by solving the consolidation equation of one dimension along the vertical axis. The weight of mud layer is the sole load activating consolidation. Numerical computation of mud consolidation has been executed by Dr. Masaki

Kobayashi of Kobayashi SoftTech Co. Ltd.

Two series of mud consolidation computation have been undertaken. One series aimed at calibrating the consolidation prediction method. The other series simulated the siltation process in the access channel within 12 months after execution of maintenance dredging. Four levels of the depth difference between the inside and outside of the channel are employed for representing a possible range of depth difference from 3.0 to 7.5 m.

The predicted siltation height with the lapse of time is shown in Figure 3.9(a) and the time evolution of mud wet density at the channel bottom is shown in Figure 3.9(b). The increase of bottom mud wet density is fast at the first three months and the effect of initial depth difference is small. Figure 3.9(b) indicates that the threshold density of ρ_s = 1.20 g/cm^3 for nautical bottom will be reached in 3 to 4 months after dredging with the thickness of 1 to 2 m.



(a) Time evolution of siltation height after maintenance dredging.

(b) Time evolution of bottom mud wet density after maintenance dredging.

Figure 3.9 Time evolution of (a) siltation height and (b) bottom mud wet density after maintenance dredging

3.2.5 Assessment of thickness of fluid mud layer for definition of nautical bottom

The main objective of mud consolidation analysis is to make assessment of the thickness of fluid mud layer with the density below ρ_s = 1.20 g/cm^3 = 1,200 kg/m^3, which is taken as the threshold density for defining the nautical bottom.

For the assessment of fluid mud layer thickness, it would be safe to assume the thickness of 0.5 m for the Outer channel in consideration of additional loading by waves. For the inner access channel, it is taken as h = 1.0 m on the safe side in consideration of the in-situ data at the site C, even though the consolidation analysis suggests larger depth up to 2.0 m.

3.3 Main Results of the Field Survey

In this chapter, results of bathymetric surveys and analysis of mud property have been summarized. Main findings from the surveys are as follows:

- From the bathymetry survey results, it is confirmed that both the inner channel and the outer channel have already filled with the sediment and the channel depth is presently the almost same level as the outside depth of the channel.

- Judging from the Team's experience in the field, it is considered that the echo sounder of 200 kHz in frequency detects the top surface of the fluid mud layer. The depth navigable for vessels is considered to be deeper than the depth measured by the echo sounder of 200 kHz, due to the thickness of the fluid mud layer.

- The fluid mud layer in the channel continues in existence for relatively long period. This indicates a possibility to reduce maintenance dredging volume by making a maintenance dredging plan taking the fluid mud layer into account.

- From the analysis of mud sampled at about two years after capital dredging, it is confirmed that fluid mud layer, the wet density of which is less than 1,200 kg/m3, is formed with the thickness of about 0.5m in the outer channel and about 1.0 m in the inner channel.

Chapter 4 Analysis of Siltation Process and Prediction Models

Chapter 4　Analysis of Siltation Process and Prediction Models

4.1 Collected Data

The data collected for analyses of siltation processes are the bathymetric data and the records of dredging. Figure 4.1 shows the periods of dredging and the times of bathymetric surveying. Newly obtained bathymetric data, July, 2013, is partly included in the analyses.

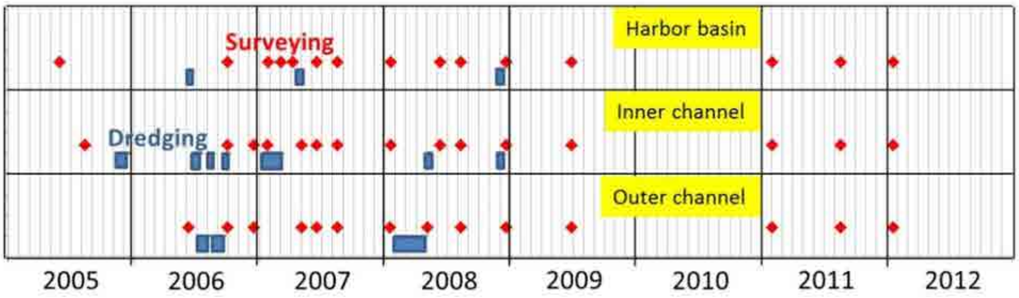


Figure 4.1 Period of dredging and times of bathymetric surveys

4.2 Siltation Speed and Depth Difference in the Channel (Exponential model)

Figure 4.2 shows the changes of water depth at representative reference lines (Figure 4.3) in the Inner and the Outer channels, in which a brown line is the mean water depth in the channel, a blue and a green line are the depths at the western and eastern banks of the channel, respectively. The periods of dredging are indicated by the gray and orange belts. From this data, it is easily understood that the siltation occurred after the dredging.

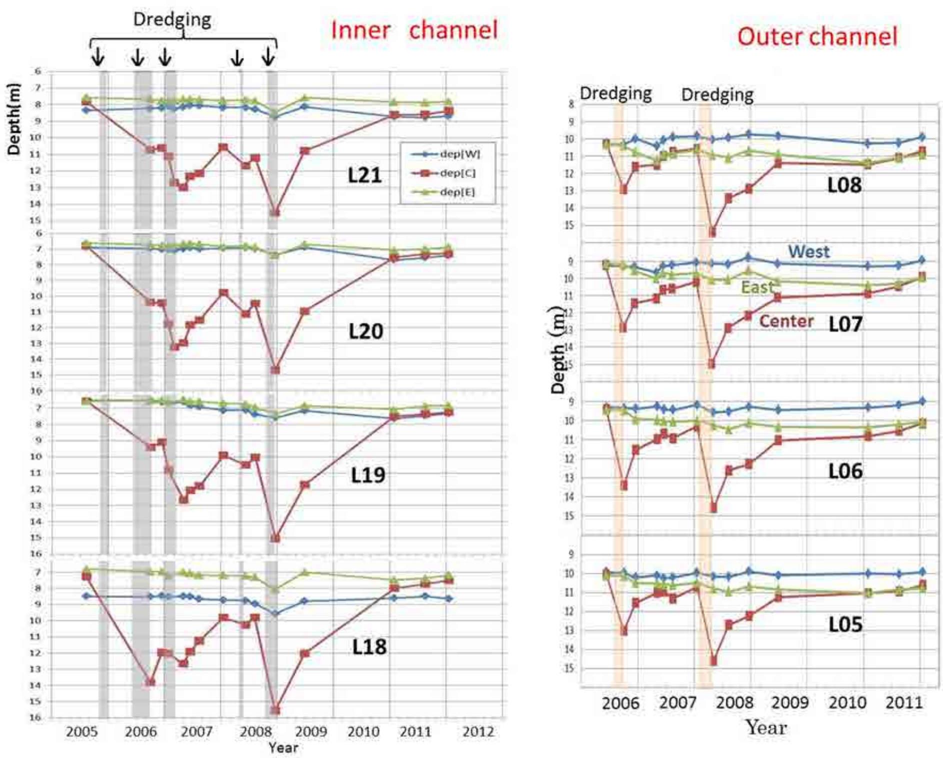


Figure 4.2 Changes of water depth in the Inner and the Outer Channel

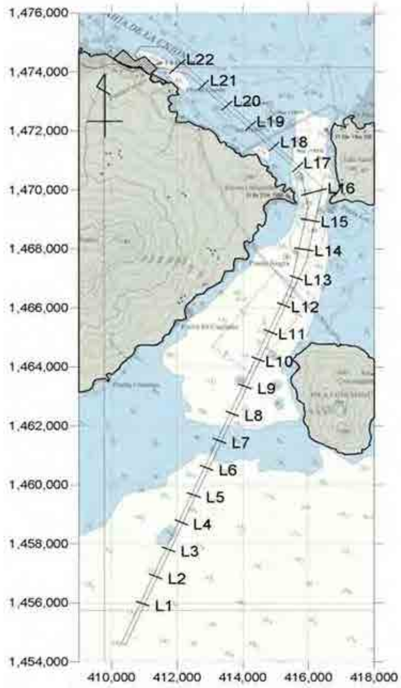


Figure 4.3 Bathymetric survey lines of access channel

Figure 4.4 shows the relationship between the siltation speed and the mean depth difference Δh (m) between the inside and outside channel depths. The definition of water depths is shown in Figure 4.5.

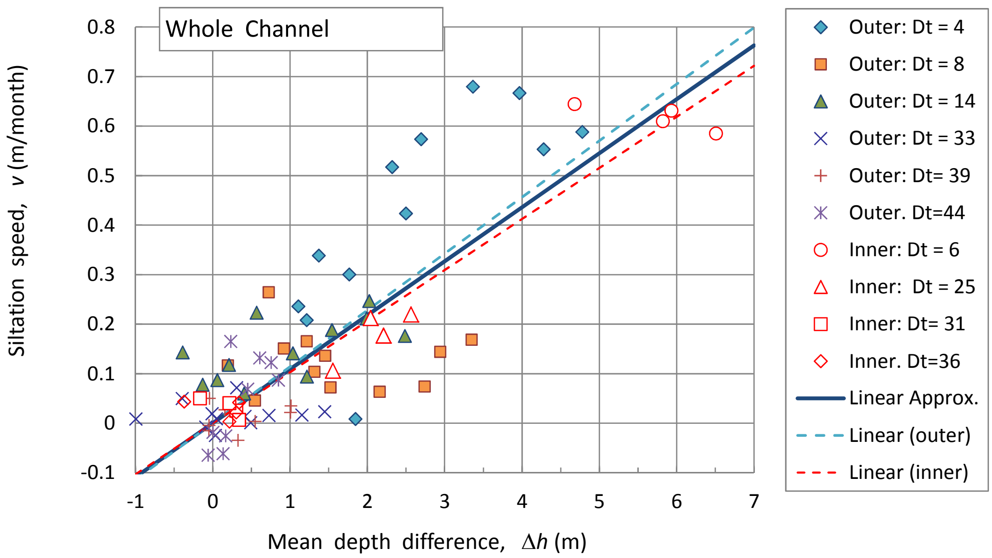


Figure 4.4 Siltation speed versus the depth difference inside and outside the access channel.

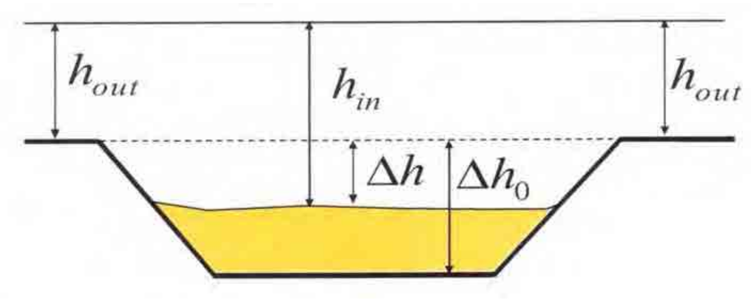


Figure 4.5 Definition of water depths

A linear regression line is tentatively drawn for the Inner and Outer channel as follows:

$$v = -\frac{d\Delta h}{dt} = 0.109\ \Delta h \qquad : \Delta h = h_{in} - h_{out} \qquad \text{: Access channel} \qquad (4.1)$$

The empirical formula of Eq.(4.1) is easily integrated for derivation of a prediction formula of the depth difference Δh as in the following:

$$\Delta h = \Delta h_0 \exp[-at] \qquad (4.2)$$

where a is assigned the value of 0.109 for the access channel. Hereinafter Eq. (4.2) is referred to as “the original Exponential Model”.

4.3 Analyses of Siltation Processes in Channel

4.3.1 Siltation in Inner Channel

Figure 4.6 shows the changes of water depths on the reference lines from L21 to L18. The water depth linearly changed on all reference lines in the Term A. On the other hand, the water depth in the Term B became shallower with relatively high speed just after the dredging, which is denoted by a red arrow for the data on the reference line L21 as an example in Figure 4.6, and the speed became slower with a decreasing of water depth.

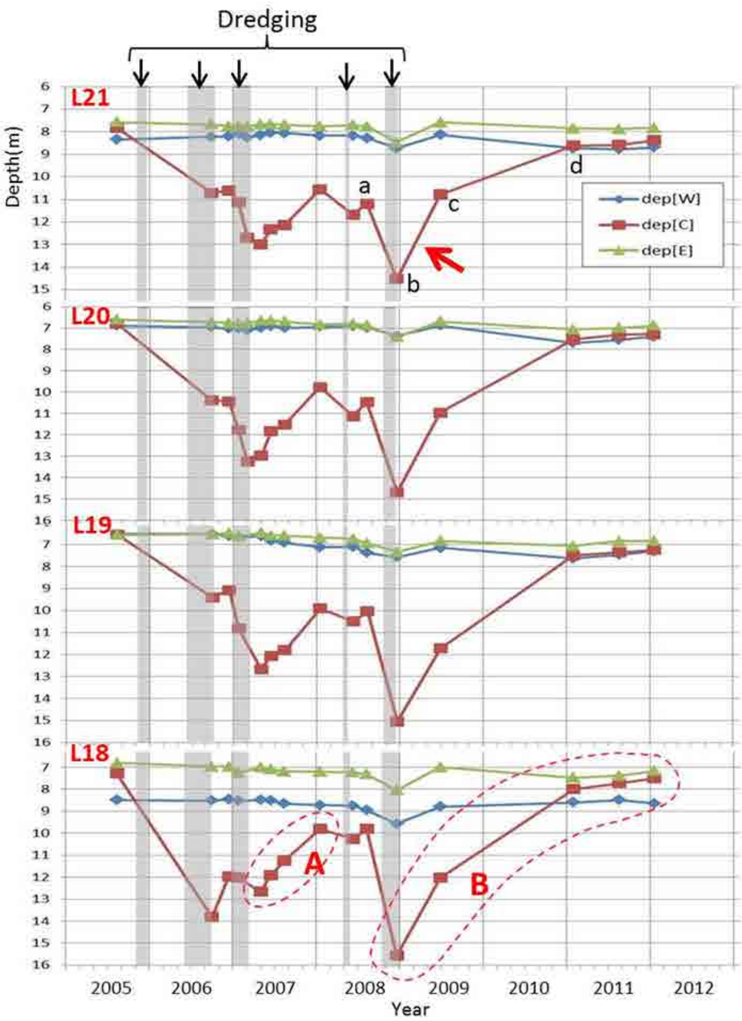


Figure 4.6 Changes of water depth on the reference lines from L21 to L18 in Inner channel

The speed of sedimentation was faster just after the dredging. In order to check the situation in detail, three cross sections are superimposed in Figure 4.7 for the reference line L21. They are the cross section before the dredging in August, 2008 (which is denoted by “a” in Figure 4.6), that of December, 2008 just after the dredging (“b”) and that of 6 months after dredging in June, 2009 (“c”).

The cross section “a” and “c” are very similar to each other. However, the cross section “b” is different from them in two points. First point of difference is the channel depth, which was due to the dredging of course. The second point is elevation of the tops of slope which is surrounded by red broken lines in Figure 4.7. The elevation of the tops of slope just after the dredging (“b”) is about 60cm lower than those of remains, which is undoubtedly unnatural. There are the same unnatural downward shifts of data on the remaining reference lines. It is probably due to some systematic error such as an inappropriate correction for the tide level or a mistaken of datum level.

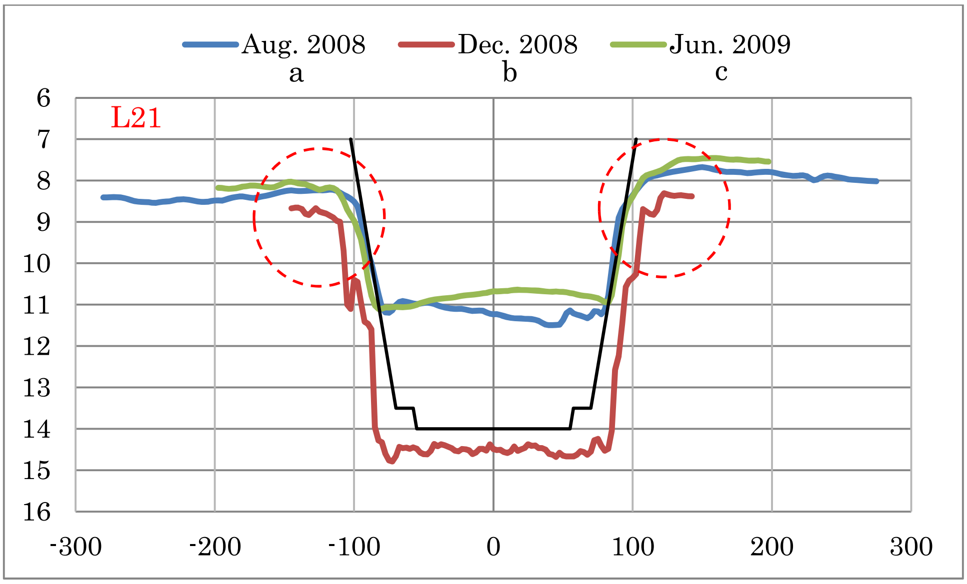


Figure 4.7 Superposition of cross section along L21

In Figure 4.8, the cross section just after the dredging has been shifted by 60cm upward so that three cross sections are well overlapped. As a result, the consistency of cross sections as the whole is improved well. This correction is considered to be well adequate.

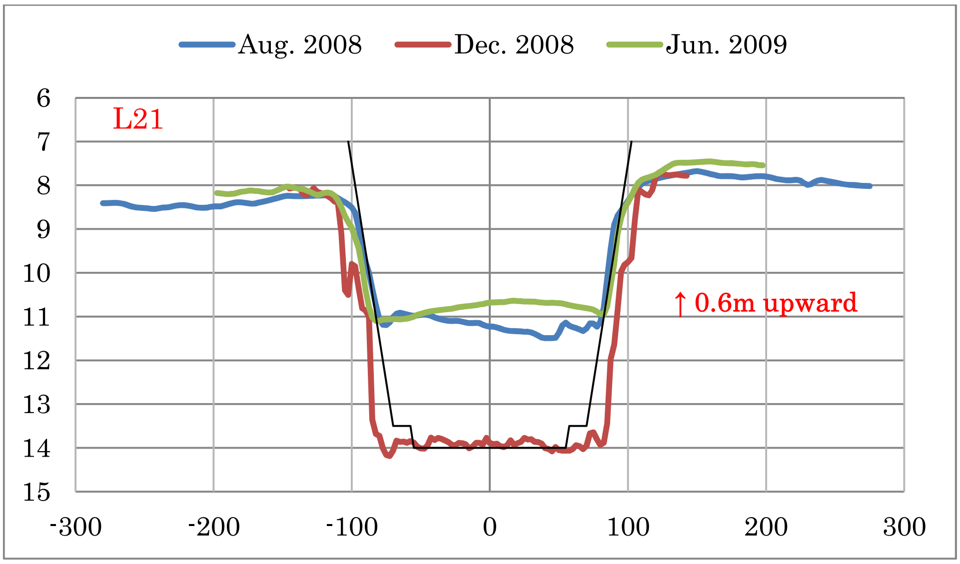


Figure 4.8 Superposition of cross sections after shifting, for L21
(Cross section in December, 2008 is shifted by 0.6m upward)

4.3.2 Siltation in Outer Channel

Figure 4.9 shows the changes of water depths on the reference lines from L08 to L05 in the Outer channel. The mean depth in the Outer channel became deeper due to the dredging. Just after the dredging, the water depth rapidly became shallow and it gradually became shallower with a constant speed as approximated by the straight broken lines in the following period. These two processes have been considered simultaneously in the original Exponential Prediction Model.

In June, 2006, before the dredging, the mean water depth in the Outer channel, the water depth of the western and the eastern banks were of equal. At the outside of the Outer channel, the water depth was kept almost constant on the western bank, while it increased gradually on the eastern bank. The water depth in the channel became shallower with time due to the siltation up to the same elevation as the eastern bank, which is lower than its original elevation before dredging in 2006.

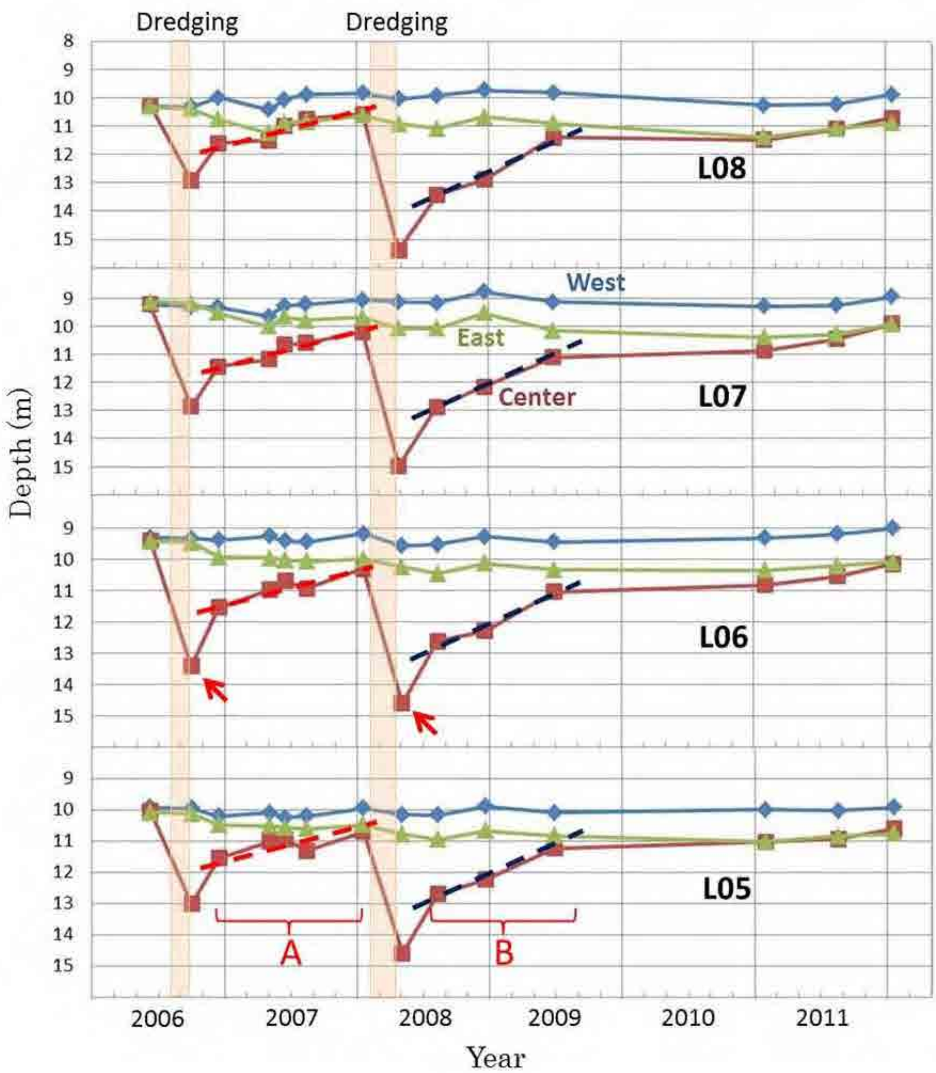


Figure 4.9 Changes of water depth on the reference lines from L08 to L05 in Outer Channel

Next, the feature of cross section in full-sedimentation is examined on the reference lines of L08 to L05. The three kinds of the bathymetric data are utilized, that is,

1. Data obtained on 10 June, 2006; before the first dredging,

2. Data obtained on 18 January, 2008; about 1 year and 4 months after the first dredging in 2006,

3. Data obtained on 01 February, 2011; about 2 years and 8 months after the re-dredging in 2008.

Figure 4.10 shows the superposition of three cross sections along the reference lines. A black line is a planned channel section, toward which the dredging were conducted in 2006 and in 2008.

The sea bottom was flat in June, 2006, which was a situation before dredging. The first stage dredging was completed by 24 September, 2006. In January, 2008, the Outer channel was almost full with sediments. The volume of sedimentation was larger in the western area than in the eastern area of the channel. Outside the channel, the sea bottom did not changed in the western area, while in the eastern area the sea bottom was eroded by January, 2008 and further by February, 2011. It is the most important and interesting situation that the water depth in the channel is usually equal to or deeper than that of eastern bank on the every reference line.

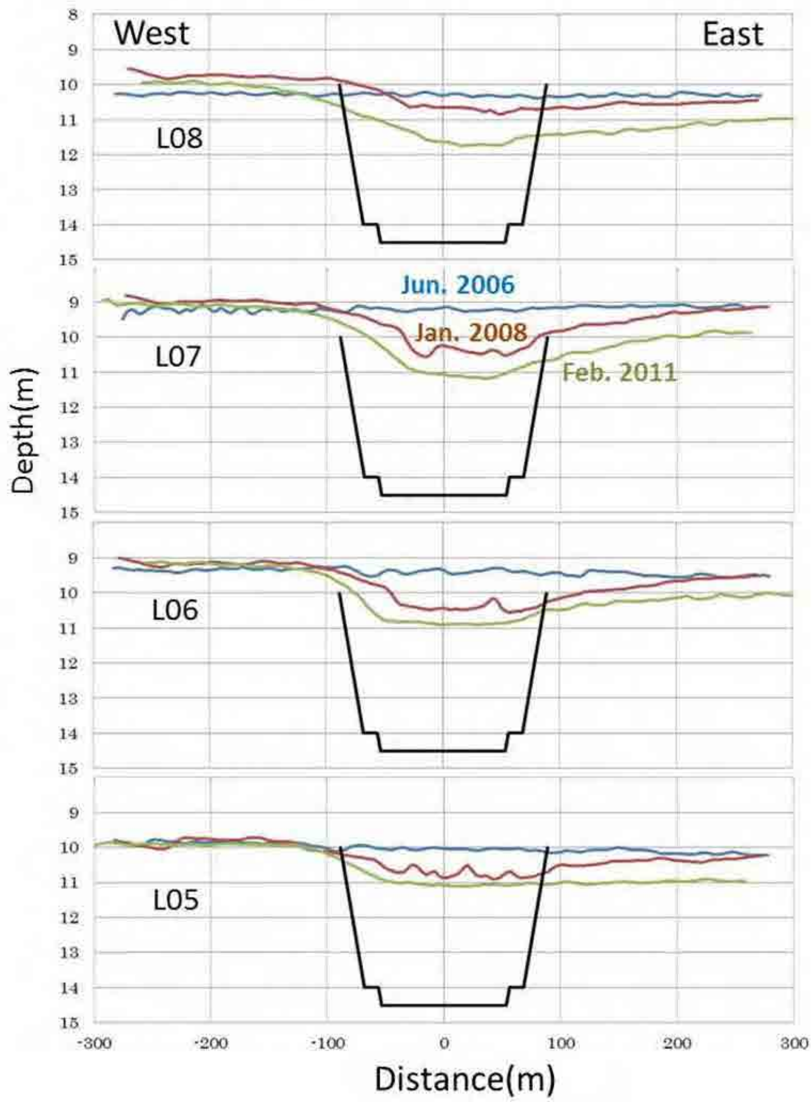


Figure 4.10 Situation of full-sedimentation along L08～L05 in Outer Channel

4.3.3 Physical consideration for rapid siltation just after dredging

Let's see Figure 4.9 again. The rapid siltation occurred two times, just after the first dredging and the second dredging. In the former rapid siltation occurred between the depth of 12 and 13 meters, while in the latter it occurred around the depth of 14 meters. Then an occurrence of rapid siltation does not depend on the water depth, but depends on the timing of just after the dredging.

Figure 4.11 shows the superposition of cross sections along the reference lines from L08 to L05, which were surveyed on 24 April and 5 May, 2008, just after the completion of second dredging in 2008. Although there are small leaving parts of unexcavated earth in the cross sections on reference lines L08 and L07, the channel was dredged almost more than planned cross section.

Figure 4.12 shows the cross sections at the time of about 3 and half months after the dredging, 11 August, 2008, in which it can be seen that the rapid siltation occurred with the embedding thickness of 1.5 to 2 meters during this period. As accumulations were horizontal in the full width of channel on all reference lines, and there is no deposition on the side slope, it is inferred that high fluidity material, e.g. fluid mud, deposited in the channel. In short, just after the dredging, it is within the bounds of possibility that the rapid siltation occurred due to the inflow of high fluidity sediment which existed in the area surrounding the channel before dredging.

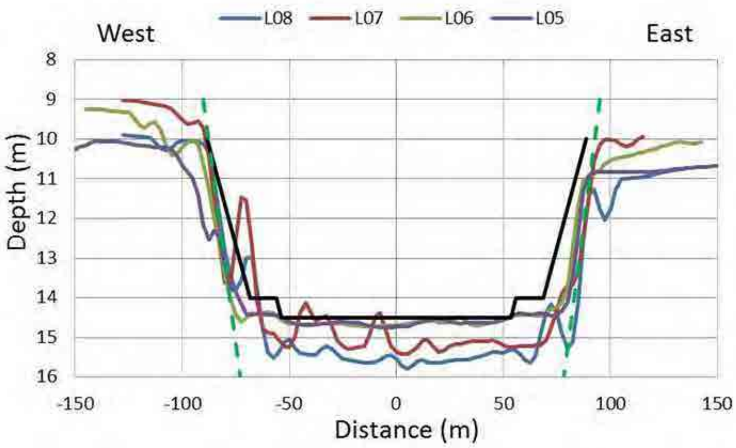


Figure 4.11 Superposition of cross sections just after the second dredging, (Surveyed on 28 April and 5 May, 2008)

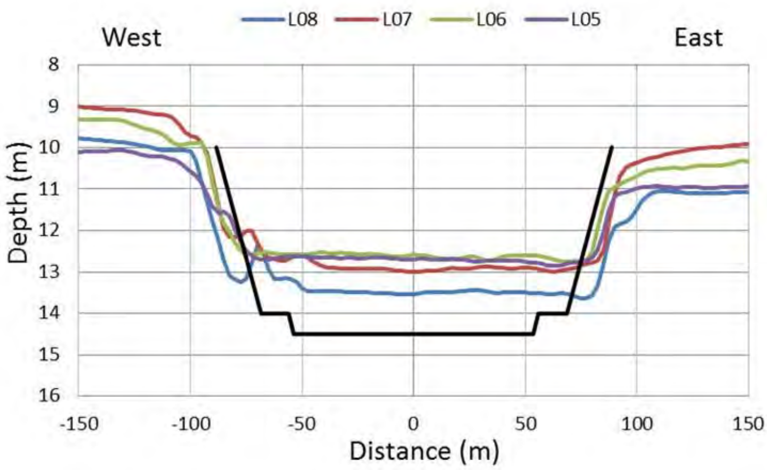


Figure 4.12 Superposition of cross sections, 11 August, 2008, about 3 and half months after the dredging

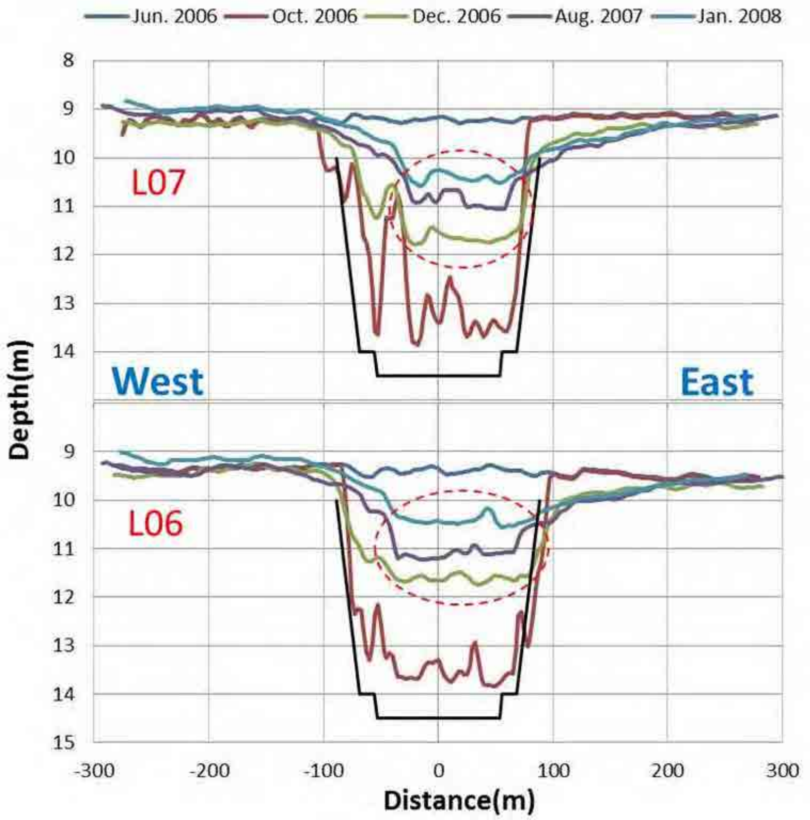


Figure 4.13 Superposition of cross sections along L07 to L06

Next, the slow siltation with a constant speed is examined. Figure 4.13 shows the superposition of cross sections along the reference lines of L07 and L06. During a period from December, 2006 to January, 2008, the siltation occurred slowly with the constant speed. From the changes of cross sections, it can be seen that the sediment accumulates from the west bank to the west-side area of channel, which is due to the deposition of the coarse material having the high falling velocity, and the erosion occurred at the east bank. More knowledge we can obtain from Figure 4.13 is a situation that the accumulation continues with rising of the flat and horizontal bed in the east side in the channel which is surrounded by red broken lines. This is considered to be due to the deposition of sediment having high fluidity, e.g. fluid mud, in the east side in the channel.

In the first stage of the rapid siltation in a few months just after the dredging, the accumulation with high fluidity sediment were horizontal in the full width of channel, while in the second stage of slow siltation, the deposition of coarse material on the western side-slope and the sea bottom erosion on the eastern bank, and the siltation of high fluidity sediment such as fluid mud occurred simultaneously. By taking these situations into account, it is inferred that the characteristics of sediment deposited in the Outer channel is as shown in Figure 4.14. In short, during a period just after the dredging, high fluidity material such as the fluid mud rapidly flowed into the channel and deposited horizontally there. After that, on the western side-slope the coarse material having the high falling velocity accumulated, while the sediment having the high fluidity such as the fluid mud deposited in the east side in the channel.

As explained in Figure 4.9, the rapid siltation just after the dredging does not depend on the channel depth, but on the timing of dredging. Then, the rapid siltation just after the dredging is considered to be due to inflow of very movable sediment which existed surrounding the channel before excavation. If so, the rapid siltation may be the bound phenomenon only once in the channel newly excavated, and it does not occur in the case that the maintenance dredging is continuously conducted.

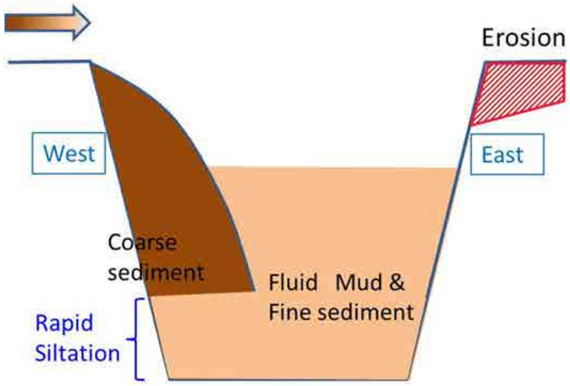


Figure 4.14 Spatial distribution of sedimentation

4.4 Siltation Prediction Models for Channel

4.4.1 Modifications of original Exponential Model

(1) Modification for Inner Channel

The water depth in December, 2008, just after the second dredging, was deepest in the Inner channel during a period from 2006 to 2011. As the corresponding data was shifted downward, as shown in Figure 4.7 by example, it has been corrected by shifting upward. The results of correction to the reference lines L21 to L18 are shown in Figure 4.15, in which the original data in the Inner channel reproduced from Figure 4.4 are denoted by the symbol ○ and the corrected data are plotted by the symbol ●. As the whole data of cross section are shifted upward, the depth difference between inside and outside of channel does not change on an abscissa, while the siltation speed decreases on an ordinate.

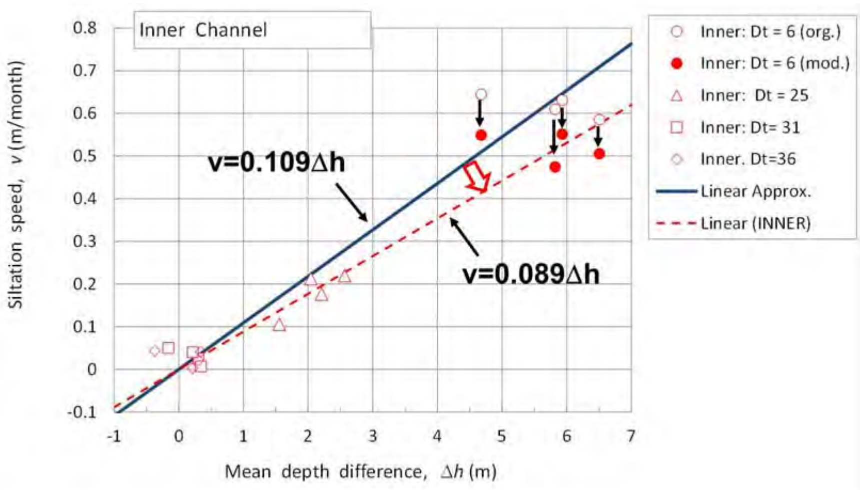


Figure 4.15 Siltation speed versus the depth difference in the Inner channel, after the correction of data

As seen in Figure 4.15, the slope of linear relation between the siltation speed and the depth difference decreases from *a*=0.109 to

$$a=0.089, \tag{4.3}$$

which is introduced into Eq. (4.2) for the Inner channel.

Figure 4.16 shows a comparison of the predicted curves by the original Exponential Model in the upper and by the modified one in the lower with the actual water depth in the Inner channel. The depth data corresponding to correction are surrounded by the red broken lines. After the modification of the original Exponential Model, in the lower figure, the slope of predicted curve around the depth from 9 to 14 meters becomes a little bit gentler than that of the original one, which means a decrease of siltation speed.

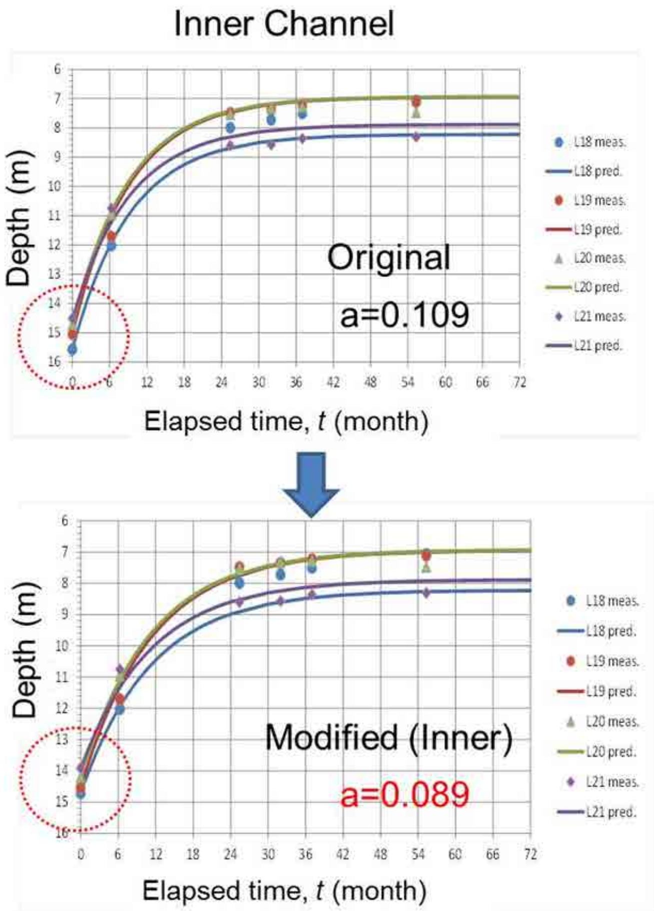


Figure 4.16 Comparison of original and modified Exponential Model with the actual depth (for Inner channel)

(2) Modification for Outer Channel

In the Outer channel, a shoaling of water depth due to siltation approaches asymptotically to the elevation of the eastern bank. Because the eastern bank is eroded after dredging, the water depth is deeper than that of before dredging. If the channel is left further without a maintenance dredging, the water depth will recover to the original depth before long, which is the same depth as that of the western bank. It is, however, considered that the depth of eastern bank is usually deeper than that of western bank when a maintenance dredging is conducted continuously.

The simplest method for taking the effect of eastern bank is shown in Figure 4.17. The water depth outside the channel, h_{out}, and the depth difference between inside and outside the channel, Δh_0, in the original Exponential Model are replaced with h_e and Δh_{0e} respectively, which are defined in Figure 4.17. The water depth at the east bank, h_e, is called “final depth” hereinafter. The coefficient is fixed without change, being a =0.109.

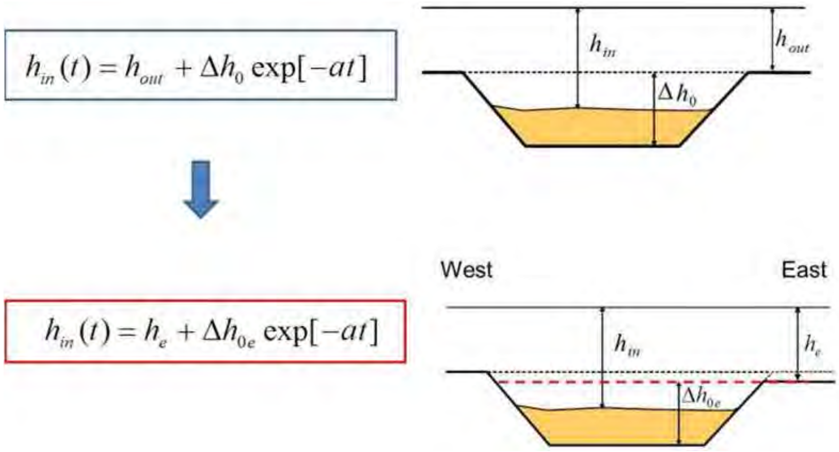


Figure 4.17 Modification of Exponential Model by introducing a concept of final depth (for Outer Channel)

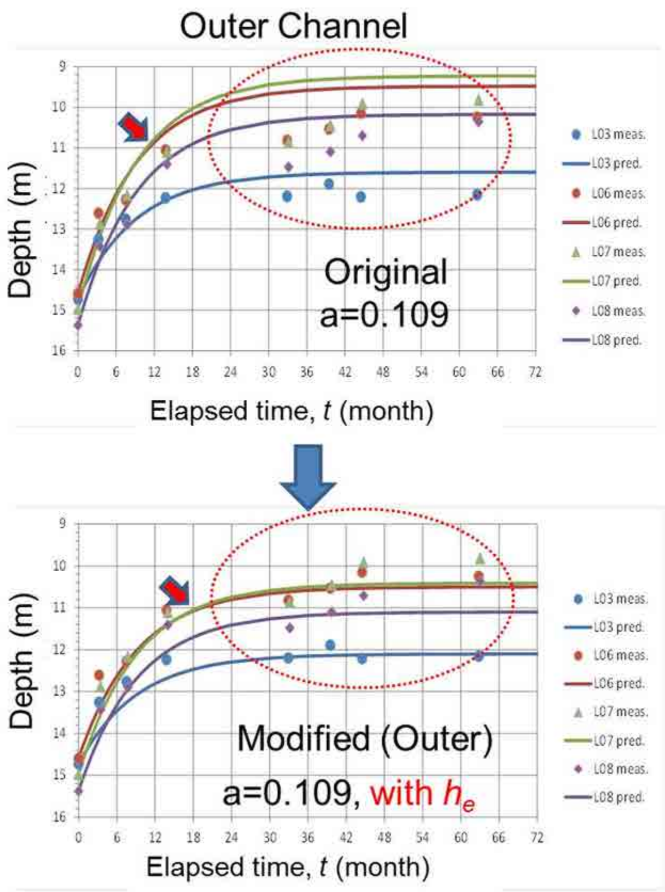


Figure 4.18 Comparison of original and modified Exponential Model with the actual depth (for Outer Channel)

Figure 4.18 shows a comparison of the predicted curves by the original Exponential Model in the upper and by the modified one in the lower with the actual water depth in the Outer channel. By introducing the final depth in the model, the predicted curve and the actual water depth become to almost agree in the shallow area surrounded by a red dotted line. Furthermore, paying attention to the points denoted by red arrows in the figure, concerning to the reference lines of L07 and L06, it takes 12 months to shoal up to the depth of 11meters in the original model while it takes 18 months in the modified model. In short, the modification for the Outer channel also makes the siltation speed slow.

4.4.2 Linear model

In section 4.2, it is explained that the siltation process in the Outer channel can be divided into two successive stages, that is to say, the rapid siltation just after the dredging and the slow siltation in the following period. The rapid siltation might be the bound phenomenon only once in the newly excavated channel. If this be so, the rapid siltation does not occur in the case that the maintenance dredging is continuously conducted. In the second stage of slow siltation, the speed of siltation is constant without depending on the water depth in the channel. As for a trial, a tentative linear model is formulated by picking up only the convenient data, which are the data such as that lying on the dotted lines in Figure 4.19.

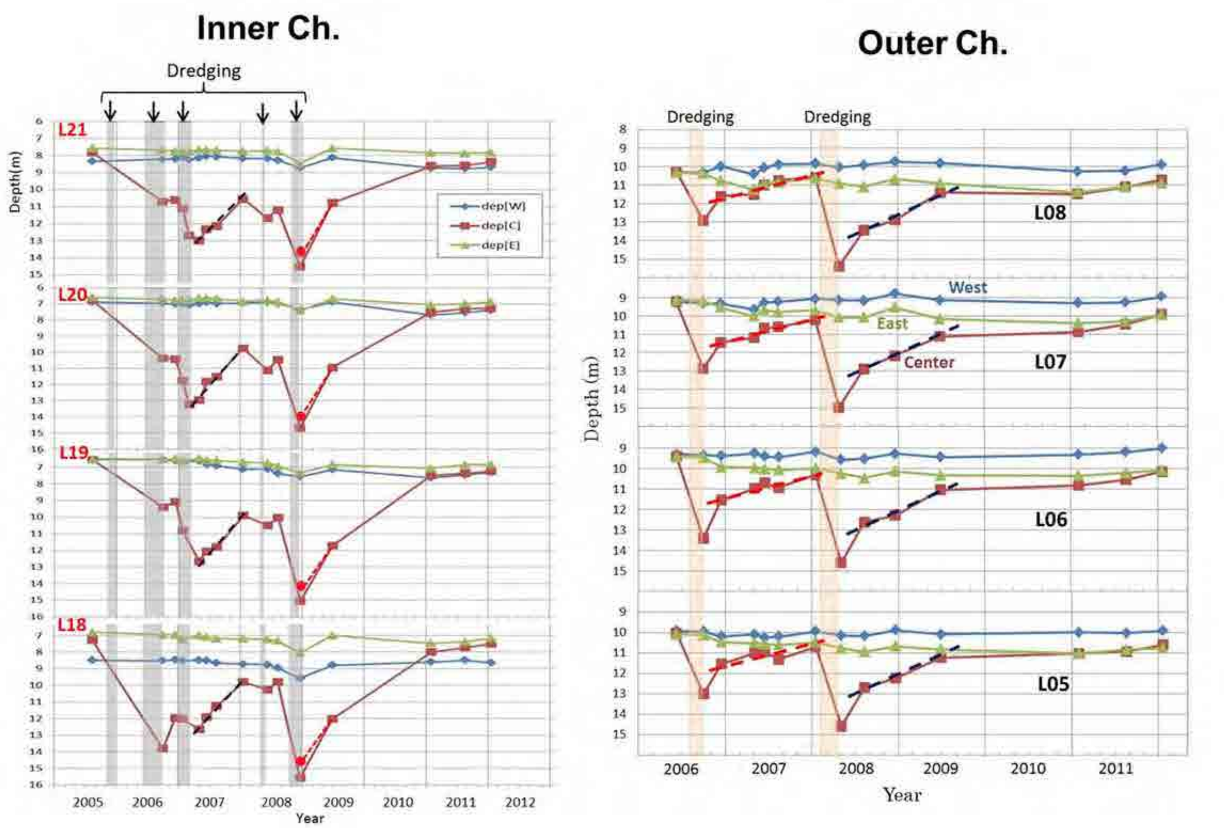


Figure 4.19 Time variations of channel depth for Inner and Outer Channels

The mean siltation speed for Inner channel is 0.39 m/month in average, and that for Outer channel is 0.14 m/month;

$$v = -\frac{dh}{dt} = \begin{cases} 0.39 & \text{(Inner channel)} \\ 0.14 & \text{(Outer channel)} \end{cases} \tag{4.4}$$

By integrating Eq.($v = -\frac{dh}{dt} = \begin{cases} 0.39 & \text{(Inner channel)} \\ 0.14 & \text{(Outer channel)} \end{cases}$ (4.4), the water depth in the channel is obtained as the linear expression of the elapsed time,

$$h = h_0 - vt \tag{4.5}$$

where h is the depth in the channel, h_0 is the initial channel depth, t is the elapsed time after dredging (unit in months). Equation (4.5) represents that the depth changes linearly with time and hereinafter we call it 'Linear Model'.

Since the Linear Model does not take into account the phenomenon of rapid siltation, it predicts the slower siltation speed than that predicted by the Modified Exponential Model when the water difference between inside and outside the channel is large. Meanwhile, however, when the water difference is small, it predicts the faster speed than those of measured one. Furthermore, after a time elapses, it yields the conflicting situation that the water depth inside the channel becomes shallower than that of outside. In order to avoid this discrepancy and to increase the conformity with the data, the Linear Model has been connected to the Modified Exponential Model in the area where the depth difference is small. Specifically, a continuity of both models is secured by the siltation speed as shown by solid lines in Figure 4.20.

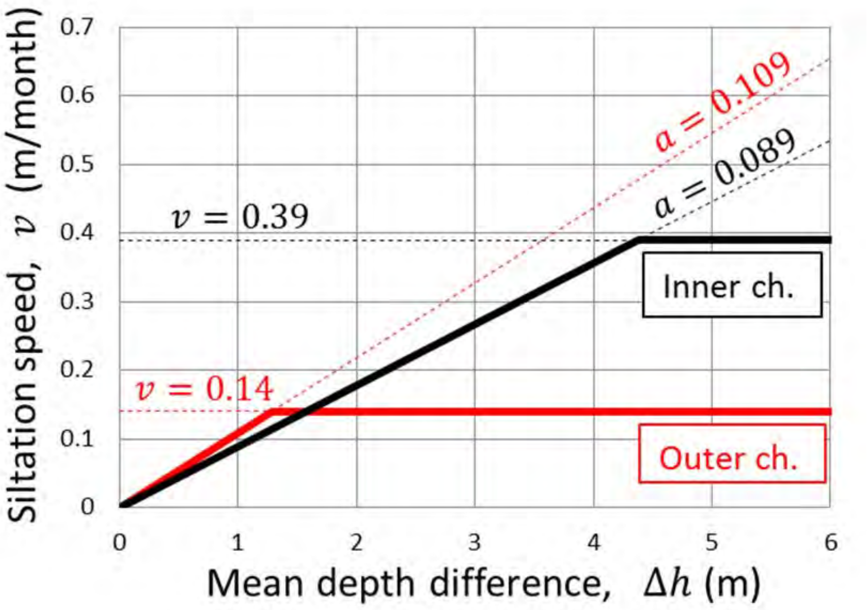


Figure 4.20 Connection of Linear Model to modified Exponential Model

4.4.3 Applicability of two models

The modified Exponential Model can be adopted for predicting the change of water depth after the re-dredging and in the maintenance dredging.

There is a possibility that the Linear Model could be applied to predict the siltation volume when the dredging is being conducted continuously. It is very important, however, to stress that the

Linear Model is formulated as for a trial. There is still a big hypothesis that the rapid siltation just after the dredging might be the bound phenomenon only once in the newly excavated channel. Then, we must refrain from the use of the Linear Model until the hypothesis is verified with the bathymetric data, or the applicability of Linear Model is confirmed with the data.

4.5 Siltation Prediction model for Harbor Basin and Port Channel

Siltation also occurs in the harbor basin. Unfortunately there is no more available bathymetric data to establish an empirical prediction model for siltation in the basin. Then, the prediction model of exponential type, Eq. (4.6), for the Outer channel, in which the concept of the final depth is considered, is applied to the harbor basin.

$$\Delta h = \Delta h_e + \left(\Delta h_{0e}\right)\exp[-at] \qquad (4.6)$$

where Δh_e is the final depth difference between inside and outside the port channel and harbor basin. The final depth Δh_e is determined at a location to a location based on the obtained bathymetric data.

Chapter 5 Estimation of Dredging Volume and Cost

Chapter 5 Estimation of Dredging Volume and Cost

5.1 Re-Dredging volume

In the case of La Union Port, the harbor basin and channel have been already filled with a large amount of mud and must be re-dredged before the start of maintenance dredging. It is hereby called the re-dredging. The re-dredging volume is estimated based on the latest bathymetric survey results at July 2013.

The total volumes of the re-dredging for six target navigation depths of D.L.-9 to D.L.-14 m varying by 1 m were estimated as listed in Table 5.1. The re-dredging volume is calculated taking the channel shape as shown in Figure 5.1 into account. It is also noted that the re-dredging volume include neither over-dredging volume nor overbreak volume, where the over-dredging means dredging to deal with siltation and the overbreak means an extra excavation to make the bed level lower than the plan shape at construction.

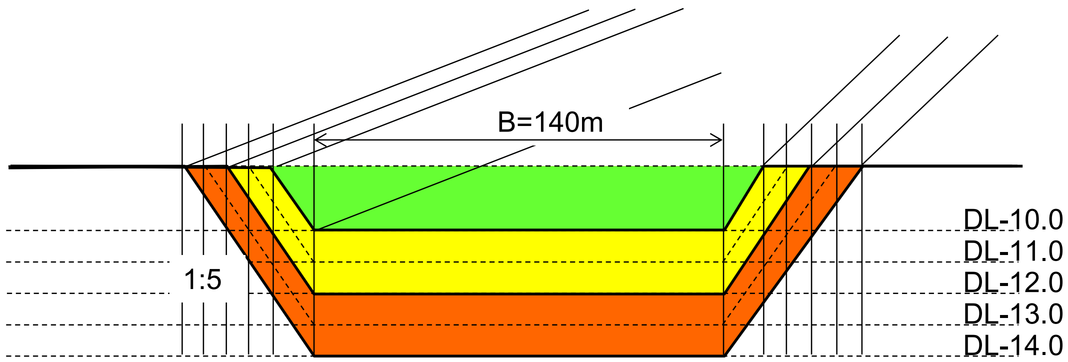


Figure 5.1 Channel Shape for re-dredging volume calculation

Table 5.1 Estimated re-dredging volume (units: 1000 m^3)

Depth (m)	Outer Ch.	Inner Ch.	Basin	Total
D.L.-9.0	0	895	0	895
D.L.-10.0	25	1,535	59	1,619
D.L.-11.0	404	2,215	344	2,964
D.L.-12.0	1,161	2,936	798	4,895
D.L.-13.0	2,284	3,696	1,471	7,452
D.L.-14.0	3,882	4,496	2,186	10,565

5.2 Maintenance dredging volume

5.2.1 Navigable depth

Figure 5.2 shows the definition of navigable depth. In this study, the navigable depth is defined as the depth including fluid mud layer, the density of which is less than 1200 kg/m^3. Based on the survey result described in Chapter 3, the thickness of fluid mud layer is set as 1.0m for the Inner channel and 0.5m for Outer channel and harbor basin.

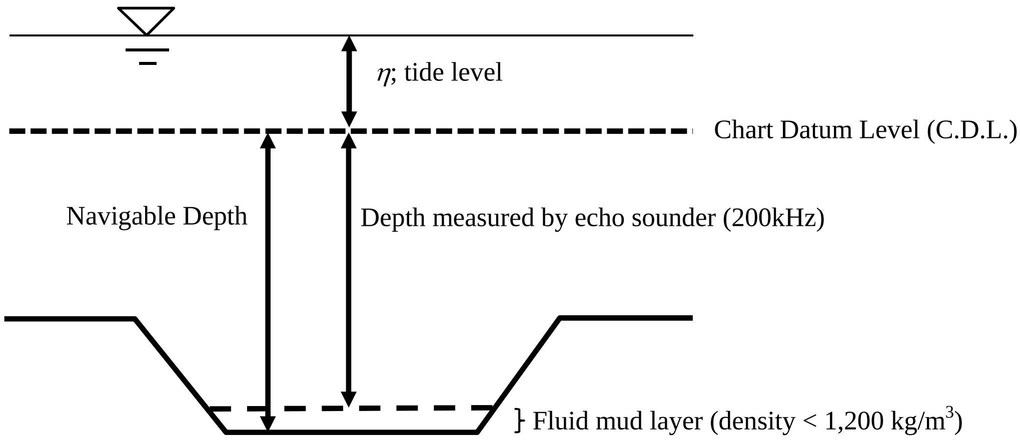


Figure 5.2 Definition of the navigable depth and the measured depth

5.2.2 Estimation method of maintenance dredging volume

In Chapter 4, the siltation speed was analyzed based on the previous bathymetric survey results and two prediction models of the modified Exponential Model and the Linear Model have been formulated. The two models are applied to estimate maintenance dredging volume.

Table 5.2 Siltation prediction models to estimate maintenance dredging volume

Prediction Model	Remarks
1. Modified Exponential Model	$V=a\Delta h$ ● a=0.089 (Inner ch.) ● a=0.109 (Outer ch.) with final depth (h_e)
2. Linear Model	$V=\min(a\Delta h, V_{max})$ ● V_{max} = 0.39 m/month (Inner ch.) ● V_{max} = 0.14 m/month (Outer ch.)

The dredging volume must be proportional to the siltation depth during the maintenance dredging cycle time. When the depth difference between the target channel depth and the outside depth is denoted by Δh_{tar} and the maintenance dredging is carried out with the cycle time of T months, the required dredging depth of D_X, which includes over-dredging, is calculated as,

1) <u>Modified Exponential Model</u>

$$D_X = \Delta h_{tar} \exp[aT] \quad \text{for Inner channel} \tag{5.1}$$

$$D_X = \Delta h_e + (\Delta h_{tar} - \Delta h_e)\exp[aT] \quad \text{for Outer channel, Port Channel and Basin} \tag{5.2}$$

2) <u>Linear Model</u>

$$D_X = v_{linear}\ T \tag{5.3}$$

where a is assigned the value of 0.089 for inner channel, and 0.109 for outer channel, port channel, and basin, Δh_e is the depth difference between the final depth and the outside depth (=

$h_e - h_{out}$), and v_{linear} is the constant siltation speed of the Linear Model and is assigned 0.39 m/month for inner channel or 0.14 m/month for outer channel.

Figure 5.3 shows the process of dredging and rise of channel bottom. To illustrate the use of Eq. (5.1), the location of L20 (KP2.9) with the assumed outside depth of DL-6.9 m is taken. If the target navigation depth is DL-11.0 m, the depth difference is Δh_{tar} = 4.1 m. Here, if the fluid mud layer of 1.0m is taken into account, the depth difference is assumed as Δh_{tar} = 3.1 m. For the dredging cycle time of T = 6 months, the initial depth difference of D_X = 5.3 m must be secured and therefore the initial target dredging depth is DL-12.2 m. Within the maintenance cycle time of 6 months, the channel bottom will gradually rise and finally reach DL-10.0 m, where the navigable depth is DL-11.0m. After 6 months, the channel will be re-dredged to DL-12.2 m again.

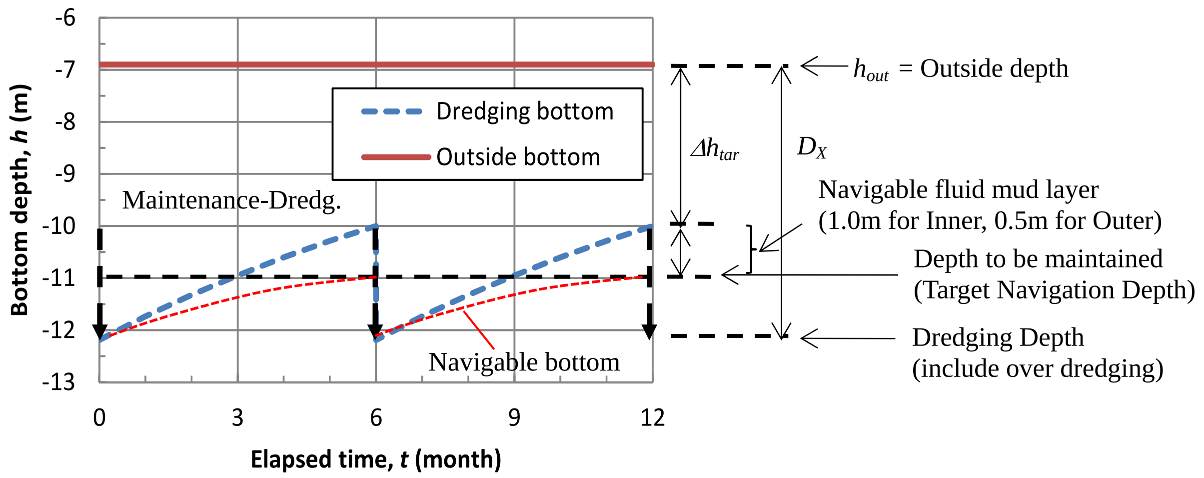


Figure 5.3 Sketch of rise of channel bottom between maintenance dredging.

5.2.3 Maintenance dredging volume by depths

The maintenance dredging volume is calculated for six levels of the target depth: i.e., DL-9.0 m, DL-10.0 m, DL-11.0 m, DL-12.0 m, DL-13.0 m, and DL-14.0 m. The cycle time of successive maintenance dredging, is set at 3, 4, 6, or 12 months. The volume of maintenance dredging at a specified cycle time and a target navigation depth is estimated by the two prediction models: the modified Exponential Model and the Linear Model. The results by modified Exponential model are shown in Table 5.3, for example.

Figure 5.4 shows all calculation results of annual dredging volume with respect to the target depth. The volumes estimated by the modified Exponential Model are represented by blue symbols and those by the Linear Model are represented by orange symbols. The curves on the diagram are drawn to connect minimum values for each target depth.

By comparing the modified Exponential Model and the Linear Model, it is found that the difference of calculated volume becomes larger in case the target depth is deeper than 13m. Because in the Linear Model the constant siltation speed is applied when the channel depth is deeper than around 12m, a difference between the modified Exponential Model and the Linear Model appears in case when the target depth is deeper than 12 m.

Table 5.3 Maintenance dredging volume by the modified Exponential Model

Target Navi. Depth (m)	Cycle time (month)	Dredging Volume by areas (10^3 m^3/cycle)			Total (10^3 m^3/cycle)	Total (10^3 m^3/year)
		Outer	Inner	Basin		
9.00	3.00	0	54	0	54	215
	4.00	0	75	0	75	224
	6.00	0	123	0	123	245
	12.00	0	323	0	323	323
10.00	3.00	0	193	0	193	770
	4.00	0	267	0	267	802
	6.00	0	435	0	435	871
	12.00	0	1,107	0	1,107	1,107
11.00	3.00	5	358	3	365	1,461
	4.00	7	495	4	505	1,516
	6.00	11	798	6	815	1,631
	12.00	33	1,937	19	1,988	1,988
12.00	3.00	164	519	53	736	2,944
	4.00	230	715	74	1,020	3,060
	6.00	384	1,140	125	1,650	3,300
	12.00	1,057	2,401	355	3,813	3,813
13.00	3.00	438	677	182	1,297	5,188
	4.00	613	928	256	1,797	5,390
	6.00	1,011	1,463	428	2,902	5,804
	12.00	2,620	2,532	1,190	6,342	6,342
14.00	3.00	818	831	419	2,068	8,272
	4.00	1,139	1,133	589	2,861	8,584
	6.00	1,857	1,766	982	4,605	9,210
	12.00	3,904	2,846	2,691	9,442	9,442

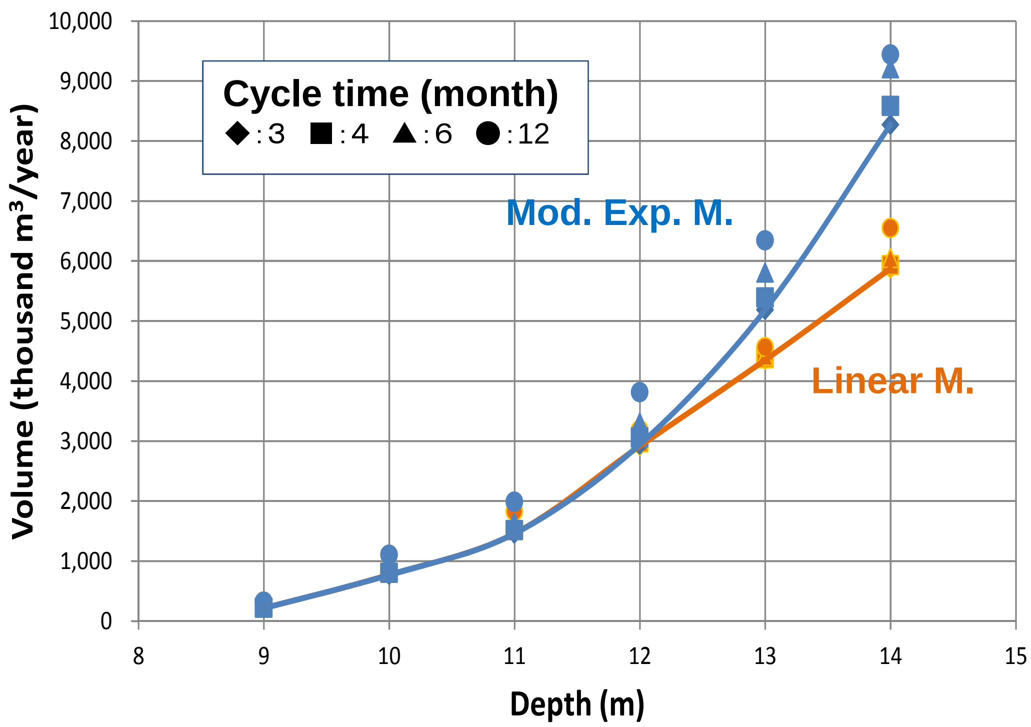


Figure 5.4 Maintenance Dredging Volume by Depths

5.3 Examination of Dredging Methods

5.3.1 Types of dredger

(1) Non-Self-Propelling Cutter Suction Dredger (CSD) (Photo 5.1)

This is a method to suck up soil together with water by pump agitating sea bottom with powered cutter head mounted at the end of the ladder. Sucked soil with water is then hydraulically discharged through pipeline to the dumping area. Economical range for discharge distance is generally 2 to 3 km. This type of dredger is positioned by spuds, which are 2 sets of piles to be able to elevate and to insert into sea bottom, and by swing winch wires drawing through the end of the ladder connecting to anchors installed on sea bottom.

Photo 5.1 Cutter Suction Dredger
(Source: "IHC Beaver Cutter Suction Dredger" International Marine Consultancy)

(2) Self-Propelling Trailing Suction Hopper Dredger (TSHD) (Photo 5.2)

This is a method to suck up soil together with water by pump, sucking soil and water from drag head mounted at the end of the suction pipe. Sucked soil is loaded onto hopper mounted on the dredger. When the hopper becomes full of soil, the dredger is self-propelling to dumping site and dump the dredged material through the bottom door of the hopper.

Photo 5.2 TSHD
(Source: "TSHD Glenn Edwards 10,000 m^3" The art of dredging.com)

(3) Grab Hopper Dredger (GD) (Photo 5.3, Photo 5.4)

This is a method to dredge sea bottom by grab bucket operated by crane. Grabbed soil is loaded onto hopper mounted on the dredger. When the hopper becomes full of soil, the dredger is self-propelled to soil dumping area and dispose soil through the bottom door of the hopper. Besides grab hopper dredger, there is pontoon-type grab dredger, which does not have own hopper or self-propulsion system. Pontoon-type grab dredger loads dredged material into hoppers of soil transporting barges.

Photo 5.3 Grab Hopper Dredger

(Source: “Hopper Dredger CRANE” Axeonalias, RC Groups.com)

Photo 5.4 Grab Dredger (pontoon type)

(Source: “The closing process of clamshell dredges in water-saturated sand” Dr. ir. S.A. Miedema et al.)

(4) Non-Self-Propelling Backhoe Dredger (BHD) (Photo 5.5)

This is a method to excavate soil by bucket operated by backhoe hydraulic arm. Main component is land-based backhoe. The dredged soil is normally loaded onto supported soil barges. Backhoe Dredger is normally equipped with 2 or 3 sets of spuds for positioning and for resisting the force of bucket excavation.

Photo 5.5 Backhoe Dredger
(Source: “Mimar Sinan” Jan De Nul Group)

5.3.2 Appropriate dredging method

Selection of dredging method and dredger suitable for the particular dredging work should be performed considering the following points:

1) Material to be dredged
2) Access for dredging area
3) Water depth
4) Configuration of dredging area
5) Sea conditions
6) Other vessel traffic
7) Soil dumping site
8) Productivity
9) Cost efficiency

The results of considerations are listed in Table 5.4. According to Table 5.4, the Cutter Suction Dredger is rejected mainly due to the item of the sea conditions and dumping site, together with the items of interruption to other vessel traffic in channel. Also, the Backhoe Dredger is rejected mainly due to the items of sea conditions in channel, together with the items of water depth. And, the Grab Hopper Dredger is rejected mainly due to the items of interruption to other vessel traffic in channel and productivity, together with the items of Cost efficiency.

Consequently, TSHD is selected as the dredger being applicable to La Union Port.

TSHD is especially superior in the appraisals of “Other Vessel Traffic”, “Productivity” and “Cost Efficiency” in comparison with other dredgers as shown in Table 5.4.

Table 5.4 Applicability of dredging methods to La Union Port

Appraisal item of conditions for dredging		NON-SELF-PROPELLING CUTTER SUCTION DREDGER	SELF-PROPELLING TRAILING SUCTION DREDGER	SELF-PROPELLING GRAB HOPPER DREDGER	NON-SELF PROPELLING BACKHOE DREDGER
1)	Material to be dredged	Good	Good	Good	Good
2)	Access to dredging area	Good	Good	Good	Good
3)	Water depth	Good	Good	Good	NG
4)	Configuration of dredging area	Good	Good	Good	Good
5)	Sea conditions	NG	Better	Good	NG
6)	Other vessel traffic	NG	Best	NG	NG
7)	Dumping site	NG	Good	Good	Good
8)	Productivity	NG	Best	NG	NG
9)	Cost efficiency	NG	Best	NG	NG
Possibility to apply overall judgment selection of dredging method			Selected		

Note: The words of “NG” stand for No Good

5.3.3 Required capacity of dredger

Dredgers of small capacity cannot complete dredging within the target period, and dredgers of big capacity are uneconomical. Therefore, an economic dredger suitable for the dredging volume and the dredging period must be selected.

For example, in case of a 3 months dredging cycle and employing a dredger which capacity allows complete the dredging in one month, the working ratio will be only 33% (one month/three months); then, the waiting time for the dredger becomes longer than the working time. This waiting time would not be necessary if a dredger of smaller capacity requiring 3 months to complete the dredging is employed. While, the working ratio will be 133% (4 months/3 months) if the dredger capacity is small and 4 months are required to complete the dredging. Then, in this case the 3 months dredging cycle cannot be maintained.

That is, as the dredger capacity is smaller, the dredging period is longer. And, since the working ratio is given by the following equality

Working Ratio

= (required dredging period by a dredger of certain capacity / dredging cycle) ×100

the dredger capacity should be selected as big as possible within a range not exceeding 100% of the working ratio.

(1) Physical condition of dredging

1) Dredging Material:	Silt and Clay
2) Soil loading efficiency in hopper:	60%
3) Distance from dredged site to dumping site:	from 15 to 36 km (Refer to Figure 5.5)
4) Dredging and Turning time:	0.5 hr and 0.25 hr (total 0.75 hr)
5) Dumping and Turning time:	0.15 hr and 0.15 hr (total 0.3 hr)
6) Speed of Dredger (full load):	10.2 kn
7) Speed of Dredger (light load):	10.8 kn

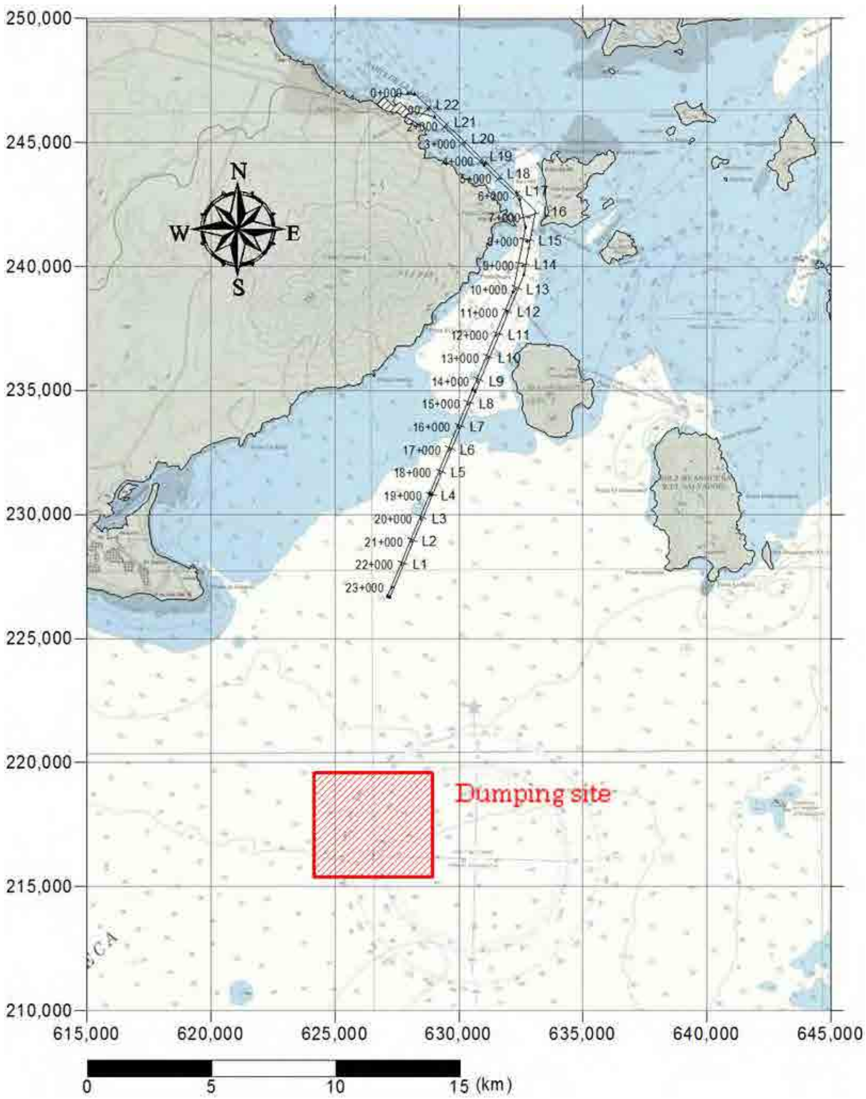


Figure 5.5 Location of dumping site

(2) Working condition of dredging

1) Annual working weeks:	44 weeks (220 days)
2) Annual inspection and the unworkable weeks:	8 weeks
(Periodical inspection in dock :)	(4 weeks)
(Repair, replacement of consumable, usual maintenance and etc. :)	(3 weeks)
(Unworkable days due to bad weather :)	(1 week)

3) Weekly working day 5 days
4) Daily actual working hour (work efficiency 0.8): 19.2 hrs.

(3) Consideration on working ratio

Considerable time is occupied to move the distance from dredging site to dumping site out of total time for dredging. The distance to dumping site is the nearest 15 km and the farthest 36 km since the channel length of La Union Port is about 22 km long. Therefore, the working ratio must be calculated in each section zoning the channel into short sections as the round-trip time to dumping site varies greatly depending on the dredging site. Here, the calculation was made on every 1 km section of channel.

(4) Decision process of necessary dredging capacity

In case of re-dredging, the case to dredge in one year is studied. In case of maintenance dredging, the study is made on each cycle cases of 3, 4, 6 and 12 months.

Calculation commences from the working ratio of 1,000 m^3 dredger capacity for each case. In case that the calculated working ratio exceeds 100%, the working ratio will be re-calculated adding 500 m^3 dredger capacity. The calculation will be repeatedly made on every other 500 m^3 and regard the dredger capacity being firstly below 100% as "necessary dredger capacity" for that case.

(5) Necessary dredger capacity

Table 5.5 shows necessary dredging volume for re-dredging and the working ratio by water depth under the condition of one year dredging period. Table 5.6 shows necessary dredger capacity and the working ratio of each dredging cycle by water depth in case of applying the modified Exponential Model.

Table 5.5 Necessary dredger capacity for re-dredging (m^3)

Target water depth for maintenance dredging	9 m	10 m	11 m	12 m	13 m	14 m
Dredger Capacity (m^3)	2,000	3,000	5,500	8,500	15,000	18,000
Working Ratio (%)	(80)	(96)	(93)	(97)	(82)	(95)

Table 5.6 Necessary dredger capacity for maintenance dredging (m^3), in the case of modified Exponential Model

Dredging cycle \ Maintenance water depth		9 m	10 m	11 m	12 m	13 m	14 m
Dredger Capacity m^3	3 months	1,000 (39)	1,500 (92)	3,000 (87)	5,000 (99)	8,500 (99)	15,000 (88)
	4 months	1,000 (40)	1,500 (96)	3,000 (90)	5,500 (94)	9,500 (92)	15,000 (91)
	6 months	1,000 (44)	2,000 (78)	3,000 (97)	6,000 (92)	9,500 (99)	15,000 (98)
	12 months	1,000 (58)	2,000 (99)	4,000 (89)	6,500 (97)	11,000 (92)	15,000 (100)

Figures shown in parentheses are working ratio (%)

5.4 Cost Estimation of Dredging

5.4.1 Cost estimation items

Cost estimation of dredging is studied on two cases, one is the case that a dredging company dredges with the consignment (dredging by contract base) and the other one is the case that CEPA dredges directly owning a dredger by oneself (dredging by own dredger). The cost by own dredger was estimated based on the concept that CEPA considers now.

Figure 5.6 and Figure 5.7 show the factors of cost estimation both dredging by contract base and by own dredger. The same colored items in these figures mean that the same cost estimation is considered in both cases. While no colored (white color) items mean that the considerations for the cost estimation differ from each other.

The structures of cost estimation in both cases are the total of direct and indirect costs in any event. The direct cost is composed of equipment cost, fuel cost and manpower cost. However, the breakdown items are slightly different between each other. The concepts of cost estimation and its content of indirect cost differs in the dredging by contract base and the dredging by own dredger except in the mobilization cost.

An actual method of cost estimation concerning to each item is described in detail in the Final Report.

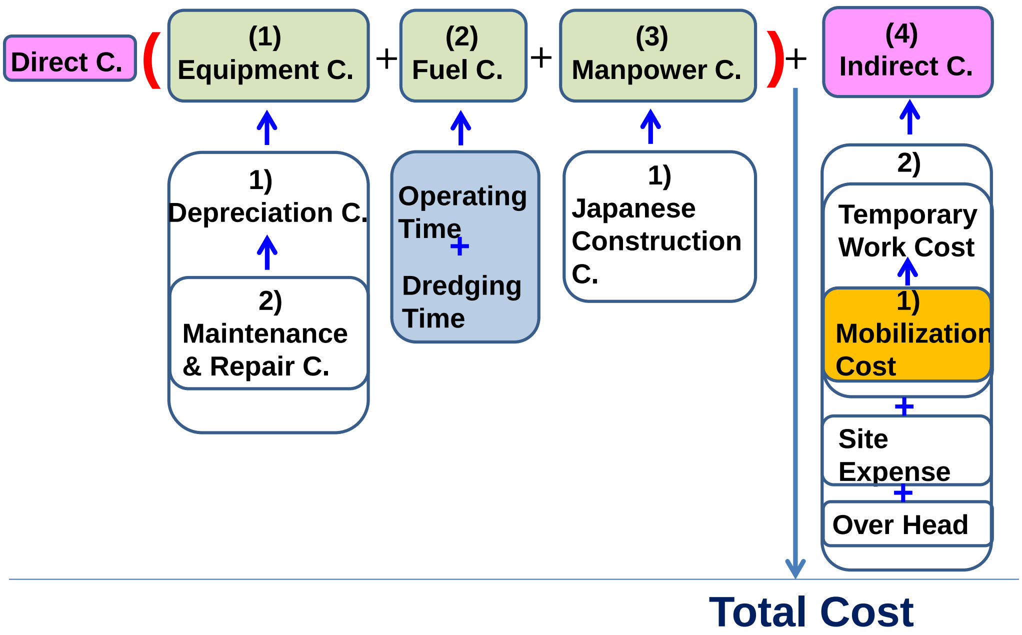


Figure 5.6 Cost estimation items of dredging by contract base

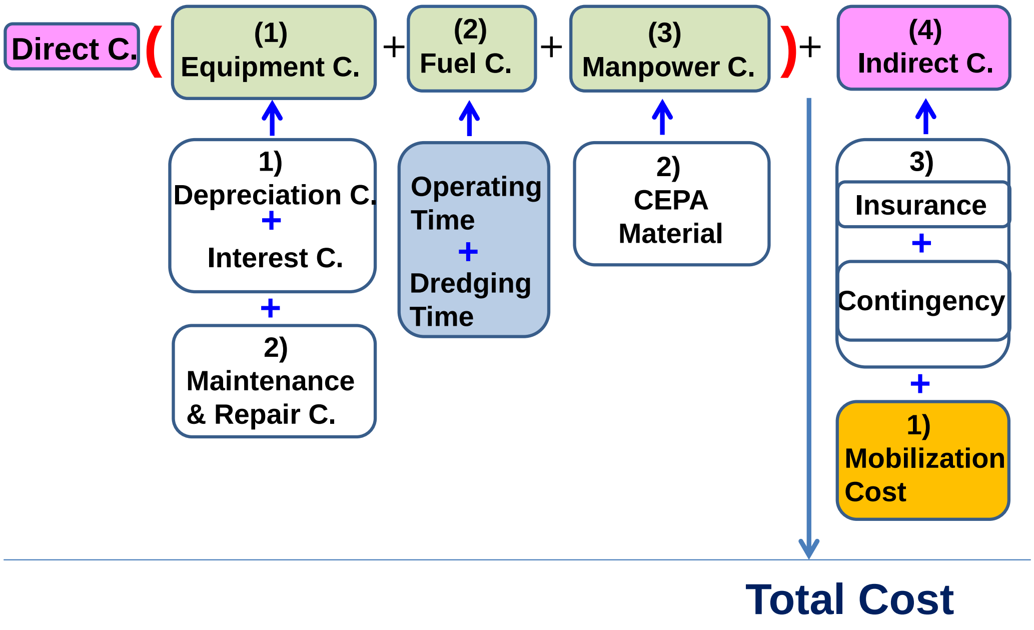


Figure 5.7 Cost estimation items of dredging by own dredger intended by CEPA

5.4.2 Cost for re-dredging

Re-dredging is commenced by contract base and the dredging by own dredger is not considered. Table 5.7 shows re-dredging volume and dredging cost by depth under the contract base. These costs include one way initial mobilization cost from Europe and one round trip cost for periodical inspection.

Table 5.7 Dredging cost by water depth

Depth (-m)	Hopper capacity (m3)	Operating hour (h)	Operating Month (m)	Volume (m3)	Dredging cost by contract base (US$/m3)	Dredgibg cost by contract base (US$)
9	2,000	3,366	9.6	895,000	13.79	12,342,319
10	3,000	4,064	11.5	1,619,000	10.87	17,603,115
11	5,500	3,941	11.2	2,964,000	9.34	27,686,793
12	8,500	4,096	11.6	4,895,000	7.15	35,010,001
13	15,000	3,464	9.8	7,452,000	7.31	54,466,014
14	18,000	4,020	11.4	10,565,000	6.47	68,371,225

5.4.3 Cost for maintenance dredging

The volume of maintenance dredging for the channel is predicted with modified Exponential Model and Linear Model. Figure 5.8 shows dredging cost of dredging by contract base in modified Exponential Model and Linear Model, in which the least dredging cost of each water depth is drawn by curve line. In the same manner, Figure 5.9 illustrates the dredging cost of dredging by own dredger.

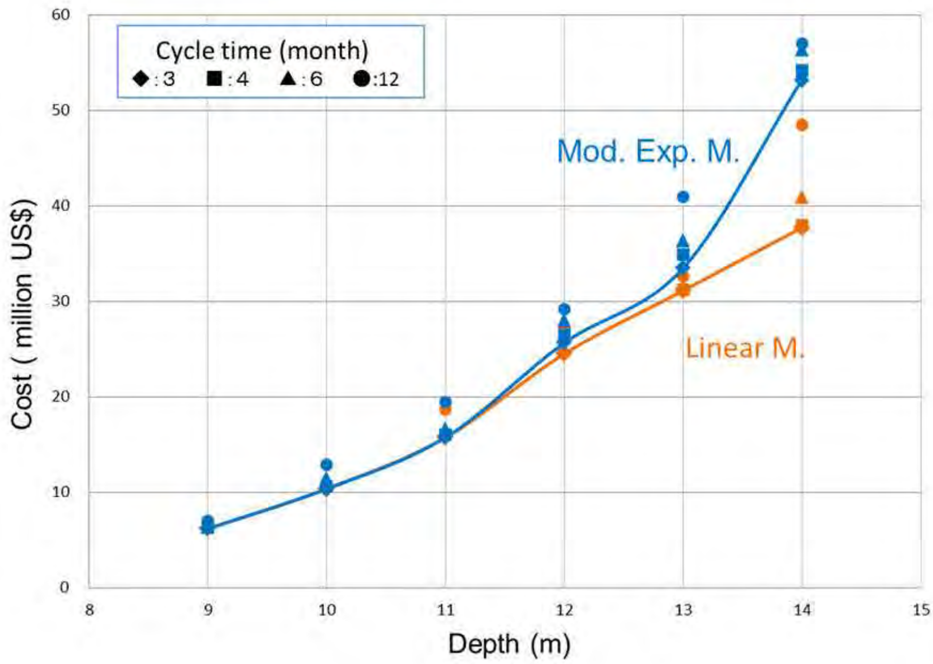


Figure 5.8 Dredging cost of dredging by contract base (Cost comparison between modified Exponential Model and Linear Model)

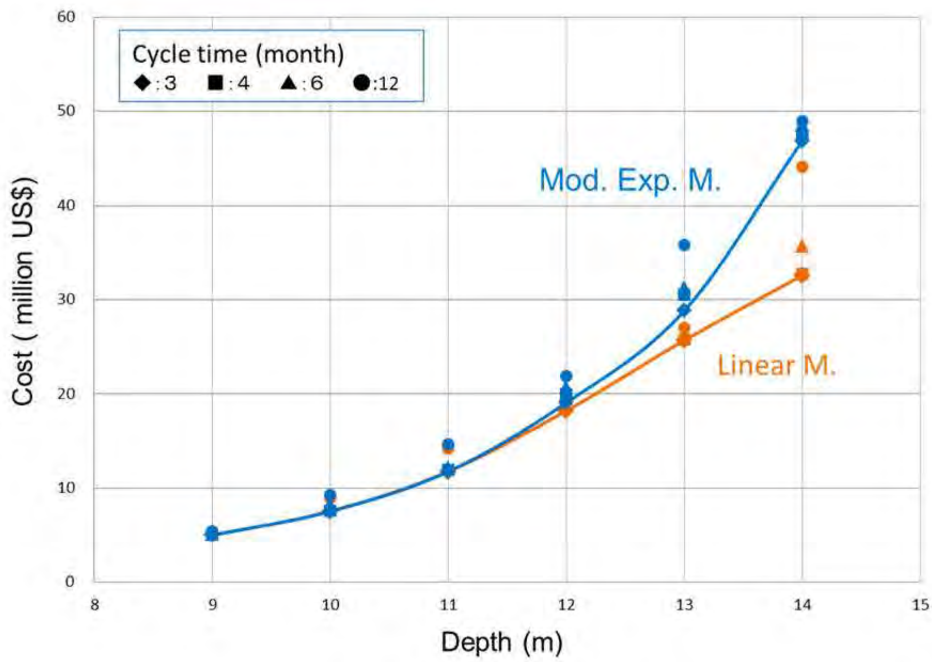


Figure 5.9 Dredging cost of dredging by own dredger (Cost comparison between modified Exponential Model and Linear Model)

5.4.4 Observations on re-dredging cost

Over-dredging foreseeing future siltation is also necessary when re-dredging is done. However, the cost of re-dredging is estimated only the cost to dredge up to the target water depth. And so, the cost of over-dredging when re-dredging is done is referred with simple method shown in Figure 5.10. That is, the cost for over-dredging is set as same as the cost for maintenance dredging. Therefore, the cost including over-dredging becomes the total cost of re-dredging and maintenance dredging.

Figure 5.10 Structure for costs of re-dredging and maintenance dredging

5.4.5 Effect of decreasing cycle time (Case study on target channel depth of 12 m)

It is examined how the dredging cost changes when the cycle time is decreased to be shorter in case of the target depth of 12 m. The volume of maintenance dredging is predicted by the modified Exponential Model.

It is impossible to dredge the whole area of channel instantaneously, and it takes a certain period of time. Then, a minimum cycle time is assumed to be one month. If you want very much to infer the situation in the cycle time shorter than one month, you can get some idea of it by extrapolating the curved lines to the zero point of cycle time in Figure 5.11 and Figure 5.12.

Figure 5.11 shows a relation between the cycle time and the volume of maintenance dredging predicted by the modified Exponential Model. The volume of maintenance dredging decreases when the cycle time becomes shorter. In this figure, the black broken line indicates that the annual dredging volume decreases by 0.11 million m^3 when the cycle time decreases by one month. When the cycle time is reduced from 3 months to 1 month, a rate of decrease in the annual dredging volume is 7.5 %.

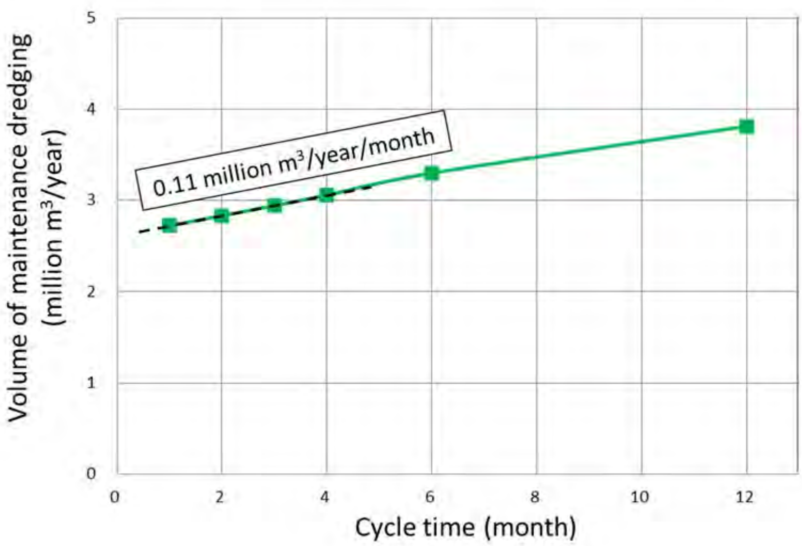


Figure 5.11 Relation between cycle time and annual volume of maintenance dredging
(predicted by modified Exponential Model for target channel depth of 12 m)

Figure 5.12 shows the annual dredging cost by the dredger with necessary capacity. The cost decreases with decreasing of the cycle time. When the cycle time is reduced from 3 months to 1 month, a rate of decrease in the dredging cost is 3.9 %, which is about a half of that of dredging cost in Figure 5.11.

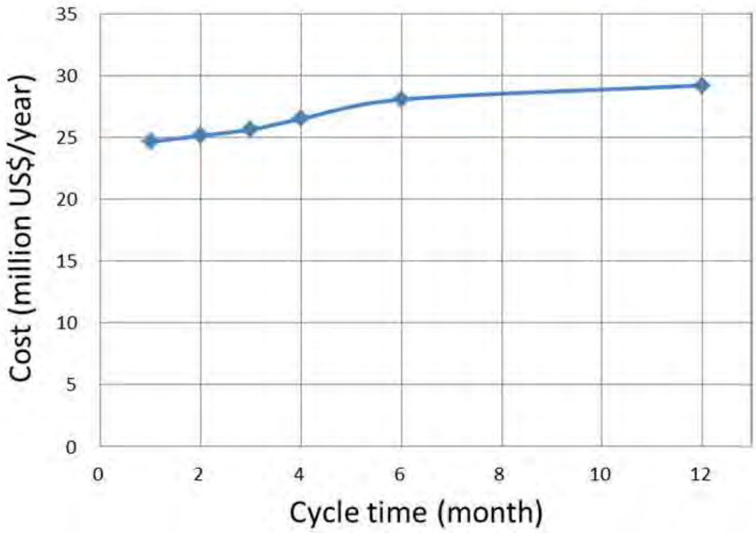


Figure 5.12 Relation between cycle time and annual dredging cost

5.4.6 Recommendation on dredging framework

(1) Cost comparison of dredging cost between dredging by contract base and dredging by own dredger

Figure 5.13 collectively illustrates the least dredging cost. As the dredging cost by contract base is described with red lines and the one by own dredger is described with green lines, both comparison can be made easily. According to this Figure, green lines always lie underneath of red lines. That is to say, the dredging cost by own dredger that CEPA considers is always smaller.

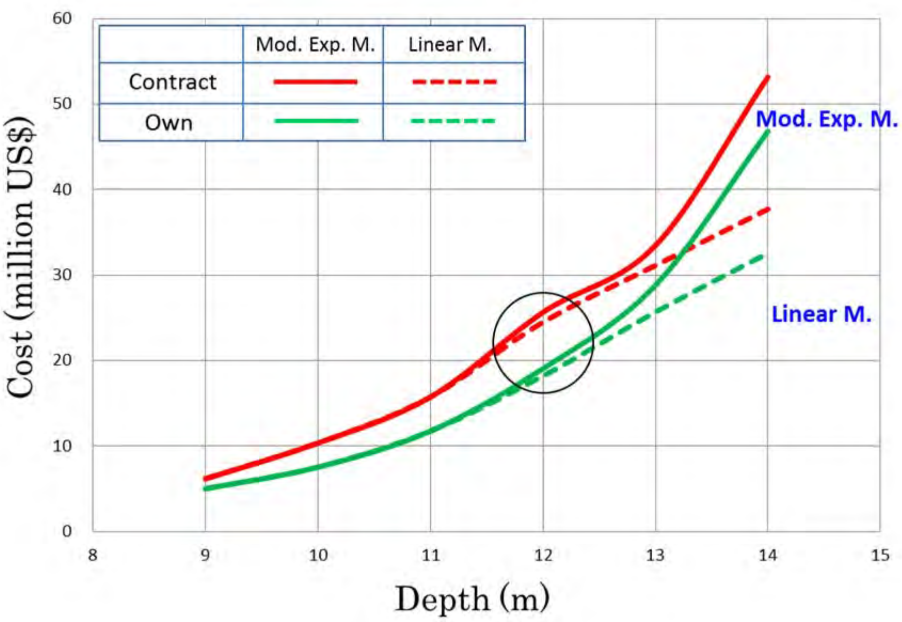


Figure 5.13 Dredging cost comparison between dredging by contract base and by own dredger

Figure 5.14 shows the comparison separating direct and indirect cost for dredging costs at the circled part in Figure 5.13 by contract base and by own dredger. According to Figure 5.14, the direct cost is almost the same but the indirect cost is way cheaper in its dredging cost by own dredger. Indirect cost of contract base includes mobilization cost, insurance cost, costs related with contingency and so on. On the contrary, indirect cost by own dredger includes only mobilization, insurance cost and contingency as other cost is difficult to estimate. However, it is not appropriate to discuss about the dredging framework only with a comparison of dredging costs by contract base and own dredger, for following reasons.

In fact, many kinds of cost considering in dredging by contract base are needed for the operation of own dredger by CEPA. For example, related with temporary cost, the followings are required.

- Fleet and the crew are required for safety boat to control navigation safety at the time of channel dredging, survey boat to conduct field survey and progress control, tag boat to support berthing and leaving of dredger, transportation boat to carry crew for emergency and etc.

- New organization for the maintenance and repair like having facility to maintain and repair (berth, slipway and repair factory) is necessary in order to repair and maintain dredger fleet.

- Organization for the technical management such as dredging quality, progress control, and work schedule the organization to control overall dredging works becomes necessary.

- And, with the above three organizations, service cost such as land, water, electricity and etc. will be increased.

Therefore, in case of dredging by own dredger, more cost than CEPA considers will be borne.

Furthermore, there are matters to be necessary in case of dredging by own dredger although it is no need to consider in the dredging by contract base. For example, workability of crew at the initial stage will be poor and a cost for crew training at the time of initial dredging period will be required.

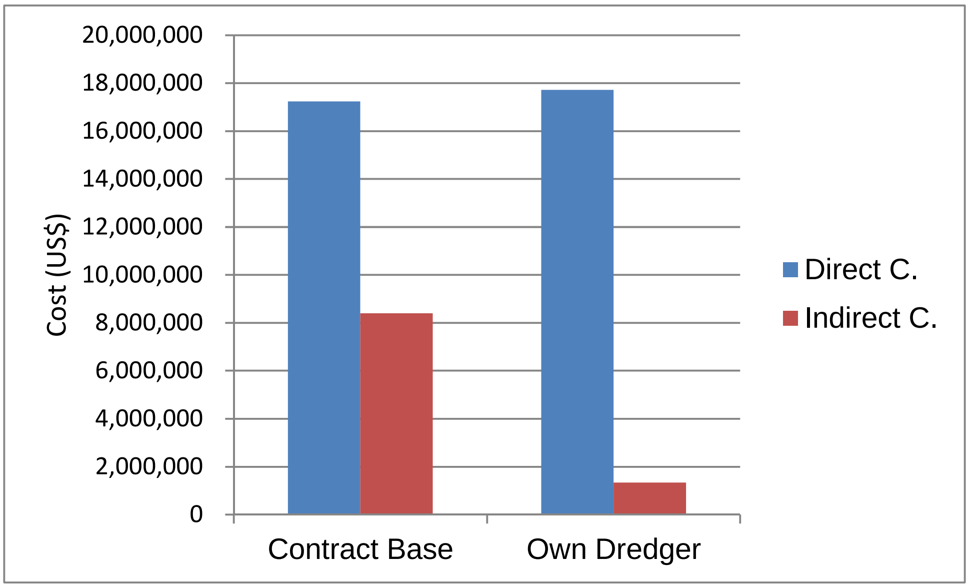


Figure 5.14 Comparison of direct and indirect cost by contract base and own dredger (12m target depth of modified Exponential Model with 3 months cycle)

(2) Accuracy of silting volume prediction model

According to the result of bottom sounding, two models to predict channel siltation were empirically made. Unfortunately, at present there are differences in two models in the result of prediction of silting volume (Figure 5.4) and dredging cost estimated (Figure 5.8 and Figure 5.9) as well. It involves taking risks for CEPA to own a dredger under the situation that the prediction accuracy of siltation volume is not high. This is explained using Figure 5.15.

Figure 5.15 is the one added necessary dredger capacity to the figure (Figure 5.9) showing dredging cost by CEPA's own dredger. For example, in case of 13 m target water depth at the channel, a dredger with the capacity of 8,500 m^3 is required in order to dredge target dredging volume predicted by modified Exponential Model, it becomes possible to dredge by a dredger with the capacity of 7,500 m^3 in case of target dredging volume by Linear Model. So, at this stage, even if target water depth is fixed as 13m, as there is difference between two models of siltation prediction volume, it is difficult to properly judge the dredger capacity therefore, there is risk that CEPA will own a dredger fixing its capacity.

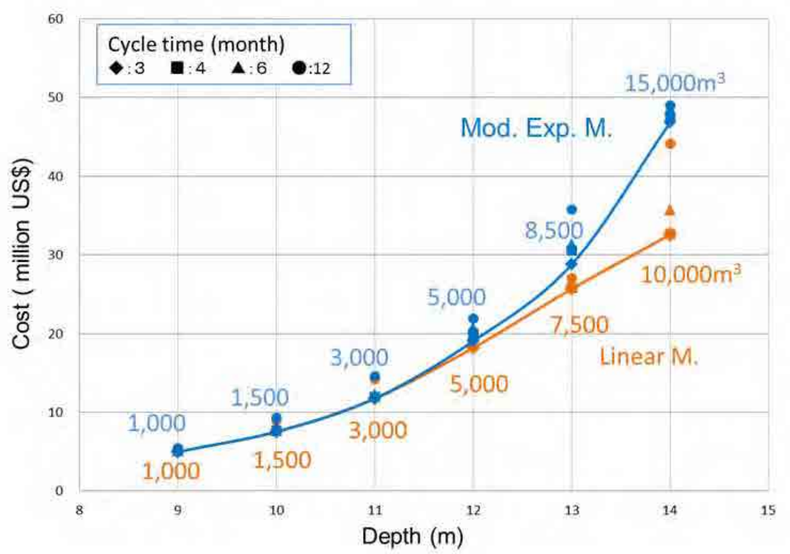


Figure 5.15 Dredging cost and dredger capacity by water depth

(3) Target channel water depth in conjunction with development of La Union Port

According to Figure 5.15, it is understood that the deeper target water depth of channel, the bigger dredger capacity to be necessary. That is, the relation that CEPA owns a dredger and the development of port becomes difficult.

The reason is explained with necessary dredger capacity (blue line in the Figure 5.15) against siltation volume predicted by modified Exponential Model. For example, in the assumption that target channel water depth is set as 10 m and build necessary dredger with the capacity of 1,500 m^3. After a while, it is needed to correspond to deeper draft vessel for her calling to the port and the target channel water depth is changed to 11 m, the necessary dredger capacity becomes 3,000 m^3 in order to maintain the water depth. For the satisfaction of this demand, it has to dispose or sell the dredger with the capacity of 1,500 m^3 and newly secure a dredger with the capacity of 3,000 m^3. Alternatively, remaining a dredger with the capacity of 1500 m^3 and owns another new dredger with the capacity of 1500 m^3 can be considered.

There arising the same problem if La Union Port is further developed and changes target water depth as 12 m. In other words, in case that CEPA owns a dredger, additional cost is required for properly maintaining channel water depth in conjunction with the development of La Union Port.

(4) Recommendation

The dredging cost by own dredger is estimated smaller than contract base because the indirect cost is estimated cheaper than by contract base while direct costs are similar. Indirect cost of contract base includes mobilization cost, insurance cost, costs related with contingency and so on. On the contrary, indirect cost of dredging by own dredger include only mobilization, insurance cost and contingency as other cost is difficult to estimate. However, it is not appropriate to discuss about the dredging framework only with a comparison of dredging costs by contract base and own dredger, for the following reasons.

If CEPA owns a dredger, CEPA would have to bear considerable cost more than the cost estimation. And, dredging works could not be functioned without long experience and the accumulation of know-how. Aside from the cost, CEPA would have to handle training and education for dredger’s crew.

Furthermore, accurate prediction of the siltation volume is necessary to design the size or capacity of the dredger before its procurement. But prediction models of siltation volume developed in this report is not reliable enough and necessary to be revised through monitoring of channel siltation for a certain period.

In addition to above, in case of change of target channel depth, the flexible response is extremely difficult if CEPA owns its dredger. This problem will remain unchanged for future as well.

Judging from the above all, "dredging by contract base" for the channel maintenance dredging for a certain period is recommended.

Chapter 6 Proposal of Monitoring Plan after Re-dredging

Chapter 6 Proposal of Monitoring Plan after Re-dredging

6.1 Purposes of Monitoring

The empirically established two models are based on the bathymetric data which is not necessarily enough in quality and in quantity. The monitoring of the channel depth by bathymetric survey is the only method for improving the precision of prediction and for enhancing the applicability of the Linear Model to the maintenance dredging.

So far the bathymetric data is not enough in the basin to formulate an empirical prediction model. At present the modified Exponential Model has been applied for estimating the siltation volume in the basin. In order to confirm the appropriateness of application, it is important and necessary to collect the bathymetric data in the Port area.

The purposes of monitoring are;

To verify an appropriateness of predicted siltation volume

To confirm the phenomenon of rapid siltation just after the dredging

The monitoring plan is set up, subject to the condition that the bathymetric survey will be conducted by CEPA themselves with their own instruments.

6.2 Verification on appropriateness of the predicted siltation volume

In order to verify an appropriateness of the siltation volume predicted by the empirical prediction model, it is basically necessary to measure the actual siltation volume. Since the re-dredging will be carried out to activate the use of La Union Port, frequent maintenance dredging should be also carried out after completion of the re-dredging. The repeating of bathymetric survey is required also in this case. However, the siltation volume cannot be obtained only by bathymetric surveys. Collecting records of maintenance dredging, such as the excavated volume and location, are required for more accurate estimation of siltation volume. In addition, the record of vessels which enter into and leave from the port must be collected.

(1) Bathymetric survey

1) A bathymetric survey should be conducted along the preset survey lines in the designated areas of the Inner channel, the Outer channel and the Harbor basin.

2) The bathymetric surveys should be conducted immediately before and just after the re-dredging. After that, the bathymetric survey shall be repeated with the time interval of two months, or one month if possible.

3) The bathymetric survey must be usually conducted with the two acoustic signals of 38 kHz and 200 kHz.

(2) Volume of dredging

The volume of dredging can be estimated by multiplying the capacity of TSHD (Trailing Suction Hopper Dredger) and the number of round trips to the dumping site.

(3) Estimation of siltation volume

At first, the volume of topographic change in the channel is calculated by use of the successive two bathymetric data. The volume of dredging, of which location and period are corresponding to those of the bathymetric data, is added to the volume of topographic change. The result is the volume of siltation fundamentally.

6.3 Confirmation of rapid siltation just after the dredging

The rapid siltation occurred just after the dredging. In order to confirm this phenomenon, it is necessary to repeat the bathymetric survey at a short interval. Note that a chance of confirming the phenomenon of rapid siltation might be limited to only one time when the re-dredging will be completed.

(1) Bathymetric survey

1) A bathymetric survey should be conducted along the preset survey lines in the designated areas of the Inner and Outer channels.

2) The bathymetric survey just after the dredging must be conducted. After that, it is recommended that the survey is repeated at an interval of two weeks for several months.

3) The same as Subsection 6.2 (1) 3)

(2)Volume of dredging: The same as Section 6.2 (2)

(3)Effect of Ship navigation: The same as Section 6.2 (3)

(4)Estimation of siltation volume: The same as Section 6.2 (4)

6.4 Tide Correction of Bathymetric Data

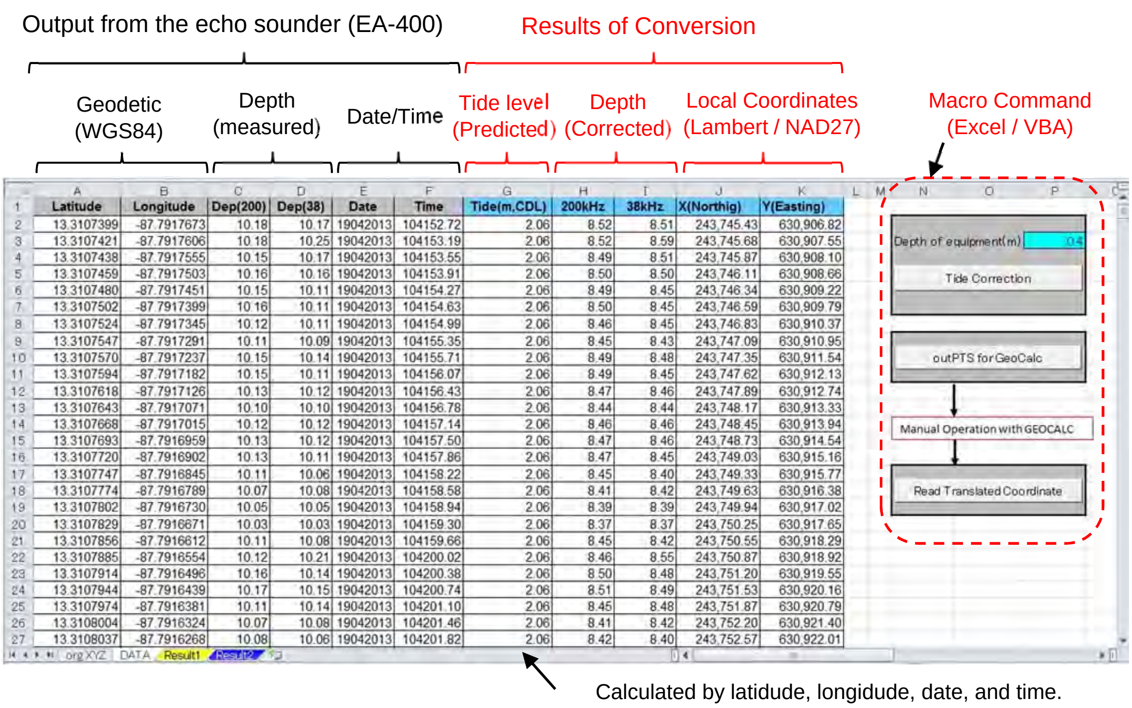
6.4.1 Improvement of tide correction of bathymetric survey data

For maintenance of the channel, continuous monitoring of channel depth is required. During 1st on-site work in April 2013, the team inspected the bathymetric survey that CEPA staffs carried out. In the bathymetric survey, CEPA's staffs smoothly operated the field works such as mounting the equipment and measurement. However, CEPA staffs took a lot of time for analysis of the surveyed data, because of lack of post-processing tools.

Therefore, the team prepared tools for smooth post-processing of bathymetric survey data as a part of technology transfer. In order to make post-processing of bathymetric survey data quickly, the team developed Excel macro book. The macro book is coded by VBA and the main functions are as follows.

- Open and Read a measured data file of the echo sounder, EA-400
- Tide prediction taking measurement position into account
- Tide correction of bathymetric data
- Coordinate conversion between geodetic / WGS84 and Lambert / NAD27
- Remove abnormal data (quasi-automatic)
- Make a dataset with coordinates based on the channel center line

Figure 6.1 shows a screenshot of the Excel macro book. As shown in the figure, depth data and positioning data are all converted on the macro book by just clicking the command buttons. The macro book and its usage were introduced in the 2nd on-site work in August, 2013.



	Latitude	Longitude	Dep(200)	Dep(38)	Date	Time	Tide(m,CDL)	200kHz	38kHz	X(Northig)	Y(Easting)
2	13.3107399	-87.7917673	10.18	10.17	19042013	104152.72	2.06	8.52	8.51	243,745.43	630,906.82
3	13.3107421	-87.7917606	10.18	10.25	19042013	104153.19	2.06	8.52	8.59	243,745.68	630,907.55
4	13.3107438	-87.7917555	10.15	10.17	19042013	104153.55	2.06	8.49	8.51	243,745.87	630,908.10
5	13.3107459	-87.7917503	10.16	10.16	19042013	104153.91	2.06	8.50	8.50	243,746.11	630,908.66
6	13.3107480	-87.7917451	10.15	10.11	19042013	104154.27	2.06	8.49	8.45	243,746.34	630,909.22
7	13.3107502	-87.7917399	10.16	10.11	19042013	104154.63	2.06	8.50	8.45	243,746.59	630,909.79
8	13.3107524	-87.7917345	10.12	10.11	19042013	104154.99	2.06	8.46	8.45	243,746.83	630,910.37
9	13.3107547	-87.7917291	10.11	10.09	19042013	104155.35	2.06	8.45	8.43	243,747.09	630,910.95
10	13.3107570	-87.7917237	10.15	10.14	19042013	104155.71	2.06	8.49	8.48	243,747.35	630,911.54
11	13.3107594	-87.7917182	10.15	10.11	19042013	104156.07	2.06	8.49	8.45	243,747.62	630,912.13
12	13.3107618	-87.7917126	10.13	10.12	19042013	104156.43	2.06	8.47	8.46	243,747.89	630,912.74
13	13.3107643	-87.7917071	10.10	10.10	19042013	104156.78	2.06	8.44	8.44	243,748.17	630,913.33
14	13.3107668	-87.7917015	10.12	10.12	19042013	104157.14	2.06	8.46	8.46	243,748.45	630,913.94
15	13.3107693	-87.7916959	10.13	10.12	19042013	104157.50	2.06	8.47	8.46	243,748.73	630,914.54
16	13.3107720	-87.7916902	10.13	10.11	19042013	104157.86	2.06	8.47	8.45	243,749.03	630,915.16
17	13.3107747	-87.7916845	10.11	10.06	19042013	104158.22	2.06	8.45	8.40	243,749.33	630,915.77
18	13.3107774	-87.7916789	10.07	10.08	19042013	104158.58	2.06	8.41	8.42	243,749.63	630,916.38
19	13.3107802	-87.7916730	10.05	10.05	19042013	104158.94	2.06	8.39	8.39	243,749.94	630,917.02
20	13.3107829	-87.7916671	10.03	10.03	19042013	104159.30	2.06	8.37	8.37	243,750.25	630,917.65
21	13.3107856	-87.7916612	10.11	10.08	19042013	104159.66	2.06	8.45	8.42	243,750.55	630,918.29
22	13.3107885	-87.7916554	10.12	10.21	19042013	104200.02	2.06	8.46	8.55	243,750.87	630,918.92
23	13.3107914	-87.7916496	10.16	10.14	19042013	104200.38	2.06	8.50	8.48	243,751.20	630,919.55
24	13.3107944	-87.7916439	10.17	10.15	19042013	104200.74	2.06	8.51	8.49	243,751.53	630,920.16
25	13.3107974	-87.7916381	10.11	10.14	19042013	104201.10	2.06	8.45	8.48	243,751.87	630,920.79
26	13.3108004	-87.7916324	10.07	10.08	19042013	104201.46	2.06	8.41	8.42	243,752.20	630,921.40
27	13.3108037	-87.7916268	10.08	10.06	19042013	104201.82	2.06	8.42	8.40	243,752.57	630,922.01

Figure 6.1 Post-processing tools coded by Excel/VBA

6.4.2 Datum level of La Union Port

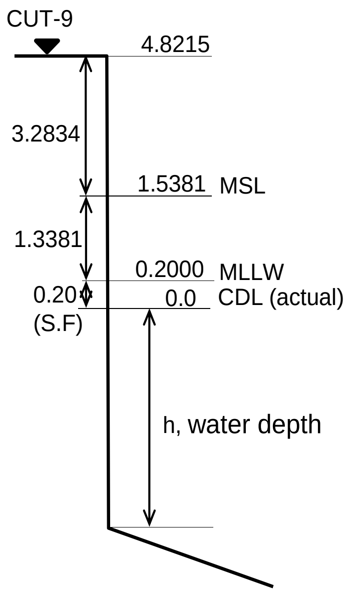
In order to confirm a reference level for bathymetric survey, the Team discussed with the CNR officials, who are in charge of tide prediction for the coasts of El Salvador. The meeting with CNR officials was made at August 24, 2011. The objective of the meeting is to clarify the tide levels and the vertical reference level employed in El Salvador.

Table 6.1 shows the relation between the GVD (geodetic vertical datum) and tide levels, which are provided by CNR. According to CNR, in La Unión, the reference level of water depth has been set as the height of MLLW (= -1.3381 m) since 1960. For the purpose of marine navigation, however, the water depths are calculated with the reference level of 1.5381 m (=1.3381+0.2) below MSL, where the additional 0.2 m is a security factor for safe navigation.

Table 6.1 Vertical Reference levels for El Salvador provided by CNR.

		La Unión	Acajutla	La Libertad
Highest Tide Obserbed	HTO	1.9812	1.5240	1.6154
High Water Springs	HWS		0.9601	1.0211
Mean High High Water	MHHW	1.2710	0.8656	0.9235
Mean High Water	MHW	1.1704	0.7711	0.8260
Mean Sea Level	MSL	0.0000	0.0000	0.0000
Mean Tide Level	MTL	-0.0518	0.0000	0.0061
Mean Low Water	MLW	-1.2771	-0.7742	-0.8138
Mean Low Low Water	MLLW	-1.3381	-0.8169	-0.8595
Low Water Springs	LWS		-0.9601	-1.0211
Low Tide Obseved	LTO	-2.2860	-1.4021	-1.4935

Through the meeting with CNR officials, it is confirmed that the chart datum level (CDL) for the purpose of navigation in La Union Port is 1.5381 m below MSL. The relation between MSL and CDL is shown in Figure 6.2. The height of benchmark of CUT-9 is also shown in Figure 6.2, where the CUT-9 is located at the southeast corner of the container wharf in La Unión Port.



CNR reference		
CDL=MSL-1.3381 - SF		
Ref. level	MSL	CDL
CUT-9	3.2834	4.8215
MSL	0.0000	1.5381
MLLW	-1.3381	0.2000
CDL	-1.5381	0.0000

Figure 6.2 Vertical reference employed by CNR

Chapter 7 Reviews of Demand Forecast Model and Market Allocation Model developed by CEPA

Chapter 7 Reviews of Demand Forecast Model and Market Allocation Model developed by CEPA

In this chapter, the method to calculate the projected growth rate of container volume from CA4 (El Salvador, Guatemala, Honduras and Nicaragua) and develop the market allocation model is shown.

7.1 Outline of Demand Forecast Model and Market Allocation Model developed by CEPA

"Port demand Study of La Union" carried out by CEPA consists of three parts:

1. Projected growth rate of container volume to and from CA4
2. Development of market allocation model
3. Projected market allocation for La Union Port

7.2 Projected growth rate of container volume to and from CA4

(1) **Acquisition of historical time series data on GDP and container volume**

In order to estimate the past GDP elasticity of container cargoes, it is necessary to obtain historical time series of GDP and container volume to/from each CA4 country (El Salvador, Guatemala, Honduras and Nicaragua).

Historical data of GDP in CA4 can be obtained from UNCTAD (United Nations Conference on Trade and Development) and the World Bank.

Historical data of container volume to/from each CA4 country were estimated from trade statistics database of SIECA (The Secretariat of Central American Economic Integration). The data from 2000 to 2010 were used for the analysis.

(2) **Estimation of the present and future GDP elasticity of container volume**

The present GDP elasticity of container volume growth was estimated using the time series of GDP and container volume between 2000 and 2010.

CEPA used a regression analysis to estimate the degree of correlation between the growth of the production of CA4 (independent variable) and the volume of import and export containers of the same (dependent variable).

CEPA assumed that the present GDP elasticity calculated in the previous subsection would basically remain unchanged until 2030. Nevertheless, the GDP elasticity is assumed to decrease linearly to 2.0 toward the target year of 2030 when the present GDP elasticity exceeds 2.0 because the elasticity of 2.0 is the upper limit of average elasticity in developing economies and there is a need to avoid overestimation in the forecast.

Table 7.1 GDP Elasticity

		2000-2010	2020	2030
EL SALVADOR	IMPORT	2.11	2.06	2.0
	EXPORT	4.57	3.28	2.00
GUATEMALA	IMPORT	0.96	0.96	0.96
	EXPORT	1.55	1.55	1.55
HONDURAS	IMPORT	0.99	0.99	0.99
	EXPORT	1.18	1.18	1.18
NICARAGUA	IMPORT	1.59	1.59	1.59
	EXPORT	2.82	2.41	2.00

Source: CEPA's calculations based on data from United Nations Conference on Trade and Development (UNCTAD),Central American Trade Statistics System (SIECA) and United States Census Bureau

(3) **Calculation of the growth rate of container volume**

The container growth rate was estimated using the future GDP growth rate and the GDP Elasticity. The future GDP growth rate was provided by USDA (Economic Research Service, U.S. Department of Agriculture) and IMF.

The calculation formula is as follows.

Container Growth Rate = (GDP Growth Rate) x (GDP Elasticity)

Table 7.2 Container Growth Rate (2010=100)

		2010-2020	2010-2030
Import	El Salvador	200	395
	Guatemala	167	278
	Honduras	158	252
	Nicaragua	203	343
Export	El Salvador	340	776
	Guatemala	167	277
	Honduras	160	248
	Nicaragua	207	349

Source: El Salvador, Guatemala:USDA, Honduras, Nicaragua:IMF

7.3 Development of Market Allocation Model

(1) **Estimated volume of import and export containers**

In order to project the market share, CEPA has estimated the Hinterland matrix by collecting and analyzing the various container flow data of CA4.

Since the exact data of the container flow in CA4 did not exist, CEPA made some assumptions. Procedure of estimation by CEPA is described below.

1) Calculate the container volume of the geographical areas where cargo is imported and exported to each port in CA4.

1. The data of total volume of containers imported / exported to ports in the CA4 is acquired from COCATRAM (The Central American Commission on Maritime Transport).
2. The data of Quetzal port and Santo Tomas on distribution of the total volume cargo imported / exported between different geographical areas are acquired from CPN (Guatemala National Port Commission).
   Geographical areas of CPN are divided into 6 areas (United States West coast: USWC, United States East coast: USEC, EU, Asia, Other Pacific and Other Atlantic).With these data we calculate the cargo share of each of the geographical areas.
3. Since the management situation and the handling situation is similar, the same share of Puerto Quetzal applies to Corinto and Acajutla. Similarly, the same share of Santo Tomas is applied to Pt Cortes and Pt Castilla.
4. To calculate the container volume of the geographical areas, total volume of containers of each port and the share of each geographical area are multiplied.

2) Calculate the container volume of the geographical areas where cargo is imported and exported to each country in CA4.

1. The data of each CA4 country of distribution of the total cargo volume imported / exported between different geographical areas are acquired from SIECA.
2. Geographical areas of SIECA are divided into 5 areas (USA, EU, Asia, Other Pacific and Other Atlantic).
   In order to divide the USA data to USWC and USEC, we calculate the proportion of USWC and USEC by using the data of US TRADE ONLINE. With these data we calculate the share of each of the geographical areas.
3. To calculate the container volume between each country of CA4 and the geographical areas, we multiply the share of the geographical areas by the total container volume of the geographical areas.

(2) Estimation of containers imported / exported by land, as the area of influence of the ports

The area of influence of the Ports and hinterland refers to how cargo entering or leaving through the Ports of CA4 is distributed in the Central American region which is the second step in developing the model. It was necessary to calculate the volume of container exported and imported by land by area of influence of the different ports under study. Data was calculated based on the data that different countries customs CA4 provided.

To calculate the container volume, we multiply the share by the total container volume of the each port calculated above. Data was classified into imports / exports of the Pacific, import / export of the Atlantic, for each country.

Table 7.3 Hinterland transport matrix (2010)

Hinterland transport matrix Import: Pacific (2010) (TEU)

	Acajutla	Quetzal	S Tomas / P Barrios	Pt. Cortes / Pt. Castilla	Corinto	Total
El Salvador (E)	484	43	10	16	25	578
El Salvador (W)	47,870	4,246	1,030	1,606	2,479	57,232
Guatemala	1,930	51,725	13,117	2,534	0	69,306
Honduras (N)	617	541	131	10,543	658	12,491
Honduras (S)	264	232	56	4,519	282	5,353
Nicaragua	89	0	0	1,220	15,504	16,813
Total	51,254	56,786	14,345	20,437	18,949	161,772

Hinterland transport matrix Import: Atlantic (2010) (TEU)

	Acajutla	Quetzal	S Tomas / P Barrios	Pt. Cortes / Pt. Castilla	Corinto	Total
El Salvador (E)	179	16	123	140	9	468
El Salvador (W)	17,731	1,573	12,203	13,876	918	46,301
Guatemala	715	19,158	150,550	21,894	0	192,318
Honduras (N)	229	200	1,555	91,107	244	93,335
Honduras (S)	98	86	666	39,046	105	40,001
Nicaragua	33	0	0	10,542	5,743	16,317
Total	18,984	21,033	165,097	176,606	7,019	388,739

Hinterland transport matrix Export: Pacific (2010) (TEU)

	Acajutla	Quetzal	S Tomas / P Barrios	Pt. Cortes / Pt. Castilla	Corinto	Total
El Salvador (E)	230	1	0	11	27	269
El Salvador (W)	22,754	145	20	1,060	2,634	26,614
Guatemala	114	37,157	6,667	1,673	0	45,612
Honduras (N)	505	17	279	6,570	925	8,296
Honduras (S)	216	7	119	1,643	396	2,382
Nicaragua	68	0	0	806	5,369	6,242
Total	23,888	37,328	7,085	11,763	9,351	89,415

Hinterland transport matrix Export: Atlantic (2010) (TEU)

	Acajutla	Quetzal	S Tomas / P Barrios	Pt. Cortes / Pt. Castilla	Corinto	Total
El Salvador (E)	83	1	11	165	10	269
El Salvador (W)	8,241	53	1,094	16,293	954	26,635
Guatemala	41	13,458	172,028	25,707	0	211,234
Honduras (N)	183	6	7,195	100,946	335	108,665
Honduras (S)	78	3	3,083	25,237	144	28,545
Nicaragua	25	0	0	12,378	1,944	14,347
Total	8,652	13,520	183,411	180,725	3,387	389,695

7.4 Projected market allocation for La Union Port

The potential market share of La Union port and the future volume of containers are calculated by Logit Model.

(1) **Acquisition of data on the present transit time and cost**

Two essential elements for the calculation of the potential demand for the CA4 countries are transit times and shipping costs and land, which were calculated with some assumptions:

Table 7.4 Transportation Cost per TEU in 2010 (USD)

	Acajutla	La Union	Quetzal	Santo Tomas	Pt. Barrios	Pt. Cortes	Pt. Castilla	Corinto
Ocean Freight Rate								
to USWC	1,823.53	1,266.49	1,764.71	1,188.28	1,188.17	2,000.00	1,254.76	1,304.87
from USWC	1,823.53	1,266.49	1,764.71	1,188.28	1,188.17	2,000.00	1,254.76	1,304.87
to USG	1,764.71	2,115.00	1,647.06	2,115.00	2,115.00	1,647.06	2,115.00	2,058.82
from USG	1,764.71	2,115.00	1,647.06	2,115.00	2,115.00	1,647.06	2,115.00	2,058.82
to China	2,400.00	2,400.00	2,400.00	2,400.00	2,400.00	2,400.00	2,400.00	2,400.00
from China	4,411.76	2,400.00	4,411.76	2,400.00	2,400.00	5,000.00	2,400.00	4,470.59
to EU	2,400.00	2,400.00	2,400.00	2,400.00	2,400.00	2,400.00	2,400.00	2,400.00
from EU	3,529.41	2,400.00	2,941.18	2,400.00	2,400.00	3,235.29	2,400.00	3,470.59
THC (Terminal Handling Charge)	73.48	65.79	117.65	64.7		64.70	64.70	58.82
Land Transportation								
El Salvador								
East	346.64	73.67	621.88	764.35	769.66	562.45	558.88	623.67
West	127.07	269.98	402.79	560.23	565.25	604.12	520.35	429.15
Guatemala	287.04	629.68	150.51	450.66	450.66	568.68	623.45	976.88
Honduras								
North	680.95	495.70	786.22	233.91	233.91	88.81	86.90	746.71
South	614.98	274.47	1,079.59	542.82	542.82	452.33	368.56	395.74
Nicaragua	877.13	536.62	1,151.70	1,053.09	1,053.09	962.59	878.82	212.33

Table 7.5 Transit Time in 2010 (Days)

	Acajutla	La Union	Quetzal	Santo Tomas	Pt. Barrios	Pt. Cortes	Pt. Castilla	Corinto
Ocean Transit Time								
USWC	6.90	7.38	6.76	12.09	12.09	12.11	11.55	7.55
USG	6.57	6.33	6.74	2.60	2.59	2.67	2.36	6.09
China	24.77	25.25	24.63	29.96	29.96	29.98	29.42	25.42
EU	18.16	17.92	18.33	15.65	15.65	15.73	15.42	17.68
Dwell Time in Port	2.50	2.50	2.50	2.50	2.50	2.50	2.50	2.50

Land Transit Time								
El Salvador								
East	0.17	0.17	0.75	0.94	0.94	0.65	1.03	0.45
West	0.31	0.17	0.32	0.63	0.63	0.80	1.37	0.84
Guatemala	0.70	1.20	0.17	0.50	0.50	0.64	1.27	1.09
Honduras								
North	0.76	0.30	0.88	0.26	0.26	0.10	0.59	0.84
South	0.69	0.60	1.21	0.61	0.61	0.51	0.68	0.44
Nicaragua	0.98	0.59	1.29	1.18	1.18	1.08	1.24	0.24

(2) The potential market share of La Union port

1)Total Cost including Time Value is calculated from the above-mentioned data.
Cost is Ocean Freight Rate and Land Transportation.

2) We calculate θ = Coefficient of Cost and γ = Coefficient of time, for Estimated Share (%) is as closest to Share in 2010 (%).

3) With these data, we calculate the Utility of each port and the potential market share of La Union port.

Table 7.6 Hinterland transport matrix(with La Union)

Hinterland transport matrix Import: Pacific (2010) (TEU)

	Acajutla	Quetzal	S Tomas / P Barrios	Pt. Cortes / Pt. Castilla	Corinto	**La Union**	Total
El Salvador (E)	67	6	1	2	4	498	578
El Salvador (W)	30,012	2,890	289	285	2,134	10,692	46,302
Guatemala	9,802	59,481	9	0	0	14	69,306
Honduras (N)	15	1	1,029	10,995	1	449	12,490
Honduras (S)	11	0	1	8	113	5,220	5,353
Nicaragua	0	0	0	0	16,813	0	16,813
Total	39,907	62,378	1,329	11,290	19,065	16,873	150,842

Hinterland transport matrix Import: Atlantic (2010) (TEU)

	Acajutla	Quetzal	S Tomas / P Barrios	Pt. Cortes / Pt. Castilla	Corinto	**La Union**	Total
El Salvador (E)	85	23	29	61	18	253	469
El Salvador (W)	15,313	1,412	11,769	10,434	1,262	6,111	46,301
Guatemala	4,577	17,212	149,886	20,555	0	87	192,317
Honduras (N)	0	0	1,891	91,444	0	0	93,335
Honduras (S)	0	0	576	28,012	15	11,397	40,000
Nicaragua	38	0	0	10,145	5,524	610	16,317
Total	20,013	18,647	164,151	160,651	6,819	18,458	388,739

Hinterland transport matrix Export: Pacific (2010) (TEU)

	Acajutla	Quetzal	S Tomas / P Barrios	Pt. Cortes / Pt. Castilla	Corinto	**La Union**	Total
El Salvador (E)	18	2	0	0	0	248	268
El Salvador (W)	19,808	1,950	73	29	293	4,482	26,635
Guatemala	4,286	41,324	1	0	0	1	45,612
Honduras (N)	75	10	1,486	5,669	13	1,043	8,296
Honduras (S)	19	0	2	7	167	2,186	2,381
Nicaragua	0	0	0	0	6,242	0	6,242
Total	24,206	43,286	1,562	5,705	6,715	7,960	89,434

Hinterland transport matrix Export: Atlantic (2010) (TEU)

	Acajutla	Quetzal	S Tomas / P Barrios	Pt. Cortes / Pt. Castilla	Corinto	**La Union**	Total
El Salvador (E)	7	0	1	13	0	248	269
El Salvador (W)	6,926	1,307	7,057	6,408	1,238	3,699	26,635
Guatemala	3,189	11,791	171,402	24,780	0	73	211,235
Honduras (N)	0	0	7,457	101,208	0	1	108,666
Honduras (S)	1	0	1,782	24,247	11	2,504	28,545
Nicaragua	27	0	0	12,134	1,905	281	14,347
Total	10,150	13,098	187,699	168,790	3,154	6,806	389,697

(3) The future volume of container for La Union port

1) Scenario 1:Change of competitiveness due to difference of inflation rate among CA4 countries

Given the differences in inflation levels of CA4, it is important to estimate the potential demand variations due to changes in inflation as follows:

a)The inflation rates were taken from USDA (United States Department of Agriculture), selected base year is 2010.

b)The elements were varied:
+Shipping costs: The costs of sea transport for 2020 and 2030 were calculated by multiplying the cost of 2010 for global inflation in 2020 and 2030 respectively, and dividing the result by the global inflation base year.

+Cost management terminal: The terminal handling costs for 2020 and 2030 were calculated by multiplying the cost of 2010 for inflation in each country in 2020 and 2030 respectively, and dividing by the country's inflation to year base.

+ Overland transport costs: Inflation data were used for land transport costs by country, by multiplying the cost of each country by its respective inflation in 2020/2030.

+ Coefficients: The time factor remains constant; at factor cost in turn is added to the country's inflation analysis.

Projected market allocation for La Union Port in 2020 and 2030 is shown below.
(Case where capacity of Acajutla port is not limited.)

	2010	2020	2030
World	100	135.7	179.73
El Salvador	100	136.26	174.63
Guatemala	100	156.13	228.59
Honduras	100	170.93	270.93
Nicaragua	100	191.48	311.75

Table 7.7 Projected market allocation for La Union Port in 2020,2030(Scenario 1)

Projected market allocation for La Union Port in 2020 (TEU)

La Union Port	IMPORT: Pacific	IMPORT : Atlantic	EXPORT: Pacific	EXPORT : Atlantic
El Salvador (E)	1,006	551	499	513
El Salvador (W)	22,422	15,235	9,528	8,856
Guatemala	0	315	5	2,099
Honduras (N)	1,987	0	2,017	5
Honduras (S)	8,335	51,388	3,573	24,070
Nicaragua	6	1,908	697	792
Total	33,756	69,397	16,319	36,335

Projected market allocation for La Union Port in 2030 (TEU)

La Union Port	IMPORT: Pacific	IMPORT : Atlantic	EXPORT: Pacific	EXPORT : Atlantic
El Salvador (E)	1,997	1,164	987	1,030
El Salvador (W)	45,726	35,768	19,467	20,529
Guatemala	178	1,243	22	6,224
Honduras (N)	385	3	3,888	3
Honduras (S)	13,268	95,934	5,747	60,650
Nicaragua	30,600	2,243	8,916	880
Total	92,154	136,355	39,027	89,316

Chapter 8 Vessel Calling Model

Chapter 8 Vessel Calling Model

8.1 Ports of El Salvador

8.1.1 Outline of El Salvador

Republic of El Salvador faces the Pacific Ocean and borders between the Republic of Guatemala and the Republic of Honduras. Its land area is 21,949 km^2 and it has a population of 6.23 million people in 2011 (World Bank data). San Salvador is the capital. The port of Acajutla faces the Pacific Ocean while the Port of La Union is located at the west side of the Gulf of Fonseca connected to the Pacific Ocean via a navigation channel.

Main industries are garment industry whose products are manufactured in Maquiladoras. GDP is USD 23,054 million and Per Capita is USD 3,728.6 in 2011 (Central Bank). GDP has sustained positive growth despite damage inflicted by an earthquake and hurricane after the end of the civil war.

The exports amounted to USD 5,308.8 million (FOB) and the imports to USD 10,118.2 million (CIF) in 2011. Main export goods are garments, coffee and sugar and main import goods are raw and in-process materials such as oil and fertilizer, consumer products and capital goods such as vehicles.

8.1.2 Outline of ports of El Salvador

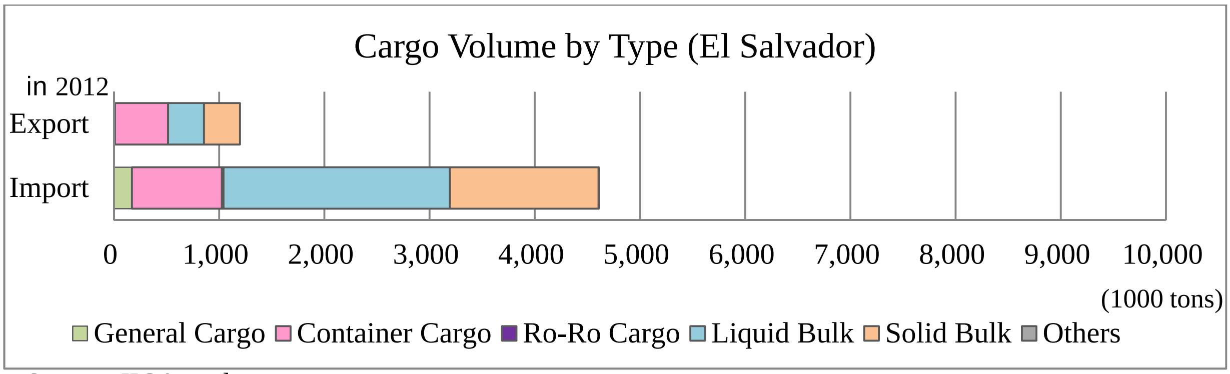
Four ports of Acajutla, La Unión, Corsain and Boyas Alba Petróleos, Cenergica y RASA are listed in the statistics of COCATRAM (2012). Acajutla Port and La Unión Port are commercial ports managed by CEPA. Corsain Ports is a port for fishery activities and managed by CORSAIN. Boyas Alba Petróleos, Cenergica y RASA is a private port owned by Alba Petróleos.

8.1.3 Major facilities of ports

In El Salvador, there are no ports with complete advanced loading/unloading systems. La Union Port, which was completed in 2009, is scheduled to be equipped with the country’s only quay side gantry crane for containers. Acajutla Port, which handles more cargo than any other port in the country, loads and unloads containers mainly using a ship’s crane, but has no quay side gantry crane.

8.1.4 Cargo volume by type

In 2012, calling vessels at these ports amounts to 742 and cargo volume through these ports was 5,806 thousand tons. A breakdown of import and export cargo by type is shown in Figure 8.1. Container cargo accounts for 42.5% of export cargo and 18.6% of import cargo. Table 8.1 shows the trend of ship calls and cargo volume of these four ports from 2007 to 2012.



Source: JICA study team

Figure 8.1 Cargo Volume of Main Ports of El Salvador

Table 8.1 Tendency of Ship Calls and Handling Cargo of Main Ports of El Salvador

		2007	2008	2009	2010	2011	2012
Ship Call		855	729	651	620	725	742
Cargo Volume	Import	1,068	1,211	980	1,204	1,119	1,199
	Export	5,087	4,800	3,951	4,187	4,729	4,607
	Total	6,156	6,010	4,931	5,392	5,848	5,806

Source: JICA study team

8.1.5 Acajutla Port

(1) Overview

Acajutla Port is located in western El Salvador on the Pacific coast of the State of Sonsonate near Guatemala. It takes about 2 hours to travel by road from the capital city of San Salvador; about 50 years have passed since it came into use during the 1960s (see Figure 8.2).

Source: Worldatlas

Figure 8.2 Location of Acajutla Port

(2) Port facilities

Acajutla Port has three piers jutting into the Pacific which form an “F” shape (see Figure 8.3). Pier A has a total berth length of 300m and its depth is 12m. The oldest pier, constructed between 1957 and 1960, is a steel sheet pile cellar-bulkhead pier, and its side facing the outer ocean is a continuous structure which acts as a breakwater. Pier B is an open-type wharf on a vertical piled jetty, with length of 328m on the side facing the ocean and 345m on the side facing the land. Pier C starts at the tip of pier A, which is the top line of the F-shape. Angled slightly to the land it is 270m in length and its depth is 14m. It is a caisson structure that also acts as a breakwater, preventing waves from flowing into the inner harbor.

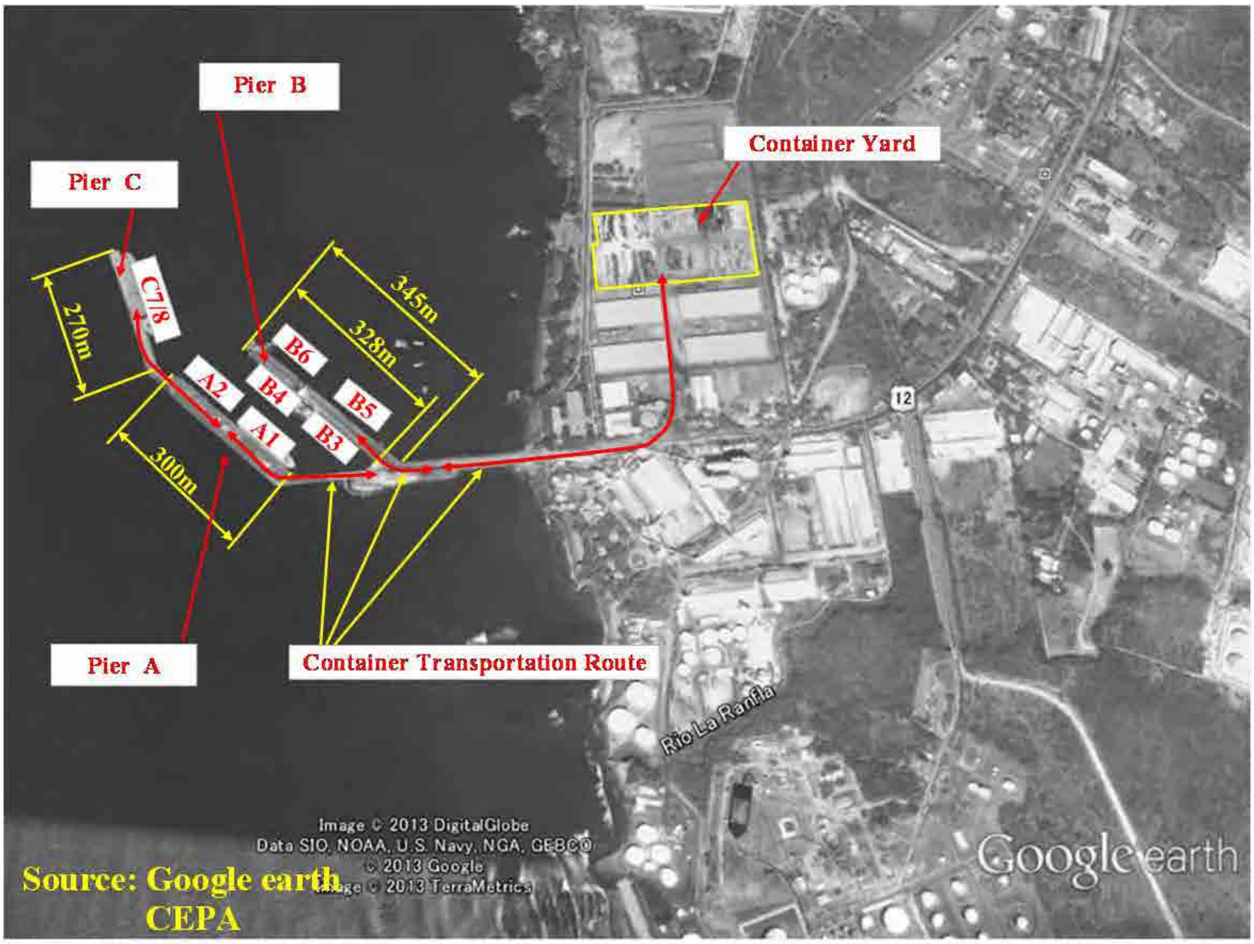


Figure 8.3 Port Layout

(3) Port activities

1) Cargo throughput

a) Total cargo

Cargo handled at the port is classified into 4 categories: general cargo, containerized cargo, dry bulk, and liquid bulk. Total cargo volume reached 3.96 million tons in 2012, a 36% increased from 2003. Imports represent 71% of total trade while exports account for 29%.

b) Container cargo in TEUs

Container cargoes handled at Acajutla Port came to 160,000 TEU in 2012: 82,000 (51%) TEU of imports, and 78,000 (49%) TEU of exports.

Concerning the partner countries of import and export commodities in container cargoes in 2012, the volume of trade with China (27.3%) and the United States (25.0%) was high, with these two countries supplying more than half of all imports. Concerning major import products, the port imported large quantities of apparel materials, paper, tires, fruit, canned goods, and miscellaneous items from the United States, and large quantities of apparel materials, metal products, and electrical appliances from China.

Among destination countries of exports, the United States was first (47.7%) followed by Chile (5.6%), Taiwan (5.6%), and South Korea (4.3%). The top products exported to the United States were apparel, coffee, and frozen foods. The top exports to Chile were apparel, frozen foods, and used paper, etc. For Taiwan and South Korea, the top exports were apparel and coffee respectively.

2) Ship calling

Most cargo ships calling at Acajutla Port were container ships. A total of 269 container ships called in 2012, followed by 115 dry bulk ships, 83 general cargo ships, 78 liquid bulk ship and 7 mixed ships. A total of 82 liquid bulk ships docked at the offshore petroleum buoy.

(4) Capacity of container handling

1) Management of container operation

The piers in Acajutla Port were constructed about 50 years ago. Structural limitations prevent cranes from being installed to handle containers, so containers are loaded/unloaded using a ship's crane. Loading and unloading container cargo is done mainly at berth A-2, B-6 and C-7/8 where the handling efficiency per hour per ship's crane is 13.5 boxes/1 ship's crane/hour. Container yard has an area of about 40,000 m^2 and its storage capacity is 2,500 TEU/time. The average number of days containers dwell in the container yard is 4.9 days. The empty container ratio is 1% for imports and 33% for exports.

2) Container handling capacity

a) Quay side capacity

The berth occupancy rates of each pier are 12% for A-1, 44% for A-2, 10% for B-3, 23% for B-4, 6% for B-5, 14% for B-6, and 58% for C7/8. Typically, when BOR reaches approximately 60%, usage of the berth is high and congestion gradually begins; when BOR exceeds 65%, construction of a new berth is usually required.

A-2, B-6 and C-7/8 berths mainly handle container cargo and container handling BOR of each berth are 24%, 10% and 26%. However, other cargo such as general cargo, bulk cargo and mixed cargo are handled at those berths so the overall BOR values of each berth are 44%, 14% and 58% respectively. Berth C-7/8 is already in a state of high usage while it would be difficult to significantly increase the volume of containers handled at berth B due to the installation of a bulk unloader with conveyor system at the middle of the pier. Berth A-2, however, can still handle more containers.

The value of expected container increase in TEU is considered based on the difference between present berth assignment and the upper limit value of BOR (65% is adopted). Expected increase in container becomes 36,115 TEU at Berth A-2, 6,054 TEU at Berth C-7/8, for a totally increase of 42,000 TEU. Therefore, capacity of the quay side is estimated at 202,000 TEU per annum.

b) Container yard capacity

Since containers are handled and stored in the container yard, the annual cargo handling capacity of a container terminal is determined by the storage capacity and turnover rate of the container at the yard. Annual container terminal capacity is estimated at 183,000 TEU.

CEPA plans to introduce measures for increasing the volume of container cargo through Acajutla Port. It will be possible to secure capacity of 26,000 TEU/year by reallocating 11,000m^2 of unused space between warehouses in the yard as container yard space. Increasing the number of stacking levels in the yard from 3 to 4 is also being studied. This will increase the yard capacity to about 61,000 TEU/year and overall capacity to approximately 270,000 TEU per annum.

(5) Diagnosis survey of deterioration degree of berth in Acajutla Port

1) Each berth of Acajutla Port

Features of port facilities in Acajutla Port are shown in Table 8.2.

Table 8.2 Port facilities and Present Status in Acajutla Port

Berth		A berth	B berth	C berth
Year constructed		1957 to 1960	1969	1973 to1974
Structure		Cell type	Steel pipe pile type	Caisson type
Heaviest Allowable Load		A1,2,3: 3.0ton/m^2 A4,5:AASHTOH※ 20-S16	B1,2,3: 0.815ton/m^2 B4:1.56ton/m^2	3.5ton/m^2
Age (years)		53	44	39
Present situation		Repair works for steel sheet pile portion are being undertaken	No repairs are currently scheduled	No repairs are currently scheduled
Repair		Performed as needed	Performed as needed	Performed as needed
Current Status	Cathodic protection	External power supply method	External power supply method	
	Steel structures	Painting on steel sheet piles Now repairing on steel sheet pile portion	Painting on steel pipe piles	
	Concrete		Painting on concrete	Painting on concrete side surface

※AASHTO：American Associations of State Highway and Transportation Officials
Source: CEPA, Study Team

2) Diagnosis survey of deterioration degree

a) Visual and hammering inspection

Visual and hammering inspections were performed from a boat for the substructures of A, B, and C berths. Continuous red-orange colored rust was observed on steel sheet piles in A berth. Rust could not be observed on steel pipe piles in B berth. Although something like red rust is observed, it is assumed to derive from the anticorrosive paint of base black paint which has peeled off. Also, neither cracks nor rust can be observed from painted surface of C berth facing to outer sea.

b) Schmidt hammer test

Concrete strength measurement was performed by Schmidt hammer on concrete beam of substructure in A berth slab and apron concrete portion in C berth. Tests were conducted at 15 points at each site. The five points where the obtained values were exceedingly low or high were excluded and then the average value was obtained from the remaining ten points. Test results by Schmidt hammer test are 391kg/cm^2 in Pier A, 469kg/cm^2 at the end of superstructure in Pier C, and 248kg/cm^2 at the center of superstructure in Pier C respectively.

c) Consideration on the remaining service life of port facilities at Acajutla Port

Concerning A berth, CEPA performed periodical inspections such as measuring the thickness of steel materials and is conducting patching or other applying other repair methods to meet the original design standard. The section of A berth where concrete has fallen off is scheduled to be repaired based on the original design. Therefore, the current structural problems are being addressed which will extend the service lives of the facilities. B and C berths are relatively well maintained in spite of the advanced age of the structures. It is required to continue current maintenance management in future.

Accordingly, based on inspection results and the age of berths, it is assumed that these facilities can be used for a period of 5 to 10 years if the current maintenance system continues to be followed. CEPA has no plan of large scale rehabilitation or expansion of the existing facilities but the service life of facilities can be extended through repair works. In order to predict the remaining life of steel structures, measuring the thickness of steel material thickness using cathodic protection as at the steel pipe pile for B berth are effective measures.

The use of anti-corrosive paint to protect concrete structures from sea water is an effective measure which has already been introduced. In order to predict the remaining service life of concrete structures, methods using nondestructive testing equipment such as breaking a part of collected core for measuring penetration depth of chloride ion in the concrete, visually observing salt damage or alkali-silica reaction etc. can be applied.

In order to perform proper maintenance management of facilities in Acajutla Port, it is important to perform periodical inspections (measuring thickness of steel materials, penetration depth of alkali-silica in concrete or etc.) and compile obtained data which can then be used to predict maintenance needs for the next 10 to 20 years.

(6) Port development plan

CEPA has no plan to expand the container terminal in Acajutla Port, but the construction of a 200 MW capacity electric power plant fueled by gas inside the port area has been proposed. This plan includes the construction of a gas pipeline from Pier C to provide natural gas as fuel.

(7) Road network from/to Acajutla Port

The road network linked to the port is a lifeline as important or even more important than the port facilities, in that it permits the smooth distribution of cargoes handled by the port. It is 85 km from this port to San Salvador, which is the capital city and an area of concentrated industries, 45 km to Hachadura on the border with Guatemala, 205 km to Quetzal Port on the Pacific Coast of Guatemala, 209 km to San Jose on the Atlantic side, and 527 m to Santo Tomas. And it is 273 km to Amatillo on the border with Honduras, and 486 km to Cortes Port on the Atlantic Coast of Honduras.

8.1.6 La Union Port

(1) Overview

La Union Port is located in La Union Department in the east end of El Salvador about 185 km from the capital, where it faces the Gulf of Fonseca. It is counted on to be a base which will stimulate industrial development in the eastern part of El Salvador to improve its sluggish economy. It has been developed as a new port with container handling as its principal role. Financed by yen loans provided by Japan, construction began in 2005 and was completed in 2009. The port opened in 2010.

(2) Port facilities

La Union Port consists of a container berth (total length of 340m and depth of 14m), a multi-purpose berth (total length of 220m and depth of 14m), and a passenger vessel berth (total length of 240m and depth of 9.5m) (see Figure 8.4).

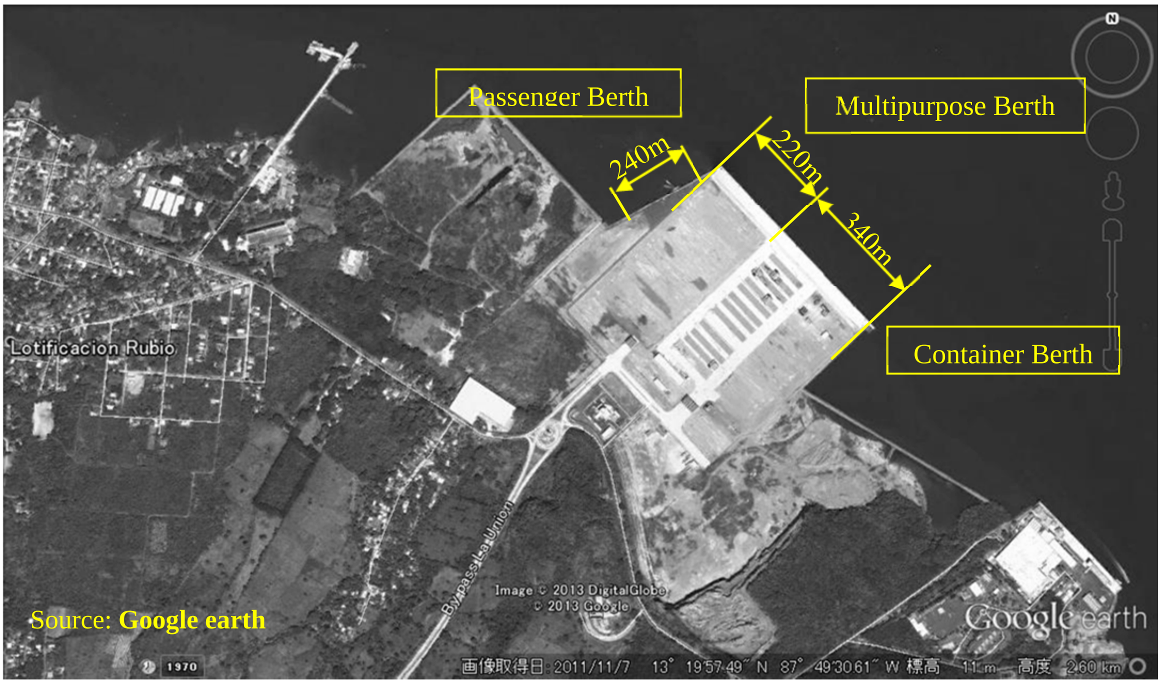


Figure 8.4 Port Layout of La Union Port

(3) Port activities

La Union Port started operation in 2010. Regular container ship service was provided, but by the end of 2012, it was difficult for container ships to visit the port. Later, dry bulk ships transporting fertilizer visited once a week. As a result of siltation, which has been a concern since the time of construction, the depth of the passage has been reduced.

1) Cargo throughput

La Union Port began to handle cargoes in 2010. After container vessels stopped calling at the port in December 2012, bulk carriers transporting fertilizer visited the port once a week. In 2010, total import and export throughput reached 19,670 tons. In 2011, it rose to 42,820 tons and to 118,424 tons in 2012, but this is a small quantity.

Container operation at La Union Port started in 2010 and container throughput was 886 TEU in 2010 followed by 3,958 TEU in 2011, 18398 TEU in 2012. Operation ended in December 2012, and since that time, no container ships have called at the port. At this time, a dry bulk ship carrying fertilizer calls once a week.

2) Ship calling

In 2012, 57 cargo ships called at La Union Port. Most (48) were container ships, followed by 5 general cargo ships and 4 dry bulk ships. The average container ship type was 18,600 DWT carrying from 1,000 to 1,200 TEU. Similarly, the average dry bulk ship was 37,000 DWT and the average general cargo ship was 2,200 DWT.

(4) Port development plan

The master plan for La Union Port is divided into four phases from Phase I to Phase IV. Phase I, which is now in progress, will be followed by Phase II, extending the port to the south-east, then Phase III, which will be an extension in the opposite direction to the north-west. Phase IV will further extend the south-east extension constructed in Phase II. The container cargo handling capacity is planned to be 750,000 TEU after Phase I, and 2.5 million TEU after Phase III.

8.2 Ports on the Pacific Coast of CA5 countries

In order to grasp the characteristics of each port and what the ports have in common, the economic situation of CA5 countries, location of the ports along the Pacific Ocean, physical conditions of the ports, outline of ship call and handling cargo, container handling, management and operation and future development of the ports are summarized.

8.2.1 Basic Indicator

Land areas of Guatemala, Honduras and Nicaragua exceed over 100, 000 km^2. Land area of Costa Rica, about 50,000 km^2, is approximately half of that while that of El Salvador, about 20,000 km^2, is less than half of Costa Rica.

Guatemala has the largest population of 15 million, followed by Honduras (7.75 million), El Salvador (6.23 million), Nicaragua (5.87 million) and Costa Rica (47.2 thousand).

GDPs of Guatemala and Costa Rica exceed USD 40 billion, that of El Salvador is about USD 20 billion, that of Honduras is about USD 17 billion. GDP of Nicaragua is USD 7 billion. Per capita of Costa Rica exceeds USD 8,000. El Salvador and Guatemala are USD 3000 levels, Honduras is 2,000 level and Nicaragua is USD 1000 level.

8.2.2 Locational conditions

There are six container ports along the Pacific Ocean of CA 5 countries: Quetzal Port (Guatemala), Acajutla Port (El Salvador), La Union Port (El Salvador), San Lorenzo Port (Honduras), Corinto Port (Nicaragua) and Caldera Port (Costa Rica).

Acajutla Port, Corinto Port and La Union Port are located far from the capital of the countries while the other ports are located less than 100 km from the capital city.

Ports besides Corinto Port and Quetzal Port are located within less than 15 km from trunk roads.

Distances between Acajutla Port and the border to Guatemala, La Union Port and the border to Honduras and San Lorenzo Port and the border to El Salvador are approximately 50 km while those between other ports and the borders are 100 km to 400 km.

Ports on the Pacific Coast of CA5 are located within one-day navigational distance at a speed of 20 knots. Nautical Distances between ports on the Pacific Coast of CA5 and Manzanillo Port in Mexico or Balboa Port in Panama which are international hub ports on the Pacific Coast of Central American region are approximately two to three-day or one to two-day navigational distance at a speed of 20 knots respectively.

8.2.3 Physical conditions

Quetzal Port is an excavated-type port with quays and yards located at several areas. Acajutla Port has several finger-type piers and land area for cargo storage. La Union Port is a newly developed port with several berths and wide back yards by reclamation in Fonseca Bay. San Lorenzo Port has a T-shaped detouched pier and land area for cargo storage and is located on Fonseca Bay. Corinto Port is located at the inner side of the peninsula and has a marginal wharf with a backyard for cargo storage.

Ports except Acajutla Port do not have a problem concerning calmness of port waters but all ports need to take measures for maintaining appropriate depth of port waters.

La Union Port and San Lorenzo Port which are located in Fonseca Bay have a long approach channel.

According to Guide to Port Entry published by Shipping guides ltd. which provides useful information to those who intend to enter a port, the depths of wharves for container vessels at each port are 11.0 m at Quetzal Port, 8.00 – 12.00 at Acajutla Port, 10.70 m at San Lorenzo Port, 10.30 to 11.30 m at Corinto Port and 7.50 to 11.0 m at Caldera Port. The maximum draft of vessels which can be accommodated is 11.1 m (MLSW) at Quetzal Port, 11.89 m at Acajutla Port, 9.45 m (MLW) at San Lorenzo Port, 11.15 m at Corinto Port and 10.0 m at Cardela Port. Information on the new La Union Port is not included in the Guide.

Many containers are loaded/unloaded at wharves not dedicated to container handling. Ports except Corinto Port do not have gantry cranes while the crane at Corinto Port is out of order at present. Yard capacities of each port are 1,974 TEU at Quetzal Port, 3,753 TEU at Acajutla Port, 1,500 TEU at Corinto Port and 700 TEU at Caldera Port.

8.2.4 Port Management and Operation

Acajutla Port and La Union Port are managed by Comision Ejecutiva Portuaria Autonoma (CEPA), San Lorenzo Port is managed by Empresa Nacional Portuaria (ENP) and Corinto Port is managed by Empresa Portuaria Nacional (EPN) .CEPA, ENP and EPN are the governmental agencies which are responsible for port management and operation of the ports in each country. Quetzal Port is managed by Empresa Portuaria Quetzal (EPQ) which is a governmental agency. EPQ is responsible for management and operation of Quetzal Port but a new container terminal will be constructed and operated by a private company under a concession contract. Regarding Caldera Port, the Costa Rican Institute of Pacific Ports (INCOP) is a governmental agency and plays a role of a regulator on the port. Puerto Caldera SPC and Puerto Caldera SPGC which are consortiums of a Costa Rican company and Columbian company are responsible for port operation under a concession contract.

Each port is open 24 hours but La Union Port, San Lorenzo Port and Corinto Port place restrictions on port use based on tidal conditions.

8.2.5 Characteristics of ports

In 2012, 1,47 ships called Quetzal Port, 552 called Acajutla Port, 57 called La Union Port, 190 called San Lorenzo Port, 403 called Corinto Port and 611 called at Caldera Port. Total number of vessels which called at these ports in 2012 is 3,059.

Container vessels account for the largest portion among the vessel types at every port except San Lorenzo Port.

Quetzal Port and Caldera Port receive all types of vessels except oil tankers. Acajutla Port also receives almost all types but refrigerator vessels, oil tankers and cruisers do not use the port. At San Lorenzo Port, most calls are from RoRo vessels, solid vessels and oil tankers. Corinto Port receives many conventional vessels.

Cargo handling volume of Quetzal Port in 2012 was 11,258 thousand tons (8,560 thousand tons of import and 2,698 thousand tons of export), while it was 5,096 thousand tons (3,967 thousand tons of import and 1,129 thousand tons of export) at Acajutla Port, 118 thousand tons (52 thousand tons of import and 66 thousand tons of export) at La Union Port, 3,903 thousand tons (2,395 thousand tons of import and 1,598 thousand tons of export) at San Lorenzo Port, 3,439 thousand tons (2,750 thousand tons of import and 689 thousand tons of export) at Corinto Port and 4,732 thousand tons (4,032 thousand tons of import and 700 thousand tons of export) at Caldera Port. The total volume of cargo handled at these ports in 2012 is 28,546 thousand tons (21,756 thousand tons of import and 6,790 thousand tons of export).

Export cargo volumes are larger than import cargo volumes at every port. Percentages of export cargo volume of each port in 2012 are 76.0 % for Quetzal Port, 77.8 % for Acajutla Port, 61.3 % for San Lorenzo Port, 79.9 % for Corinto Port and 85.2 % for Caldera Port.

Dominant cargo types of each port are:

- Imported and exported solid bulk and exported containers for Quetzal Port;
- Imported and exported solid bulk, exported containers and exported liquid bulk for Acajutla Port;
- Imported liquid bulk and exported solid bulk for San Lorenzo Port
- Imported liquid bulk, imported and exported solid bulk and exported containers for Corinto Port; and
- Imported and exported containers and imported solid bulk for Caldera Port

8.2.6 Characteristics of handling containers

Container throughput of Quetzal Port in 2012 was 324,507 TEU, while it was 160,981 TEU at Acajutla Port, 13,398 TEU at La Union Port, 89,538 TEU at Corinto Port and 184,315 TEU at Caldera Port. Total container throughput of these ports in 2012 was 777, 379 TEU.

Ratios of empty containers are approximately one fourth to one third. Percentages of empty containers in all loading containers are high such as 53.8 % at Acajutla Port, 47.5% at Corinto Port, 41.9% at Caldera Port and 33.2 % at Quetzal Port.

Quetzal Port and Corinto Port handle transit containers and transshipment containers. Acajutla Port handles transshipment containers.

8.2.7 Future Development and Improvement

Quetzal Port has a plan to develop a new container terminal. It is scheduled to be open next to the existing commercial berth in 2015 Phase I). A 540m long berth with 14.5 m in depth and four gantry cranes (300 m in Phase I)will be constructed by Terminal de Contenedores de Barcelona (TCB) under a concession contract. The targeted container volume is 150 thousand TEU in 3-5 years and 450 to 600 thousand TEU in 5-10 years. There is another project of expanding the existing commercial berth to a multipurpose berth with 400 m in length. Quetzal Port aims to become a transshipment port in the Central America and South Mexico region.

Acajutla Port has a plan to improve the access road and expand container yard capacity corresponding to the urgent requirements.

La Union Port is planning the improvement of the channel. In addition, concession contract procedures are in process.

San Lorenzo Port Office of ENP has a plan to deepen the channel up to 11 m.

EPN plans to dredge the outer channel of Corinto Port in 2014. The volume is estimated to reach

5.6 million m^3. The dredging cost was USD 12 per m^3 in the previous work but it is estimated to be USD 5-7 per m^3 at this time because the dumping cost and ship mobilization cost is expected to be less than the previous time. In addition to the dredging, EPN would like to improve the south wharf which is not used at present. Quay crane which is out of commission at present will be repaired. Productivity of a gantry crane is 18-22 boxes/h. That of a ship gear is 13-15. Owing to its high usage charge, only Maersk used the gantry crane. Corinto Port has a possibility to introduce a concession scheme under the act in the future.

At Caldera Port, a new bulk berth with 180 m in length and 13 m in depth is under construction. The project was planned by INCOP and is being implemented by SPGC. Regarding dredging work, the government is responsible for improving and maintaining the channel and basin and SPC is responsible for dredging the water area in front of the berths.

8.3 Container Activities of Central American region

8.3.1 Containership movement in the Central American region

Container movement of the Central American region has been increasing and container throughput of ports in the region reflects such a situation. Number of containers handled in Central American ports has been growing steadily in these ten years and total number of containers handled in these twenty two ports has exceeded 10 million TEUs since 2008.

Container throughputs of the ports of Cristobal, Balboa and Manzanillo show distinctive features. These ports function as international hub ports and their activities have been increasing. Another characteristic feature is the increase of container throughput at the ports on the Pacific Coast. It accounted for a quarter of container throughput at the ports on the Caribbean Sea Coast in 2001. However container throughput of the ports along the Pacific Ocean Coast in 2010 exceeded that at the ports on the Caribbean Sea Coast.

According to MDS Containership Databank provided by MDS Transmodal Inc. (hereinafter referred to as MDS data) in May 2013, thirty-one vessels are deployed in the container service to the ports on the Pacific Coast of CA5. The largest vessel has 5040 TEU of capacity and the smallest one 860 TEU.

The ports on the Pacific Coast of CA5 receive mostly vessels with less than 11.0 m of full load draft. Larger vessels with full load draft of more than 13.0 may call at the ports when these vessels enter the port in half cargo loaded conditions.

Table 8.3 shows the changes in number of container services calling at ports. (MDS: May 2010 and February 2012 and May 2013) Although the number of total services decreased from 13 to 9 between May 2010 and May 2013, the number of the services which offered joint sailing increased from 3 to 6. Also, the number of shipping companies which chartered slots increased from 1 to 4.

Various types of containerships with capacity changing from 204 TEU to 4,420 TEU were deployed on each service. Containerships calling to Acajutla Port had capacity from 905TEU to 2,517 TEU. Average capacity is 1,577 TEU. Containership of 4,000 TEU class called at Quetzal port. These container ships handle Asian cargo which is transshipped at Quetzal port.

Table 8.3 Changes in number of container services calling at ports

MDS 2010,May

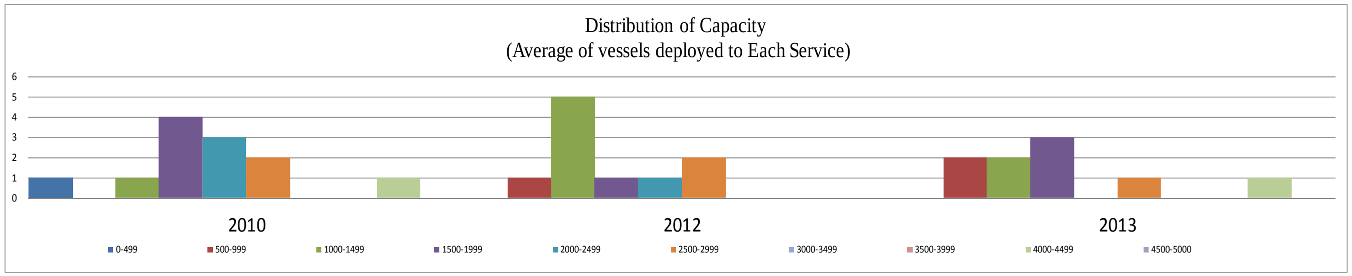
Called Port (CA -Pacific side)	Service	Shipping company	TEU Average of container ship	Service frequency
Acajutla Puerto Quetzal	-	APL	830	52
Acajutla Caldera	ANDEX 2	CSAV	1,695	52
Acajutla Puerto Quetzal Corinto	ACSA	CMA-CGM CSCL CCNI (Slot charter)	2,516	52
Acajutla Puerto Quetzal Corinto Caldera	MAREX	NYK	1,610	52
Acajutla Puerto Quetzal Caldera Balboa	MAYA	MSC	1,232	26
Acajutla Puerto Quetzal Corinto Caldera Balboa	WCCA	MAERSK LINE	1,695	52
Puerto Quetzal	NACSA	CCNI CSAV HAMBURG-SUD	1,892	52
	ALPALGA	CCNI MSC HAMBURG-SUD	4,184	52
	MPS	HAPAG-LLOYD	2,336	33
	WC	GREAT WHITE FLEET	204	52
	ALEX	NYK	2,706	52
Puerto Quetzal Caldera Balboa	PUMA	MSC	2,350	52
Puerto Quetzal Caldera	MXP	HAPAG-LLOYD	2,211	26
Total Services				*13*
The number of services which call at Acajutla port				*6*
The number of services which call at Puerto Quetzal				*12*

MDS 2012,Feb

Called Port (CA -Pacific side)	Service	Shipping company	TEU Average of container ship	Service frequency
Acajutla Puerto Quetzal	MCX/WECA 2	APL HAMBURG-SUD	1,100	52
Acajutla Puerto Quetzal Corinto Caldera Balboa	ACSA	CMA CGM MSC CSAV	1,000	52
	WCCA	MAERSK LINE MSC (Slot charter)	2,504	52
Acajutla Puerto Quetzal Corinto Caldera	MAREX	NYK	1,458	52
Acajutla Puerto Quetzal Caldera	MXC	CFS HAPAG-LLOYD (Slot charter)	1,304	26
La Union Puerto Quetzal Caldera Balboa	WCX/WECA1	APL HAMBURG-SUD	1,324	52
Puerto Quetzal	WC	GREAT WHITE FLEET	2,625	36
	WAMS	HAMBURG-SUD CCNI	1,982	52
	MXP	HAPAG-LLOYD	2,294	26
Puerto Quetzal Caldera	WCSA	DOLE	910	52
Total Services				*10*
The number of services which call at Acajutla port				*5*
The number of services which call at La Union port				*1*
The number of services which call at Puerto Quetzal				*10*

MDS 2013,May

Called Port (CA -Pacific side)	Service	Shipping company	TEU Average of container ship	Service frequency
Acajutla Puerto Quetzal Balboa	WCX	APL	1,310	52
Acajutla Puerto Quetzal Corinto Caldera	TIKAL/WCCA	CMA-CGM CSAV	1,553	52
Acajutla Puerto Quetzal Corinto	MAREX/CCE	NYK HAPAG-LLOYD	2,517	52
Acajutla Puerto Quetzal Corinto Balboa	WCCA	MAERSK LINE MSC (Slot charter) Evergreen (Slot charter)	1,922	52
Acajutla Puerto Quetzal San Lorenzo Corinto Caldera	WCA	Evergreen X-Press Feeders Hamburg-Sud (Slot charter)	905	52
Puerto Quetzal	WSA2	COSCO Evergreen PIL WAN HAI	4,420	46
Puerto Quetzal Caldera	WCSA	DOLE	910	52
Puerto Quetzal Balboa	WAMS	Hamburg-Sud CCNI Great White Fleet (Slot charter)	1,820	52
Caldera Balboa	PAN/CHL	MAERSK LINE	1,122	52
Total Services				*9*
The number of services which call at Acajutla port				*5*
The number of services which call at Puerto Quetzal				*8*



Source: Prepared from MDS Databank

8.3.2 Views of shipping operators

(1) General view of the container shipping on the Pacific Coast of CA5

Interviews with shipping agents, shippers and other organizations which are located at El Salvador and neighboring countries were conducted. Main points grasped through the interviews are summarized as follows.

a) Each shipping operator develops their business based on its own policy but almost all operators have the view that the ports on the Pacific Coast of CA5 are situated as feeder ports in Mexico or Panama-based container networks.

b) Many operators provide weekly services to Quetzal Port, Acajutla Port, Corinto Port and Caldera Ports. However some operators select one or a few ports as calling ports according to expected cargo volume. Some services skip Caldera Port due to problems in berth assignment.

c) Many services are carried out by joint operation of some companies because cargo volume which one operator can collect is not enough to operate by itself.

d) Various sizes of container vessels are deployed in the service of this region. The largest is 2800 TEU class (LOA: 200m, Draft: 11m) one and the smallest is 670 TEU (draft 8.5m). Several shipping operators think that the size of the vessels deployed to this region will not be affected by the project of the third lock of the Panama Canal.

e) All operators pointed out that the Central American market is small and will not expand rapidly in the near future. Most cargoes which are imported from or exported to EU and North and South America use ports on the Caribbean Coast. Such cargoes are not often transported through the Panama Canal.

f) Complicated procedures at the borders and at ports are pointed out by several operators.

(2) Comments on each port

a) Acajutla Port

Several problems were pointed out; i) it was observed that a vessel had to wait to enter the port owing to swell; ii) Pier A has a safety issue during bad weather because the pier is open to the sea; iii) conditions of berths for container vessels are not satisfactory; iv) depth of quays (10 m) is insufficient for larger vessels; v) RORO vessels are occasionally forced to wait for an adequate tide to set up a ramp way and vessels cannot enter the port when the swell is observed in March to April and August to September; vi) five straddle carriers cannot work simultaneously in the container yard resulting in inefficient operation; vii) physical conditions of the facilities Acajutla Port are aged; viii) Pier B3 does not have sufficient space for cargo handling owing to a conveyor belt; ix) there are 140 to 160 reefer plugs but more plugs are required; x) the port has a problem with power supply; and xi) some bulk carriers must wait for high tide.

On the other hand, most did not have any problems with the manner in which CEPA operated the port. However, they pointed out that administrative procedures by customs, quarantine authority and police take a long time; inspection of container box takes a long time because both customs and the police carry out their own duties. Sample inspection rate by customs is about 16 % (import and export containers) and that by the police is 6% (import containers). Actual time for the inspection is about four hours but it may sometimes take one to three days including waiting time. Nevertheless, almost all shipping companies do not believe cargoes will shift from Acajutla

Port to Quetzal Port after the opening of a new container terminal due to several problems such as security and border issues when cargo from/to El Salvador uses Quetzal Port.

b) La Union Port

(negative/positive views)

Most shipping companies stated that if CEPA decides that the container cargo handling must be shifted to La Union Port, they would have to accept it. However, no shipping company would shift to La Union Port of its own will. The major drawbacks of La Union Port are high transportation cost due to long distance to the port, shortage of inspection area and shallow channel. Also, it would be risky for a shipping company to start a container business in a new region; one of the problems is that the major area where most cargoes are produced and consumed is located near Acajutla Port (such as San Salvador) not La Union Port. In addition, the cargo volume of El Salvador is not large enough to call at both ports. Therefore, at present, some shipping companies consider that there is no benefit to using La Union Port.

However, there are some positive views from shipping companies. For example, some shipping companies said that if La Union Port could provide a channel with a certain depth, there is a chance that La Union Port could replace the port of Manzanillo (Mexico), which is always congested, as a transshipment port. Also, La Union Port is user-friendly and not under bureaucratic management. From the viewpoints of safety and security, La Union Port has an advantage over Acajutla Port. Therefore, La Union Port could be used if the port provides good services such as sufficient equipment, high efficiency or time saving procedures.

For some shipping companies, the depth of the channel is not a crucial factor and quay cranes are not required if small vessels with ship gears are deployed. One shipping operator has expressed an interest in La Union Port because of its modern features. The existing problems can be overcome by deploying a small draft vessel with cranes.

(requests/proposals)

Some shipping companies said that if La Union Port could offer good service which reduces costs in operation, storage and land transportation and there would be enough potential cargo, they would examine calling at La Union Port. Some companies requested that CEPA reduce the tariff of La Union Port in order to compensate for the high land transportation cost or introduce a special tariff for land transport between San Salvador and La Union Port.

Some shipping companies insisted the depth of the channel should be 12 m at least, because 12 m in depth is the threshold level from a shipping company’s viewpoint. On the other hand, other companies said that the required depth of the channel is 11.0 to 11.5 m because they can use the 2 m tidal advantage.

Many companies also requested that a Gantry Crane be installed. Some companies pointed out the need to introduce systematic port-related procedures. Shipping companies desire not only low cost but stable efficiency. Savings in time increase profits.

(3) Preconditions for model analysis based on views of shipping companies

Such views of shipping operators provide necessary information for scenario writing (i.e. setting of future maritime container shipping network) in the simulations which are described in Chapter 10. Also, basic knowledge on container shipping in CA4 to support a model development and input data preparation as summarized as follows is also acquired or reinforced from the findings of the interview survey to the shipping operators.

a) Role of ports on the Pacific Coast and the Caribbean Sea Coast

Cargoes from/to Asia and the west coast of North and South America are imported or exported mainly through the ports on the Pacific Coast in principle. On the other hand, cargoes from/to Europe and the east coast of North and South America are imported or exported mainly through the ports on the Caribbean Sea Coast in principle. In addition, cargoes from/to CA 5 countries are not transported via the Panama Canal in principle.

b) Basic idea on relation between land transportation (cross border transport) and sea transport (using ports)

Cargoes produced and consumed in a country are exported or imported mainly through the ports of the country. However, most Salvadoran cargoes from/to Europe and the east coast of North and South America are imported or exported through the ports of Honduras (Puerto Cortes) and Guatemala (Puerto Barrios and Santo Tomas de Castilla) because El Salvador has no coast along the Caribbean Sea. Also, some Nicaraguan cargoes from/to Europe and the east coast of North and South America are imported or exported through the ports of Honduras (Puerto Cortes) and Costa Rica (Puerto Lemon) because Nicaragua has no major coastal ports along the Caribbean Sea, although it has a long coastal line along the Caribbean Sea. On the other hand, some Honduras cargoes from/to Asia and the west coast of North and South America are imported or exported through the ports along the Pacific Coast of neighboring countries such as Acajutla and La Union because there are only small ports such as San Lorenzo in Honduras along the Pacific Coast.

c) Existing and possible patterns of liner shipping network

The existing liner shipping services in the Pacific Coast of CA4 provided by each shipping company are classified into three patterns; namely, i) feeder service under Mexican or North American west coast-port based service network under which vessels call at ports in every country; ii) feeder service under Panamanian port based service network under which vessels call at ports in every country; and iii) "way-port” service under the route between Asia/North American west coast-ports and South American west coast ports and feeder service network under which vessels of way-port service call at selected port(s). In addition, for the future simulation, a fourth pattern that a certain port in CA5 countries has a hub function on the Pacific Coast in Central America will also be considered.

8.4 Outline of Vessel Calling Model

The outline of the vessel calling model that is developed for this project is shown in Figure 8.5. Major input variables into the model are level of service in each port including channel depth of port of La Union and container cargo shipping demand (container cargo OD).

The model is divided into two parts; consideration of behavior of shipping companies to decide each liner service network and a container cargo assignment model. In the first part, various combinations of the liner service network for each shipping company including port to call and their order, vessel size and frequency which are conditionally restricted by the level of service for each port such as channel and berth depth are prepared. Then, every combination of liner service network is respectively input into the container cargo assignment model, which is developed to include both land and maritime shipping network. By the calculation results of the container cargo assignment model, each combination of liner service network is examined from the viewpoint of whether it would be advantageous for a shipping company to call at the port of La Union.

The output of the model is container cargo flow on the intermodal shipping network for each combination of liner service network. Aggregating them by port, container cargo throughput for each port of Central America as well as the number of vessels and their sizes to call at the port are estimated. Also, the total shipping cost and time from origin to destination along the intermodal shipping network can be calculated for each combination of liner service network.

The most significant difference from the past demand forecast models conducted by JICA (1998, 2002) is the assumption on the usage of Acajutla Port. The past models estimated the container cargo throughput of La Union Port on the assumption that the container handling in Acajutla Port is terminated and consolidated into La Union Port. However, in order to reflect the present situation that the function of container handling in Acajutla Port is maintained, the model developed in this project can consider the role-sharing of both ports in terms of container handling, although the handling capacity of Acajutla Port is very limited because any massive investment plan to increase the capacity is not considered. Also, the model results do not depend on the operation system of container terminal; i.e. the estimated results are also in effect after the implementation of the concession contract which will be introduced in La Union Port.

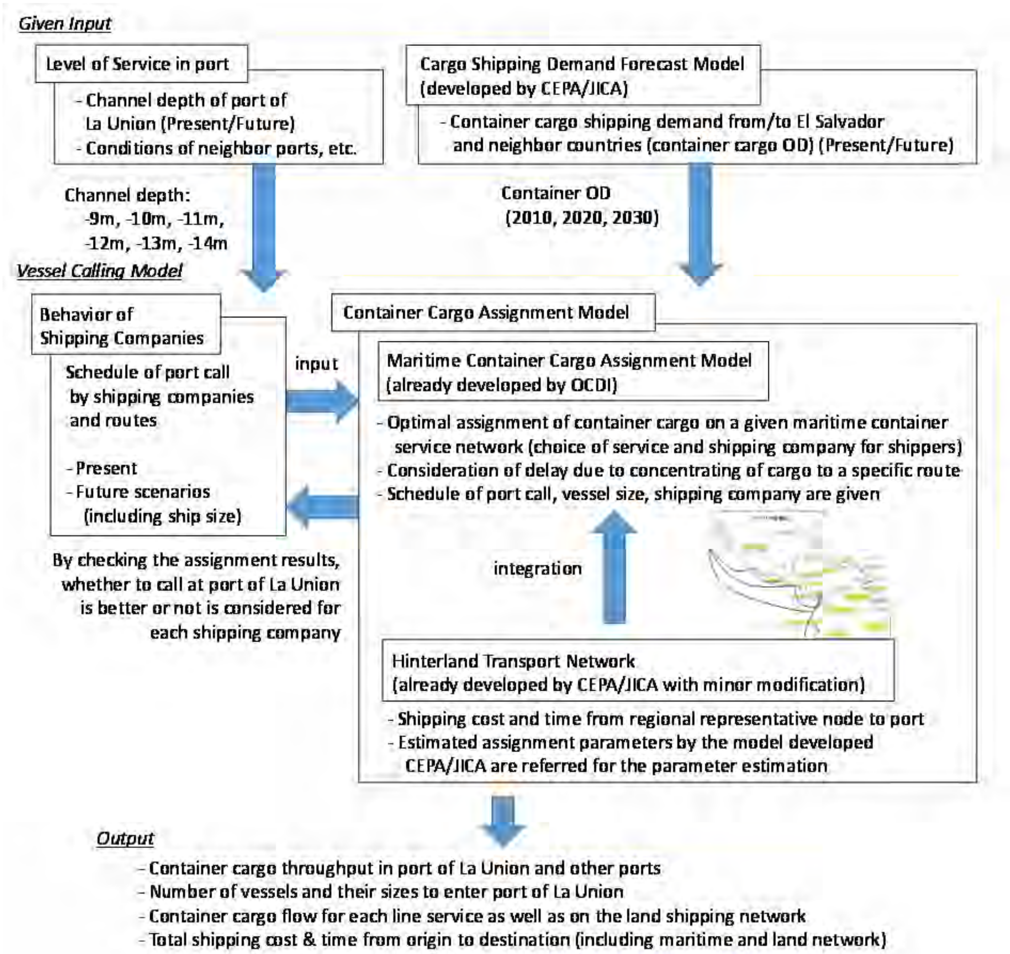


Figure 8.5 Whole structure of the vessel calling model (source: JICA Study Team)

8.5 Behavior of Shipping Companies

8.5.1 Liner shipping network

The present shipping network (as in 2010) is structured based on the MDS data. The MDS database provides information for each containership such as vessel name, IMO number, operator name (carrier), partner company(ies) of the service (if any), slot chartered company(ies) (if any), route category defined by MDS, list of port to call and its order, service frequency (yearly basis), TEU Capacity, DWT, vessel speed, etc. By aggregating this vessel-basis data into service(loop)-basis, i.e. a vessel group of carrier which navigates the same sea route and calls at the same ports as one regular service, liner shipping network is structured.

On the other hand, the MDS database unfortunately does not include any information on the actual schedule (i.e., exact day and time for arriving and departing for each port). Therefore, the schedule for the connection in the transshipment ports between mother and feeder vessel cannot be considered in the model. In the model, the expected waiting time for departure after the transshipment is assumed to be half of the duration time of the service which will be loaded from the transshipment port.

8.5.2 Shipping company

Hereinafter, network and model calculations are made for the 20 largest container shipping companies of the world plus eight additional companies for middle and small class which have liner service network in Central America. The liner services that are not included in any of these 28 companies as operators, partners or slot charters are excluded. The capacity assigned to the companies which are not among these 28 companies is also neglected. As a result, out of 2857 services from MDS database (as of May 2010), 988 services are included in the model. Although the number of services included in the model is about one-third of the total, 61.3% of the annual vessel capacity of the world is covered by the model because larger companies provide more significant and heavy services across the world. Furthermore, one APL feeder service (Lazaro Cardenas – Acajutla – Puerto Quetzal, capacity: 1,118 TEU, weekly) is also added to the network based on other sources, although it is not available from the MDS database.

8.5.3 Port

The liner shipping network all over the world is covered in this model. In principle, all the container ports where throughput was more than 500,000 TEU per year (2010, domestic and empty containers are included) are considered. According to CI-online database, there were 155 ports of the world at which throughput exceeded 500,000 TEU in 2010. In addition, several ports are added or eliminated.

In addition, our focus in this report is on the international trade from/to El Salvador and other Central American countries (mainly CA4 countries). Since the total amount of containers handled in this region is relatively small, the following ports are added to the maritime shipping network; Puerto Quetzal (Guatemala), St. Tomas de Castilla/Puerto Barrios (Guatemala), Acajutla (El Salvador), La Union (El Salvador), San Lorenzo (Honduras), Corinto (Nicaragua), and Caldera (Costa Rica) are added to the maritime shipping network, although the container cargo throughput at the port of La Union and San Lorenzo is zero as of 2010. Port of St. Tomas de Castilla and Puerto Barrios are integrated as one port in the network, since these ports are in close proximity to each other. The ports in Central America dealt in this model are shown in Figure 8.6.

Figure 8.6 Location of Ports in Central America (added ports in this model are shown in red letter) (Source: JICA Study Team)

8.6 Container Cargo Assignment Model

8.6.1 Whole model structure

In order to consider the competition among ports for getting local (i.e. export and import) cargo, hinterland shipping and port choice behavior of shippers should be included in the model. Therefore, the existing model developed by OCDI is extended this time to include land shipping network in CA4 countries. The intermodal network including both land and maritime shipping is shown in Figure 8.7.

The model is developed from a viewpoint of cargo owners (shippers). Each shipper is assumed to choose the ports to be used for export and import, given the freight charges for maritime and land transport, and shipping time. In this report, a stochastic assignment model that can consider the influence of unobservable elements from the model developer is applied to describe the behavior of shippers for port choice, since it usually has a good fitness to the reality although the model formulation is quite simple.

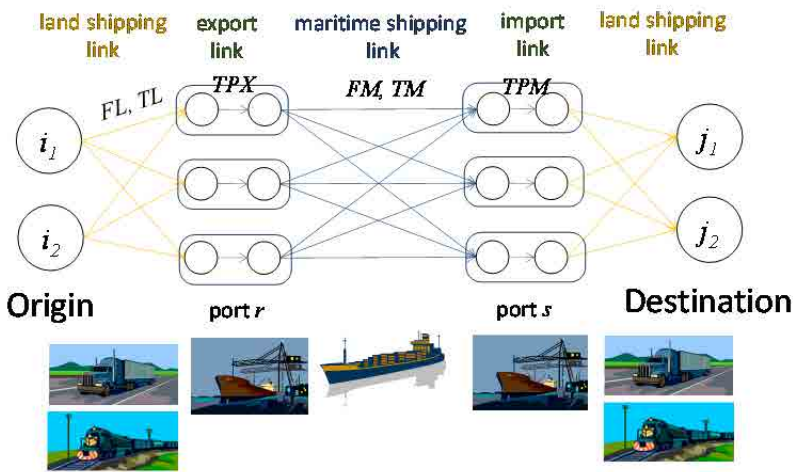


Figure 8.7 Shipping network considered in the container cargo assignment model
(Source: JICA Study Team)

8.6.1 Formulation of container cargo assignment model

When H_{ij} is the path choice set of cargo shipping demand Q_{ij} (TEU) from region i to region j ($ij \in \Omega$; Ω is the set of OD pair), a path h is chosen for a cargo m so as to maximize utility U_{ijhm}, including an error term ε_{ijhm}, that is,

$$U_{ijhm} > U_{ijh'm}, \quad \forall h \in H_{ij}, \forall h' \in H_{ij}, h \neq h', \forall ij \in \Omega, \tag{1}$$

$$s.t. \quad U_{ijhm} = -G_{ijh} + \varepsilon_{ijhm}, \tag{2}$$

where G_{ijh}: shipping cost (US$/TEU) of path h from region i to region j.

If the error term ε_{ijhm} follows Gumbel distribution, the choice of shipper is formulated as

$$F_{ijh} = Q_{ij} \cdot \frac{\exp(-\theta \cdot G_{ijh})}{\exp(-\theta \cdot G_{ijh}) + \sum_{h' \in H_{ij}} \exp(-\theta \cdot G_{ijh'})}, \tag{3}$$

where F_{ijh}: cargo volume on a path h from region i to region j, and θ: distribution parameter.

The shipping cost G_{ijh} for each path is expressed by the equation below.

$$G_{ijh} = GL_{ir} + GPX_r + GM_{rs} + GPM_s + GL_{sj} \quad , \forall r \in h, \forall s \in h , \tag{4}$$

where GL_{ir}, GL_{sj}: generalized land shipping cost from origin region i to port r and from port s to destination region j, GPX_r: generalized port cost of export port r, GM_{rs}: generalized maritime shipping cost from export port r to import port s, and GPM_s: generalized port cost of import port s.

The generalized cost of each link is expressed as the sum of freight charge and "time cost" which is defined by multiplying shipping time by value of time for shippers. Namely,

$$GL_{ir} = FL_{ir} + vt \cdot TL_{ir} \qquad \text{(also } GL_{sj} = FL_{sj} + vt \cdot TL_{sj} \text{)}, \tag{5}$$

$$GPX_r = vt \cdot TPX_r , \tag{6}$$

$$GM_{rs} = FM_{rs} + vt \cdot TM_{rs} , \text{ and} \tag{7}$$

$$GPM_s = vt \cdot TPM_s , \tag{8}$$

where vt: value of time for shipper (US$/TEU/hour), FL_{ir}, FL_{sj}: freight charge of land shipping from origin i to port r and from port s to destination j (US$/TEU), TL_{ir}, TL_{sj}: shipping time (hours) from origin i to port r and from port s to destination j, TPX_r: lead time when exporting in port r (hours), FM_{rs}: ocean freight charge from port r to port s (US$/TEU) including port charges, TM_{rs}: maritime shipping time (hours) from port r to port s, and TPM_s: lead time when importing in port s (hours). Note that any monetary costs are not considered in the port links (i.e. export and import link), since we assume the ocean freight charge, FM_{rs}, includes all port charges, not only for export and import port but also transshipment port on the way of shipping.

8.6.2 Maritime shipping submodel

The maritime shipping time, TM_{rs}, shown in Equation (7) are calculated from the output of the maritime shipping submodel which has been developed by OCDI.

8.6.3 Ocean freight charge

The ocean freight charge on each maritime shipping link, FM_{rs}, in Equation (7) provided by carrier is generally different from the monetary cost of the route for the carrier, reflecting feature of the market on the balance of demand and supply. In particular, since the maritime container shipping industry has an oligopolistic market in which surplus of supplier may exist, it should be carefully examined.

The ocean freight charge, FM_{rs}, in each market is uniquely set to be equal to the highest marginal shipping cost in the companies that participate the market (from export port r to import port s); namely,

$$FM_{rs} = \max_{g \in G} MC_{grs} , \tag{9}$$

where MC_{grs}: marginal cost of shipping company g from export port r to import port s, G: set of shipping company.

8.6.4 Land shipping time and freight charge

The shipping time, TL_{ir} and TL_{sj}, and the freight charge, FL_{ir} and FL_{sj}, in the land shipping link, are defined as sum of time or cost for driving and border-crossing, respectively. In addition, the freight charge can approximate the shipping cost, since the truck industry in this area is sufficiently competitive to be able to assume the perfect market competition. Therefore,

$$TL_{ir} = TD_{ir} + \alpha \cdot TB_{ir} \quad \text{(also } TL_{sj} = TD_{sj} + \alpha \cdot TB_{sj}\text{), and} \tag{10}$$

$$FL_{ir} = CD_{ir} + \alpha \cdot CB_{ir} \quad \text{(also } FL_{sj} = CD_{sj} + \alpha \cdot CB_{sj}\text{),} \tag{11}$$

where TD_{ir}, TD_{sj}: driving time of the land shipping link *a* (hour), TB_{ir}, TB_{sj}: border-crossing time of the land shipping link *a* (hour), CD_{ir}, CD_{sj}: driving cost of the land shipping link *a* (US$/TEU), CB_{ir}, CB_{sj}: border-crossing cost of the land shipping link *a* (US$/TEU), and α: coefficient on bonded transportation. The coefficient on bonded transportation, α, is an adjustment parameter, since TB_{ir}, TB_{sj} and CB_{ir}, CB_{sj} are considered as the time and cost for documents preparation in export and import, not transit. The results will be compared later for the several settings of α.

8.7 Input Data

8.7.1 Container cargo OD (container cargo shipping demand)

The demand of container cargo shipping (OD cargo volume), Q_{ij}, from origin *i* to destination *j* is estimated using the following steps. First, cargo shipping demand of maritime containers, q_{grs}, from export port *r* to import port *s* is estimated. Then, cargo shipping demand including land shipping is estimated.

(1) Maritime container OD

1) OD cargo between countries/regions

The OD cargo volume between countries or regions is available from the World Trade Service (WTS) database provided by IHS Inc. The WTS database provides an annual OD matrix of maritime container cargo of the world in TEU basis in 2010 between 100 countries/regions including coastal division for major countries. The OD matrix is aggregated into 51 countries/regions for the next step of data processing.

2) Division into port basis OD

The OD matrix in country/regional basis divided into a port-basis OD according to the share of the port out of the country/region in terms of the laden (i.e. not empty), local cargo throughput, which is estimated by CI-online data and a Drewry's report, 2011.

3) Division of Central American containers into port basis OD

In the WTS database, Central American region including seven countries (Guatemala, Belize, El Salvador, Honduras, Nicaragua, Costa Rica, and Panama) is treated as one region; therefore, it should be first divided into each coast. Then, they are divided into each port.

(2) Container OD including land shipping

The container cargo OD originated from/destined to CA4 countries (hereinafter CA4 OD) are integrated from the maritime container OD estimated in (1), while for other OD cargo the maritime container OD is used without any changes. The division process of CA4 OD is as stated below;

1) Based on the UN trade statistics and the trade data provided by CIECA, trade value of cargo

from/to each CA4 country by partner regions is summarized. The share in trade value for each country by partner regions is calculated and CA4 OD is divided by the share. Also, Salvadoran and Honduras cargo are divided into two zones by constant ratio (El Salvador West: 94%, El Salvador East: 6%; Honduras North: 70%, Honduras South: 30%).

2) The container cargo shipping demand within Central America is also estimated according to the above procedure and the same rule is applied in the maritime container OD estimation.

(3) Elimination of OD shipped by carriers not considered in the model

In the model, a balance between the vessel capacity and the amount of containers shipped in each service is important because the congestion due to overcapacity is considered in the calculation. Therefore, the container shipping demand that will be shipped by carriers not among the 28 container carriers should be eliminated. According to the share of carriers in terms of the vessel capacity arriving at and departing from each port, the total amount of container shipping demand for each port is declined by the share of carriers which are not considered in the model. Then Frater method is applied in order to adjust errors, by inputting the total amount of container shipping demand for each port for the target carriers as given and the OD matrix estimated in the previous section as initial input.

8.7.2 Level of service in each port

The container handling charge, lead time for export and import, and transshipment time in CA4 countries' ports and other ports of the world are set as shown in Table 8.4 from the CEPA data and other data source.

Table 8.4 Settings of level of service in each port

Port Name		Container Handling Charge	Maximum Draft	Lead Time (Export)	Lead Time (Import)	Transshipment Time
		CHC_r (US$/TEU)	(m)	TPX_r (hours)	TPM_r (hours)	TR_r (hours)
Puerto Quetzal	Guatemala	117.65	-13	60	24	48
Acajutla	El Salvador	73.48	-11	60	48	48
La Union	El Salvador	65.79	-8	60	48	48
San Lorenzo	Honduras	64.70	-8	60	48	48
Corinto	Nicaragua	58.82	-11	168	84	48
Caldera	Costa Rica	100.00	-11	48	24	48
Puerto Cortes/ Puerto Castilla	Honduras	64.70	-12	48	24	48
Santo Tomas De Castilla/ Puerto Barrios	Guatemala	64.70	-11	60	24	48
Other ports of the world		100.00	*	48	24	*

*: varied by port

Source: JICA Study Team's estimation

8.7.3 Land shipping network

According to the market allocation model developed by CEPA/JICA (hereinafter, the "CEPA allocation model"), the land shipping network in the CA4 region is considered in the model (see Figure 8.8). Considering the geographical characteristics, El Salvador and Honduras are divided into two regions (El Salvador West/East, Honduras North/South), respectively. All representative nodes (O node and D node) of the region and all ports in the CA4 regions are connected with each other, while any land connection between the CA4 region and neighbouring countries (e.g. Mexico and Costa Rica) is not allowed.

The driving time, TD_{ir} and TD_{si} (included in Equation (10)), and cost, CD_{ir} and CD_{si} (in Equation (11)), are set to coincide with the CEPA allocation model as shown in Table 8.5. The border-crossing time, TB_{ir} and TB_{si} (also included in Equation (10)) and cost, CB_{ir} and CB_{si} (in Equation (11)), are derived from the average hours of "Documents Preparation" (exports and imports) in the Doing-Business website provided by the World Bank. The estimated border-crossing time and cost are shown in Table 8.6. Note that in some combinations more than two borders should be crossed (for example, from Nicaragua to port of Acajutla, the border between Honduras and Nicaragua, and the border between El Salvador and Honduras are crossed).

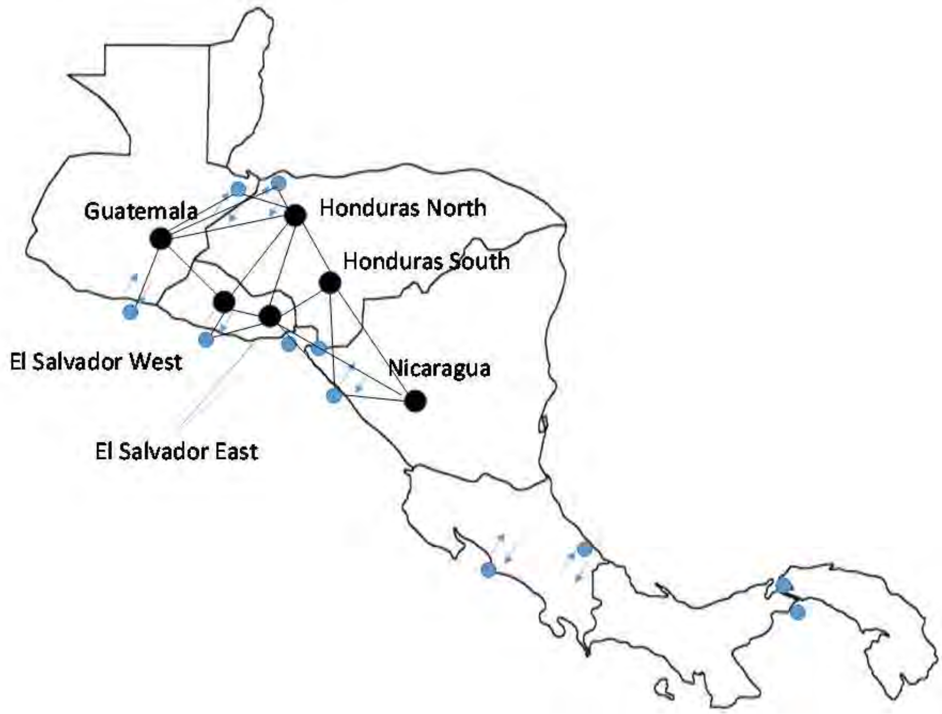


Figure 8.8 Land shipping network considered in this project
(Source: JICA Study Team)

Table 8.5 Driving time and cost between zone representatives (O and D node) and ports

- Driving Time (hours)

Zone Representative \ Ports	Guatemala		El Salvador		Honduras		Nicaragua
	Quetzal	Santo Tomas	Acajutla	La Union	Pt. Cortes	San Lorenzo	Corinto
Guatemala	1.7	5.0	3.2	7.0	6.3	8.0	11.0
El Salvador West	4.5	6.4	1.4	3.1	6.8	4.1	7.1
El Salvador East	6.7	8.6	3.7	0.8	6.7	2.1	4.9
Honduras North	8.6	2.5	7.2	5.5	1.0	5.6	8.6
Honduras South	12.0	6.0	6.8	3.1	5.0	1.9	4.6
Nicaragua	14.1	12.3	11.1	7.3	11.3	5.7	2.3

Source: CEPA

- Driving Cost (US$/TEU)

Zone Representative \ Ports	Guatemala		El Salvador		Honduras		Nicaragua
	Quetzal	Santo Tomas	Acajutla	La Union	Pt. Cortes	San Lorenzo	Corinto
Guatemala	151.5	450.0	286.5	630.0	568.5	723.0	990.0
El Salvador West	403.5	571.5	129.0	277.5	612.0	372.0	637.5
El Salvador East	603.0	774.0	328.5	73.5	600.0	186.0	439.5
Honduras North	774.0	220.5	649.5	495.0	88.2	504.0	771.0
Honduras South	1080.0	541.5	615.0	274.5	451.5	169.5	417.0
Nicaragua	1270.5	1102.5	996.0	655.5	1012.5	510.0	207.0

Source: CEPA

Table 8.6 Border-crossing time and cost between zone representatives (O and D node) and ports

- Border-crossing Time (hours)

Zone Representative \ Ports	Guatemala		El Salvador		Honduras		Nicaragua
	Quetzal	Santo Tomas	Acajutla	La Union	Puerto Cortes	San Lorenzo	Corinto
Guatemala	0	0	84	84	192	276	528
El Salvador West	240	240	0	0	192	192	444
El Salvador East	240	240	0	0	192	192	444
Honduras North	240	240	84	84	0	0	252
Honduras South	324	240	84	84	0	0	252
Nicaragua	516	432	276	276	192	192	0

Source: JICA team's estimation from Doing Business Database (by World Bank)

- Border-crossing Cost (US$/TEU)

Zone Representative \ Ports	Guatemala		El Salvador		Honduras		Nicaragua
	Quetzal	Santo Tomas	Acajutla	La Union	Puerto Cortes	San Lorenzo	Corinto
Guatemala	0	0	380	380	261	641	958.5
El Salvador West	278.5	278.5	0	0	261	261	578.5
El Salvador East	278.5	278.5	0	0	261	261	578.5
Honduras North	278.5	278.5	380	380	0	0	317.5
Honduras South	658.5	658.5	380	380	0	0	317.5
Nicaragua	919.5	539.5	641	641	261	261	0

Source: JICA team's estimation from Doing Business Database (by World Bank)

8.8 Calculation Results of the Container Cargo Assignment Model

8.8.1 Unknown parameter estimation

The container cargo assignment model contains three unknown parameters vt, θ, and α. All other parameters are preliminarily set as exogenous variables and have already been explained in the previous section. vt is value of time for shipper (US$/TEU/hour) included Equation (5) to (8); θ is a distribution parameter included Equation (3) in which probability that each route is chosen is defined; and α is an adjustment parameter on bonded transportation, which is multiplied by border-crossing time and cost as described in Equation (10) and (11) in 8.6.5.

An optimal combination of coefficients of unknown parameters is selected to reproduce the actual container cargo flow well. Trial-and-error-basis calculation and grid search is conducted for estimation of unknown parameters by changing each parameter with the range of ($3.0 < vt < 13.0$), ($0.001 < \theta < 0.05$), and ($0.0 < \alpha < 0.5$). As a result, it is estimated that (vt, θ, α) = (8.0, 0.01, 0.3) is an optimal combination of coefficient for both export and import cargo.

8.8.2 Model reproducibility

(1) Container cargo throughput

The container cargo throughput reproduced by the model under the above optimal combination of coefficient of unknown parameters is shown in Figure 8.9. As shown in the figure, the container cargo throughput in the port of Acajutla is well reproduced by the model for both export and import cargo. However, in the port of Puerto Quetzal (Guatemala), the throughput for both export and import cargo is overestimated by the model compared with the actual, while in the port of Puerto Cortes/Puerto Castilla (Honduras), the throughput for both export and import cargo is underestimated by the model.

For the transhipment cargo, a certain amount of cargo is estimated in some ports (especially in two Guatemalan ports) as similar amount to the actual.

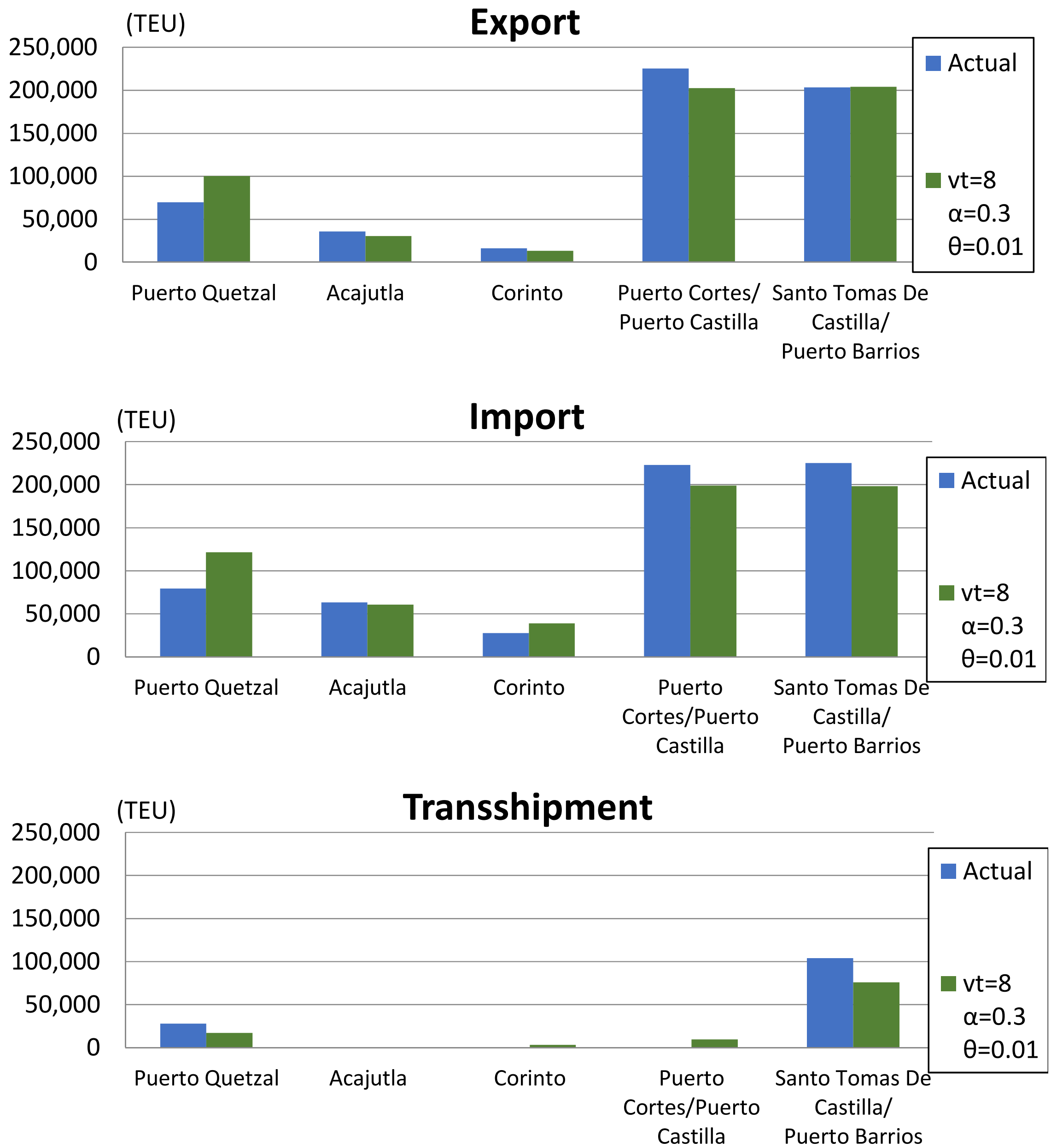


Figure 8.9 Container cargo throughput reproduced by the developed model compared with the actual throughput (Source: JICA Study Team's estimation)

(2) Share by partner countries

Table 8.7shows the estimated amount and share of container cargo by partner country/region of trade (in coastal basis) from/to CA4 ports. Although this kind of statistics is not actually available, the share in the port of Acajutla for the Atlantic cargo including East coast of North and South America and Europe is considered around 10-20% of the total amount of containers for both export and import. Therefore, the estimated results shown in Table 8.7 are considered reasonable.

Table 8.7 Estimated amount and share of containers by partner country/region of trade from/to CA4 ports (Source: JICA Study Team's estimation)

	export				import			
	Atlantic countries/regions		Pacific countries/regions		Atlantic countries/regions		Pacific countries/regions	
	TEU	share	TEU	share	TEU	share	TEU	share
Puerto Quetzal	31,784	31.7%	68,622	68.3%	1,087	0.9%	120,318	99.1%
Acajutla	5,920	19.4%	24,560	80.6%	5,670	9.4%	54,957	90.6%
Corinto	3,365	25.3%	9,949	74.7%	2,169	5.6%	36,846	94.4%
Puerto Cortes/ Puerto Castilla	201,016	99.3%	1,460	0.7%	195,669	98.4%	3,194	1.6%
Santo Tomas De Castilla/Puerto Barrios	201,395	98.6%	2,768	1.4%	191,493	96.6%	6,761	3.4%

(3) Export and import port of containers in CA4 countries

Table 8.8 shows the estimation results of export and import ports of containers originated from/destined into CA4 countries. Although this kind of statistics is also not actually available, it is well-known that more than half of the containers from/to El Salvador utilize the ports on the Atlantic coast (i.e. Puerto Cortes/Puerto Castilla and Santo Tomas De Castilla/Puerto Barrios) and that very little cargo utilize the port of Corinto. The estimation result of the model is in keeping with these well-known facts.

Table 8.8 Estimation results of export and import port of containers from/into CA4 countries (TEU)

- exported container from CA4 countries

	Puerto Quetzal	Acajutla	Corinto	Puerto Cortes/ Puerto Castilla	Santo Tomas De Castilla/ Puerto Barrios
Guatemala	88,240	8,004	0	20,467	186,875
El Salvador West	5,376	13,961	0	29,267	11,227
El Salvador East	321	476	0	2,447	438
Honduras North	2,003	4,192	0	84,616	2,973
Honduras South	743	3,449	1	34,933	1,511
Nicaragua	3,722	398	13,314	30,746	1,138

- imported container into CA4 countries

	Guatemala	El Salvador West	El Salvador East	Honduras North	Honduras South	Nicaragua
Puerto Quetzal	90,548	17,925	880	9,766	2,280	4
Acajutla	4,347	35,003	2,238	11,396	7,182	455
Corinto	0	472	290	5,402	2,929	29,920
Puerto Cortes/ Puerto Castilla	20,724	44,083	4,294	73,511	31,863	24,381
Santo Tomas De Castilla/Puerto Barrios	147,589	39,324	1,030	7,445	1,825	1,031

Source: JICA Study Team's estimation

(4) Share by container shipping companies

The model can calculate the amount of container shipping by shipping company or by service. Table 8.11 shows the share by container shipping company which called at the port of Acajutla in 2010, in terms of handling amount and vessel capacity. Compared with the shares in handling amount basis and vessel capacity basis, some companies (e.g. APL) are considered efficient because their shares in terms of handling amount exceed those in terms of vessel capacity, while other companies (e.g. MSC, CSAV, and China Shipping) are considered inefficient because their shares in terms of handling amount are less than those in terms of vessel capacity.

Table 8.9 also shows the actual handling amount of containers in the port of Acajutla in 2010. The table shows that the estimated share in terms of handling amount is more approximate to the actual share, compared with the share in terms of vessel capacity except for NYK. The main difference between the actual and model estimated handling amount of containers is that the estimated results are calculated, based on the vessel movement data as of only May 2010 and may be slightly different from other months in 2010. However, the above finding (that the estimated share in terms of handling amount is more approximate to the actual share) may imply the usefulness of the model from the viewpoint of efficiency analysis of shipping companies.

Table 8.9 Actual and estimated share of shipping companies in port of Acajutla (2010)

	Actual*	model estimated			
		handling amount basis**		vessel capacity basis***	
	share	TEU/year	share	TEU/year	share
Maersk	37.5%	34,107	37.4%	352,560	32.6%
MSC	2.2%	2,800	3.1%	64,064	5.9%
CMA-CGM	8.7%	8,408	9.2%	104,684	9.7%
Hapag-Lloyd	0.9%	0	0.0%	0	0.0%
APL	24.0%	27,315	30.0%	116,272	10.7%
CSAV	5.4%	2,054	2.3%	120,132	11.1%
China Shipping	1.4%	6,337	7.0%	104,684	9.7%
NYK	19.8%	7,344	8.1%	167,440	15.5%
CCNI	0.0%	2,741	3.0%	52,342	4.8%
Total	100%	60,627	100.0%	1,082,178	100.0%

Source: *CEPA (handling amount basis). **calculation result of the model. ***Estimated form MDS Database.

(5) Estimated results by shipping service

The model can predict the container flows by shipping service provided by each shipping company. An example of the estimated results on container flow for all services to call at Central American ports (from Guatemala to Costa Rica, except for Panama) operated by Maersk is shown in Figure 8.10.

Since the actual data on how many containers are loaded, unloaded, and shipped for each service is not available, it is not possible to compare these estimated results with the actual data. However, judging from general knowledge on load factor of container vessel and handling amount of containers at one time call at port, large portion of estimated results are considered within the reasonable range.

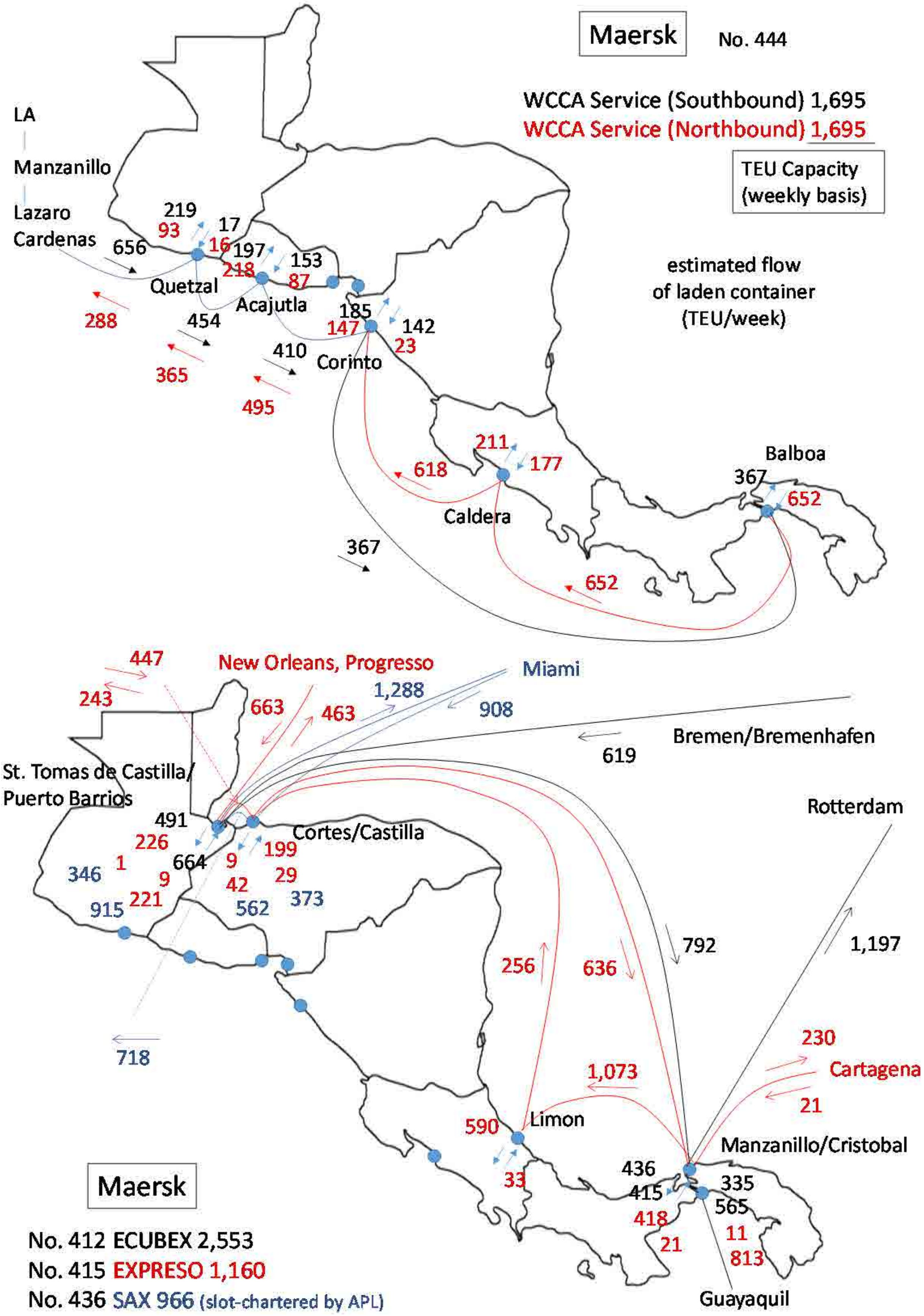


Figure 8.10 Example of estimated container flow by liner service (Maersk, 2010)

(Source: JICA Study Team's estimation)

8.8.3 Sensitivity of the model output

Figure 8.11, Figure 8.12, and Figure 8.13 show sensitivities of unknown parameters in terms of container cargo throughput for each CA4 port.

(1) Sensitivity on value of time

Figure 8.11 shows sensitivity of the container cargo throughput as the model output by significance of value of time, *vt*. In particular, in export containers, some correlation between the throughput and value of time is observed; namely, the throughput in the Pacific ports (i.e. Puerto Quetzal, Acajutla, and Corinto) increases as value of time decreases, while that in the Caribbean ports (i.e. Puerto Cortes/Puerto Castilla and Santo Tomas De Castilla /Puerto Barrios) decreases as value of time decreases. It seems to be because the volume of export cargo to the Pacific side (i.e. cargo exported to West coast of North and South America, Asia, etc.) is relatively smaller than that to the Atlantic side (i.e. cargo exported to East coast of North and South America, Europe, etc.). For the import containers, no tendency is observed.

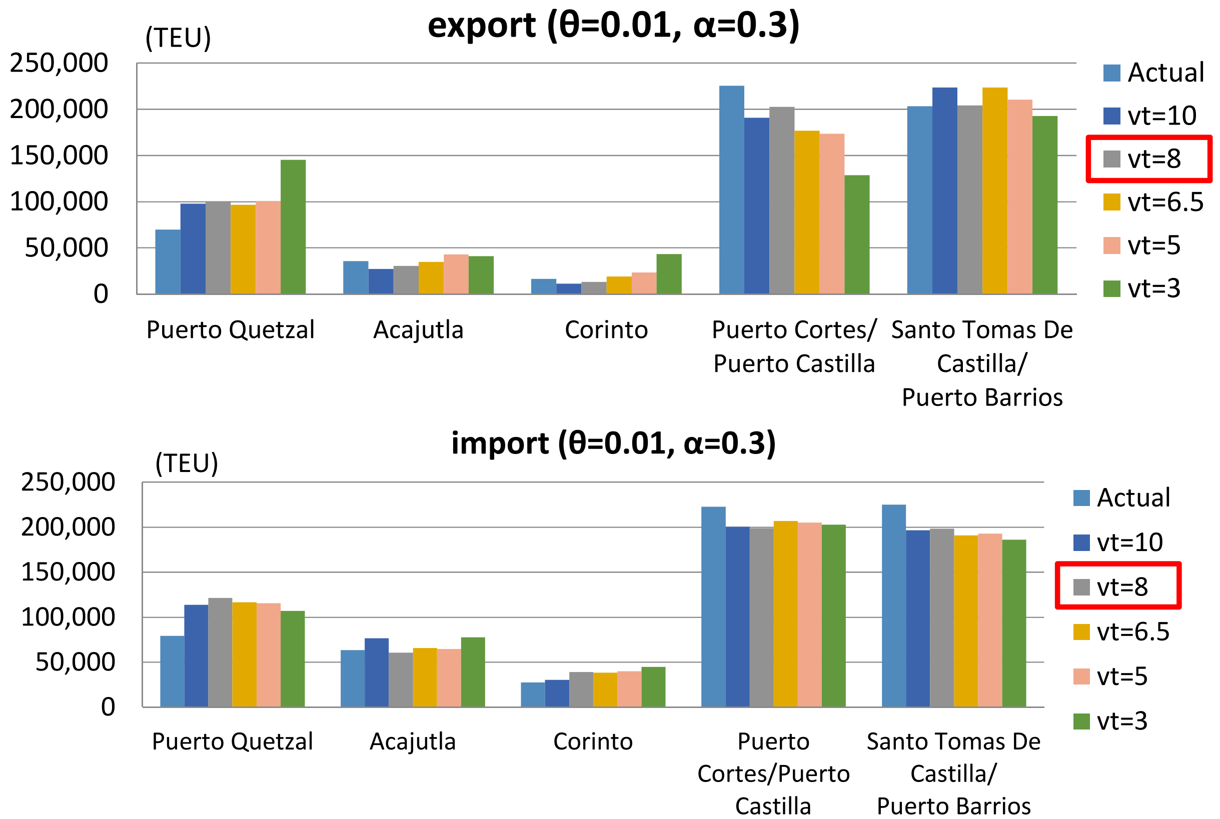


Figure 8.11 Sensitivity of unknown parameters [1] value of time for shippers *vt* and container cargo throughput by each CA4 port (Source: JICA Study Team's estimation)

(2) Sensitivity on distribution parameter

Figure 8.12 shows sensitivity of the container cargo throughput by significance of distribution parameter, θ. According to Equation (3), if θ is smaller, each shipper is less sensitive to the difference of the generalized cost (including shipping time and cost) for each alternative, while if θ is larger, each shipper is more sensitive to the difference of the generalized cost. From the figure, when the shipper becomes sensitive to the shipping cost and time, the amount of export containers handled in port of Acajutla and Corinto is expected to decrease. For the import cargo, no tendency is observed as similar to the sensitivity to the value of time.

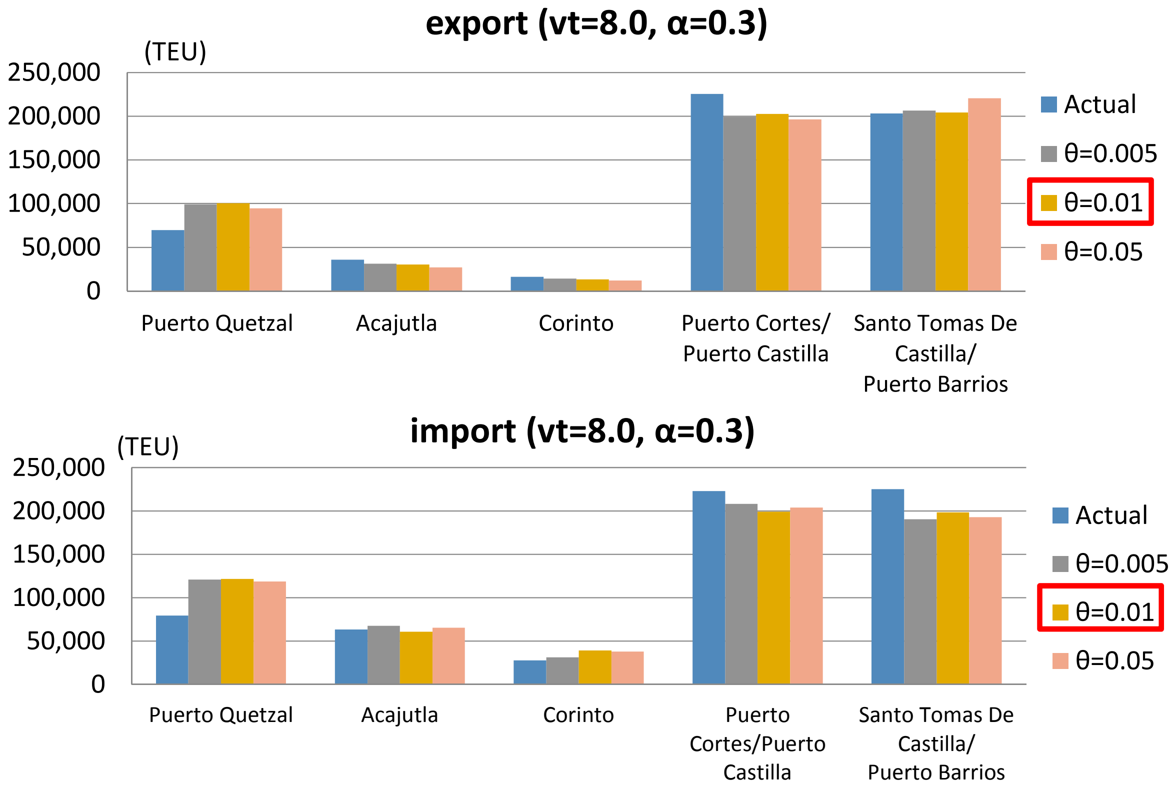
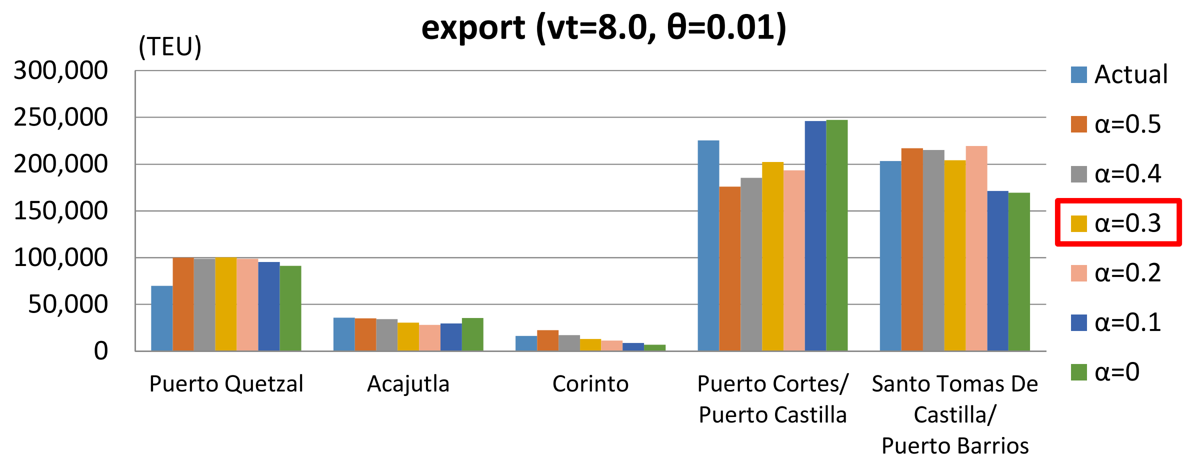


Figure 8.12 Sensitivity of unknown parameters [2] distribution parameter θ and container cargo throughput by each CA4 port (Source: JICA Study Team's estimation)

(3) Sensitivity on significance of barrier at land national border

Figure 8.13 shows sensitivity of the container cargo throughput by significance of adjustment parameter on bonded transportation, α. If α is larger, the barrier at national border becomes larger; therefore, each shipper tends to utilize their own port(s) in the country. If α is smaller, each shipper can utilize the port for export and import more flexibly according to their needs. The figure shows that in some ports such as Puerto Cortes for export cargo and Qutzal for import cargo, the throughput is larger as α is smaller; it implies that these ports are potentially more competitive when the barrier at national border is declined. On the other hand, in some ports such as Quetzal for export cargo and Corinto for both cargo, the throughput is smaller as α is smaller; namely, they are less competitive.



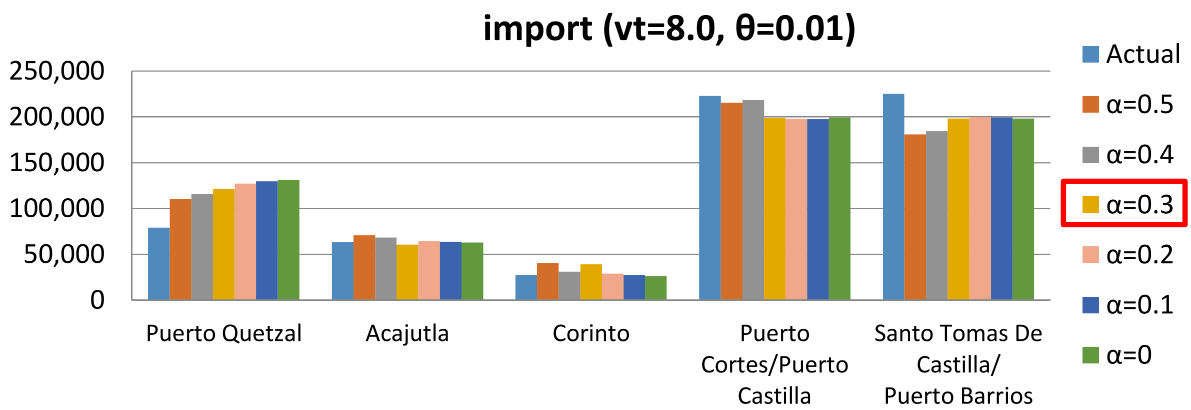


Figure 8.13 Sensitivity of unknown parameters [3] adjustment parameter on bonded transportation α and container cargo throughput by each CA4 port
(Source: JICA Study Team's estimation)

8.9 Conclusion of Chapter 8

The main focus of this chapter is a description of the vessel calling model for financial and economic analysis of La Union Port. For that purpose the current status of Salvadoran ports (8.1) as well as other major ports in CA5 countries (8.2) is summarized. Although the economic aspects are key to underpinning the model development, physical condition of each port is also discussed because it affects the capacity of cargo handling. In particular, the physical condition of Acajutla Port is focused on (8.1.5(5)) because the present and future limitation of its handling capacity is considered to directly influence the future container cargo throughput in La Union Port.

The strategy of maritime container shipping companies in the Pacific Coast of Central America (8.3) is also important for developing the model. It is examined by two approaches; the first approach is to develop the liner shipping network of each company from the containership movement database (8.3.1). It can be compared among shipping companies and different times. The second approach is interview surveys to shipping companies and other stakeholders (8.3.2). From the interview survey, a general view of container shipping on the Pacific Coast of CA5 is acquired as well as comments specific to each port.

The latter part of this chapter focuses on the vessel calling model. After a description of the model outline (8.4), each component of the model is described including behavior of shipping companies (8.5), container cargo assignment model (8.6), and input data (8.7). The key information on behavior of shipping companies is a shipping network of regular services operated by each company which is structured from the containership movement database (the MDS data) on the targeting companies and ports (8.5). The container cargo assignment model is the core element of the vessel calling model (8.6). The container cargo assignment model is an application of stochastic network assignment model on the intermodal shipping network of international container cargo, based on the generalized cost including both monetary cost and shipping time. The maritime shipping submodel in the container cargo assignment model is described in Annex D2. Preparing the input data is also important for the vessel calling model (8.7). One of the most important data as a model input is container cargo shipping demand (container cargo OD) between each port or region of the world. It is estimated from container cargo OD between countries and various statistics and information on regional economy, trade, and cargo handling in ports. Data on the shipping network including physical distance and shipping cost is also necessary. The information on the cost and time in border-crossing on land is also included.

The last section of this chapter (8.8) summarizes the calculation results of the container cargo assignment model. After the description of the calculation procedure and unknown parameter estimation, the calculation results are examined from the viewpoint of the model reproducibility by several benchmarks such as container cargo throughput, share by partner countries, export and import port in CA4 countries, shares by shipping company, and estimated volume shipped by each liner service. Also, the sensitivity of the model to the estimated unknown parameters (i.e. value of time, distribution parameter of stochastic assignment, and significance of barrier at national borders) is also examined. As a result, the container cargo assignment model well describes the actual container cargo shipping market including the container throughput in each port of CA4 countries and reasonably behaves against the change of the model input.

Chapter 9 Vessel Calls to La Union Port and Economic Analysis

Chapter 9 Vessel Calls to La Union Port and Economic Analysis

9.1 Present Navigation of La Union Port

9.1.1 Present status of navigation channel and navigation rule

(1) Present status of navigation channel

The navigation channel (passage) of La Union Port has a total length of 22km; the inner channel is 5 km and the outer channel is 17km. The bed width of the inner channel is 110m while that of the outer channel is 107m. The inner channel has been dredged to a depth of -14m while the outer channel has been dredged to -14.5m. It has been in service since 2010, but the entire passage has been filled in by siltation, and the depth when it was completed has not been maintained. Figure 9.1 shows the navigation channel of La Union Port.

(2) Present navigation rules

A control tower located on the sixth story of the administration building inside the port manages ships navigating through the passage to enter or leave La Union Port. Navigation rule of La Union Port was described in the operation manual for La Union Port.

9.1.2 Tidal conditions

In the Republic of El Salvador, the CNR is the tide level supervisory agency that predicts tide levels and publishes tide level tables based on observations in the field. Chart Datum Level (CDL), which is used as the standard for water depth on marine charts, was set at –1.5381m from MSL by the CNR.

9.1.3 Navigable condition by depth of channel

(1) Navigation channel depth and vessel size of La Union Port

At present, the channel is scheduled to be deepened, but if the depth increases, the cost of dredging will increase, so the optimum depth will be selected by comparing the profits earned from container ships calling the port and dredging costs to maintain the appropriate depth for calling vessels.

When a container vessels call at La Union Port, a high tide level is used for passing through the channel, but restrictions on navigation traffic differ depending on the channel depth. Therefore, three items such as navigable time by shipping draft, maximum waiting time and expected waiting time are calculated for channel depths of 9m, 10m, 11m, 12m, 13m and 14m.

(2) Navigable time in navigation channel

Navigable time in the channel managed by tidal difference is obtained by comparison with the actual water depth and required channel depth which is decided based on the draft of calling vessels. The actual water depth of the navigation channel is determined adding the various design depths in the channel to the tide levels given in tide table of La Union Port in 2013.

As study conditions, allowance of gross under-keel clearance for the draught was set at 10% based on Permanent International Association of Navigation Congress (PIANC) suggestions, and the speed ships cruise in the channel was set as 5 knots, which is almost the same as present.

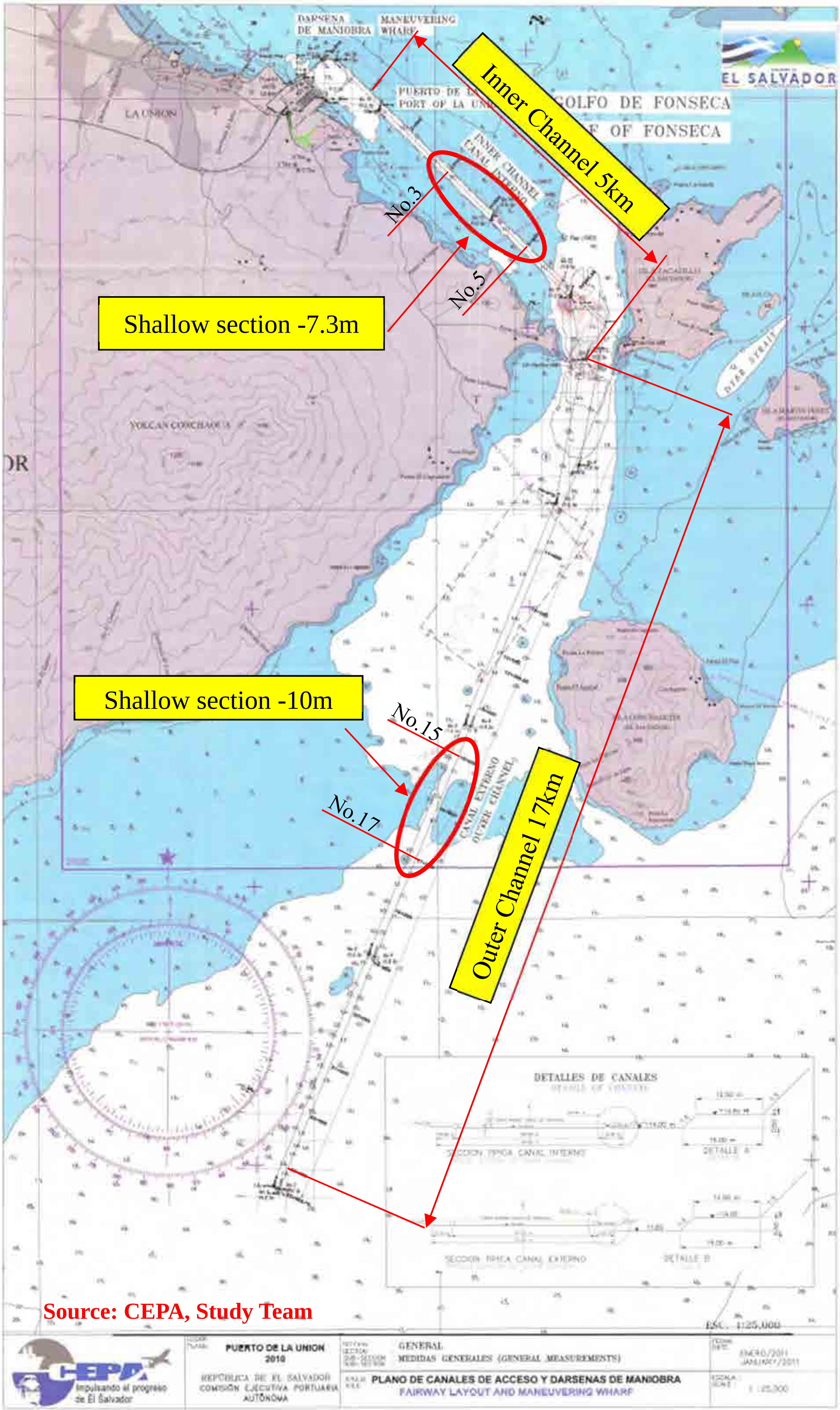


Figure 9.1 Navigation Channel of La Union Port

Table 9.1 Result of Calculation for Navigable Time in the Channel

(Unit: hours)

Ship Draft (m)	Navigation channel depth							
	7.3m (present)	8.0 m	9.0m	10.0m	11.0m	12.0m	13.0m	14.0m
6.0	8,760							
6.5	8,506							
6.8		8,760						
7.0	6,376	8,585						
7.2		8,350						
7.4		7,683						
7.6		6,631						
7.8		5,431	8,760					
8.0	2,860	4,572	8,585					
8.2	2,358	3,976	8,082					
8.4	1,849	3,215	7,267					
8.5	1,569	2,950						
8.6		2,467	6,034	8760				
8.8		1,959	5,021	8709				
9.0		1,363	4,572	8,392				
9.2			3,735	7,767				
9.4			3,215	6,743				
9.5					8,760			
9.6			2,736	5,517				
9.8			2,215	4,605	8,634			
10.0			1,700	4,019	8,139			
10.2			1,077	3,500	7,370			
10.4				2,994	6,132	8,760		
10.6				2,515	5,081	8,740		
10.8				1,982	4,324	8,422		
11.0				1,423	3,783	7,840		
11.2					3,258	6,910		
11.4					2,779	5,615		
11.6					2,251	4,694	8,760	
11.8					1,746	4,078	8,192	
12.0					1,129	3,544	7,465	
12.2						3,046	6,253	8760
12.4						2,557	5,151	8747
12.6						2,026	4,375	8537
12.8						1,473	3,823	8055
13.0							3,313	6,967
13.2							2,828	6,129
13.4							2,302	5,250
13.6							1,796	4,127
13.8							1,190	3,599
14.0								3,081
14.2								2,608
14.4								2,070
14.6								1,529

Source: Prepared by the Study Team

Table 9.2 Calculation Results of Daily Navigable Time

(Unit: hours)

Ship Draft (m)	Navigation channel depth							
	7.3m (present)	8.0 m	9.0m	10.0m	11.0m	12.0m	13.0m	14.0m
6.0	24.0							
6.5	23.3							
6.8		24.0						
7.0	17.5	23.5						
7.2		22.9						
7.4		21.0						
7.6		18.2						
7.8		14.9	24.0					
8.0	7.8	12.5	23.5					
8.2	6.5	10.9	22.1					
8.4	5.1	8.8	19.9					
8.5	4.3	8.1						
8.6		6.8	16.5	24.0				
8.8		5.4	13.8	23.9				
9.0		3.7	12.5	23.0				
9.2			10.2	21.3				
9.4			8.8	18.5				
9.5					24.0			
9.6			7.5	15.1				
9.8			6.1	12.6	23.7			
10.0			4.7	11.0	22.3			
10.2			3.0	9.6	20.2			
10.4				8.2	16.8	24.0		
10.6				6.9	13.9	23.9		
10.8				5.4	11.8	23.1		
11.0				3.9	10.4	21.5		
11.2					8.9	18.9		
11.4					7.6	15.4		
11.6					6.2	12.9	12.0	
11.8					4.8	11.2	11.2	
12.0					3.1	9.7	10.2	
12.2						8.3	8.6	24.0
12.4						7.0	7.1	24.0
12.6						5.6	6.0	23.4
12.8						4.0	5.2	22.1
13.0							4.5	19.1
13.2							3.9	16.8
13.4							3.2	14.4
13.6							2.5	11.3
13.8							1.6	9.9
14.0								8.4
14.2								7.1
14.4								5.7
14.6								4.2

Source: Prepared by The Study Team

The channel of La Union Port is 22km long, and for about 1km including the front surface of the quay wall at its end and the turning basin located at this front surface, the depth is a maximum of 11m. It takes about 2.38 hours for a ship cruising at 5 knots to navigate the channel, so it is necessary to plan this before the tide falls. Table 9.1 shows the result of calculation for navigable time by ship draft and navigation channel depth.

Average daily navigable time can be calculated using the information in Table 9.1. But in this case, average daily navigable time is different from the actual time because both spring tide and neap tide are included in the value, thus the Output Tool of Navigable Time Range described as Figure 9.4 is used for obtaining actual time. Table 9.2 shows the calculation results of average daily navigable time by channel depth and vessel draft.

(3) Maximum waiting time

Maximum waiting time shows that the maximum time of vessel waiting for navigable tide condition on one way of the channel. In cases where ship waiting time exceeds 12 hours (including the time required to navigate the whole channel) of one cycle of sea level variation, ship waiting time isn't considered as it would be irrational for a container ship to call under such circumstances.

Unnavigable time for the whole navigation channel is calculated by deducting navigable time from annual hours in general.

(4) Expected waiting time in probability theory

The expected waiting time is defined as an average waiting time before it is actually able to enter the port when a container vessel randomly calls at La Union Port. The conceptual drawing is shown in Figure 9.2 Note that because of the navigation time on the access channel, a vessel cannot enter the access channel 2.4 hours before the actual depth becomes lower than the navigable depth. Table 9.3 and Figure 9.3 show expected waiting times by channel depth and by draft. From them, it is found that the draft becomes larger as expected waiting time increases.

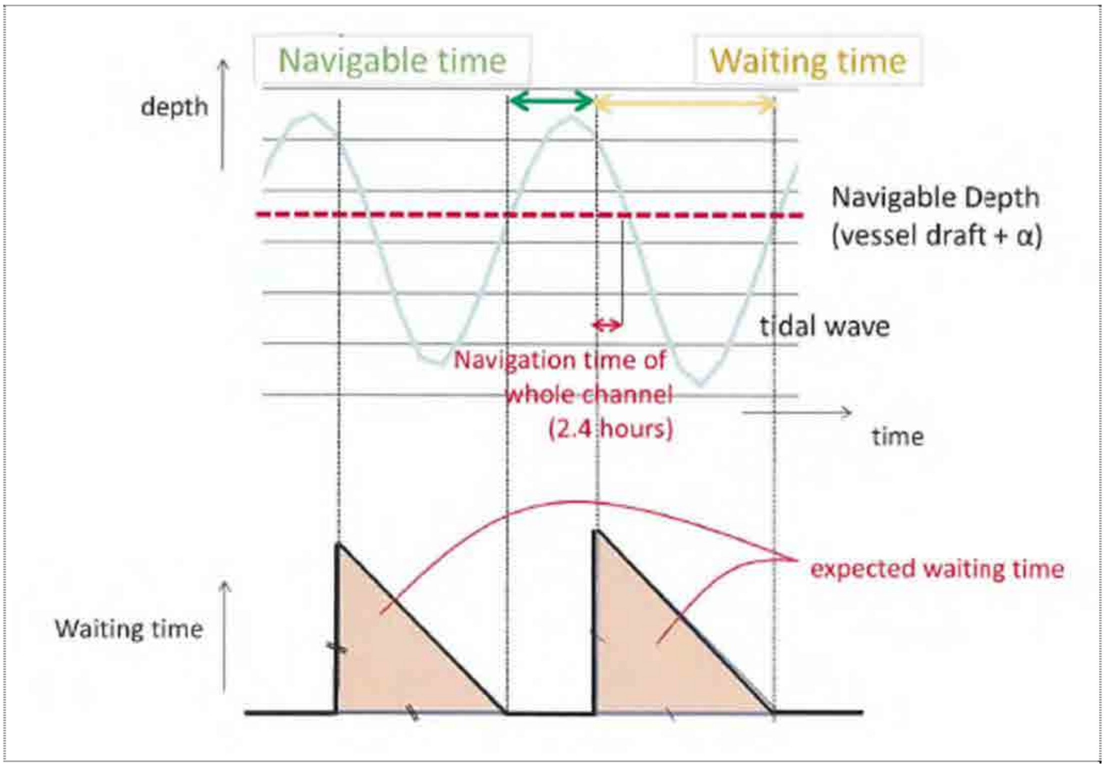
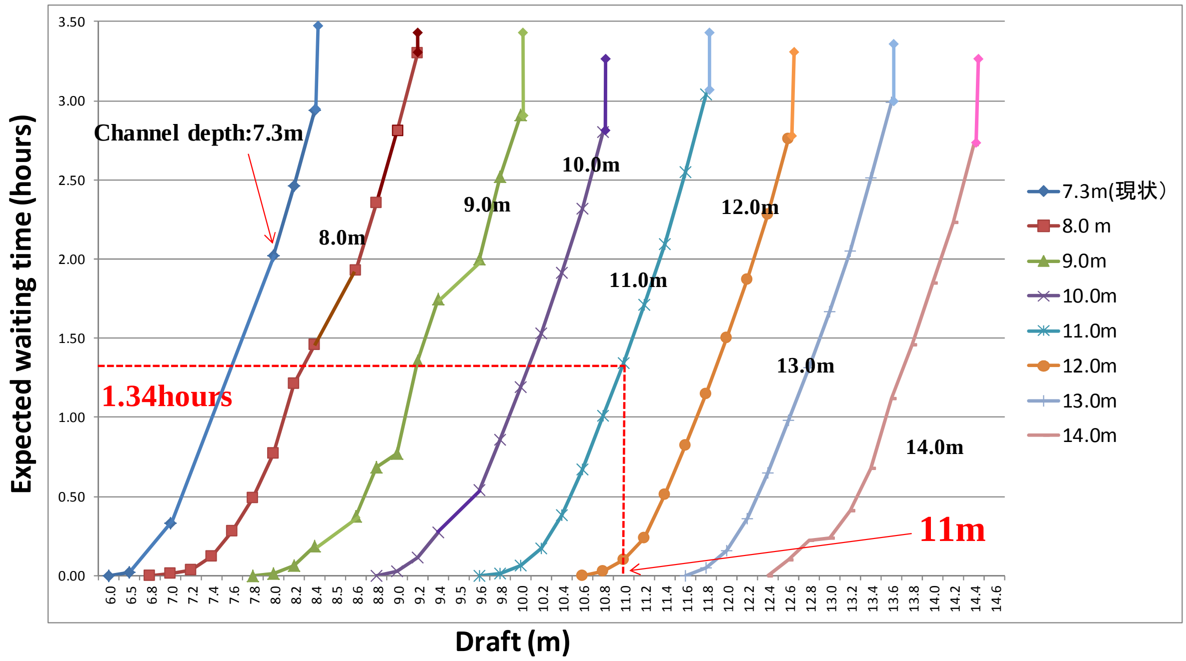


Figure 9.2　Concept for calculation of expected waiting time

Table 9.3 Result of Calculation for Expected Waiting Time

Ship Draft (m)	Expected Waiting Time (hour)							
	7.3m(Present)	8.0 m	9.0m	10.0m	11.0m	12.0m	13.0m	14.0m
6.0	0.00							
6.5	0.02							
6.8		0.00						
7.0	0.33	0.01						
7.2		0.04						
7.4		0.12						
7.6		0.28						
7.8		0.49	0.00					
8.0	2.02	0.77	0.01					
8.2	2.46	1.21	0.07					
8.4	2.94	1.46	0.18					
8.5								
8.6		1.93	0.38					
8.8		2.35	0.68	0.00				
9.0		2.81	0.77	0.03				
9.2		3.3	1.36	0.11				
9.4			1.74	0.27				
9.5								
9.6			2.00	0.54	0.00			
9.8			2.52	0.86	0.01			
10.0			2.91	1.19	0.06			
10.2				1.53	0.17			
10.4				1.91	0.38			
10.6				2.32	0.67	0.00		
10.8				2.80	1.01	0.03		
11.0					1.34	0.10		
11.2					1.71	0.24		
11.4					2.09	0.51		
11.6					2.55	0.82	0.00	
11.8					3.04	1.15	0.05	
12.0						1.50	0.16	
12.2						1.87	0.36	
12.4						2.28	0.65	0.00
12.6						2.76	0.98	0.10
12.8							1.31	0.22
13.0							1.67	0.24
13.2							2.05	0.41
13.4							2.51	0.68
13.6							2.99	1.12
13.8								1.46
14.0								1.85
14.2								2.23
14.4								2.72
14.6								

Source: Prepared by The Study Team



Source: Prepared by the Study Team

Figure 9.3 Calculation Results of Expected Waiting Time by Channel Depth

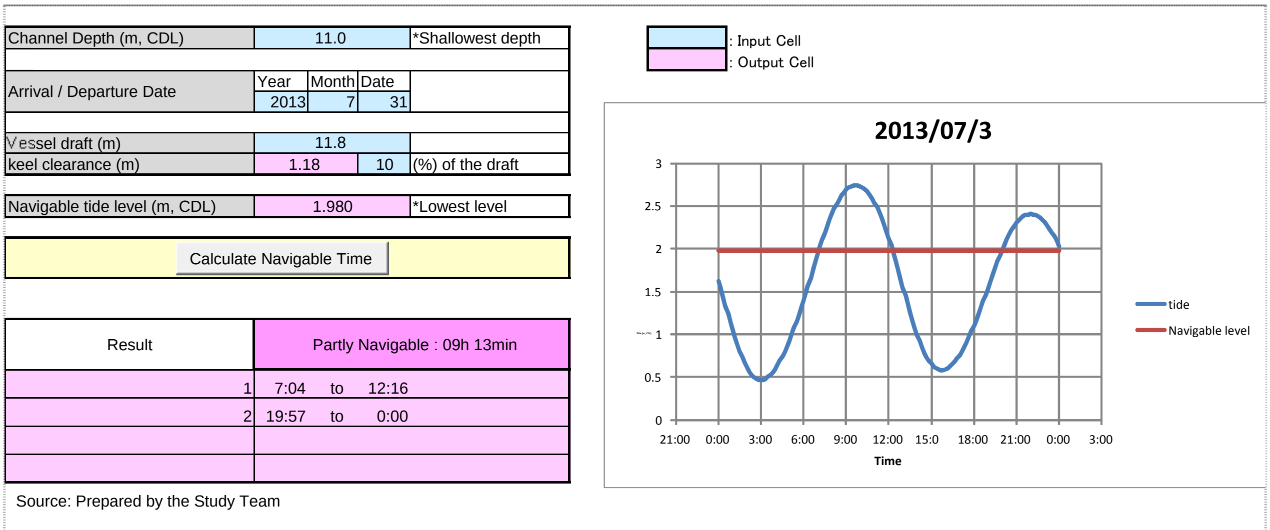
(5) Container Vessel Draft and Loading Capacity

The relationship between draught and container loading capacity was calculated by analyzing container vessels that cruise the entire world based on MDS and FAIRPLAY data to obtain a correlation formula. The correlation formula is expressed below:

$$Y=0.6624X^{3.4324} \quad (R^2=0.9324).$$

(6) Setting up Calculation Tool for obtaining navigable time range in the navigation channel

In order to obtain the time range of navigable time in the navigation channel, a calculation tool is prepared by the Study Team. By inputting the date of calling (year, month, date), the channel depth (in meters) and ship draft, the tool indicates Navigable Time that the vessel can use the channel and produces graph showing the lowest navigable tide level. Figure 9.4 shows Output Tool of Navigable Time Range.

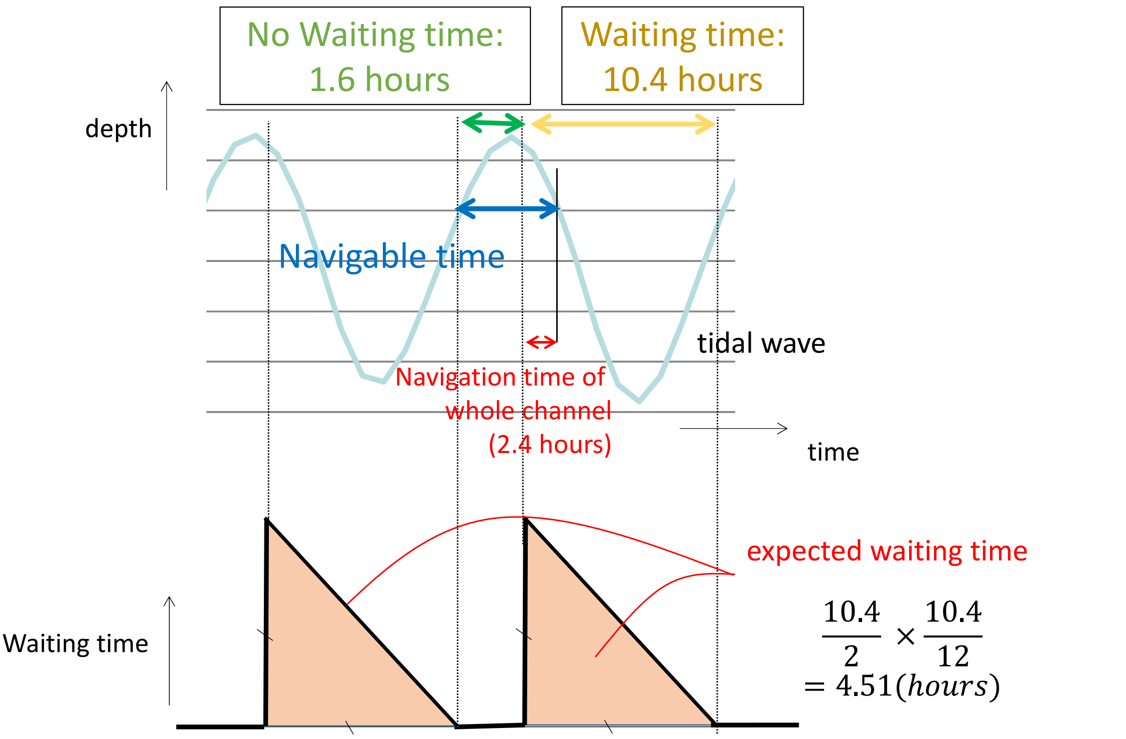


Source: Prepared by the Study Team

Figure 9.4 Output Tool of Navigable Time Range

(7) Comparison of existing and proposed navigation rule

Based on the similar concept shown in (4), the expected waiting time in the existing navigation rule is calculated as shown in Figure 9.5. As shown in the figure, the expected waiting time in the existing navigation rule which allows ships to navigate for only four hours before and after the high tide is estimated to be 4.51 hours. This might be generally larger than the expected waiting time calculated based on the proposed navigation rule shown in Figure 9.4; however, if slightly larger vessels (for example, a vessel with -9m draft) enter the channel with the existing depth, the expected waiting time is nearly 3 hours. More specifically, the existing navigation rule may approximate the waiting time under the current situation that only a slightly larger vessels enter the present shallow channel, but it may lose the significance in future which vessels of various sizes navigate the deepened channel.



$$\frac{10.4}{2} \times \frac{10.4}{12} = 4.51(hours)$$

Figure 9.5 Calculation result of expected waiting time according to the current navigation rule

9.2 Vessel Calling Model Calculation and Results

9.2.1 Simulation of calling at La Union Port at the present moment (as of 2010) using the developed model

In 2012, there was one liner service co-operated by APL and Hamburg-Sud calling at La Union Port weekly as shown in Figure 9.6. The vessel capacity in TEU basis was 1,324 TEU with 9.5m maximum draft. The service was temporarily stopped at the end of 2012; however, in this simulation, this service is additionally input into the 2010 maritime shipping network structured until the previous chapter from MDS database. The channel depth of La Union Port is assumed to be -8.0m; therefore, the expected waiting time for this vessel when entering into La Union Port is 3.30 (hours) according to the calculation based on the previous section. All other data including container cargo OD and level of service in each port are set as of 2010 as in the previous chapter.

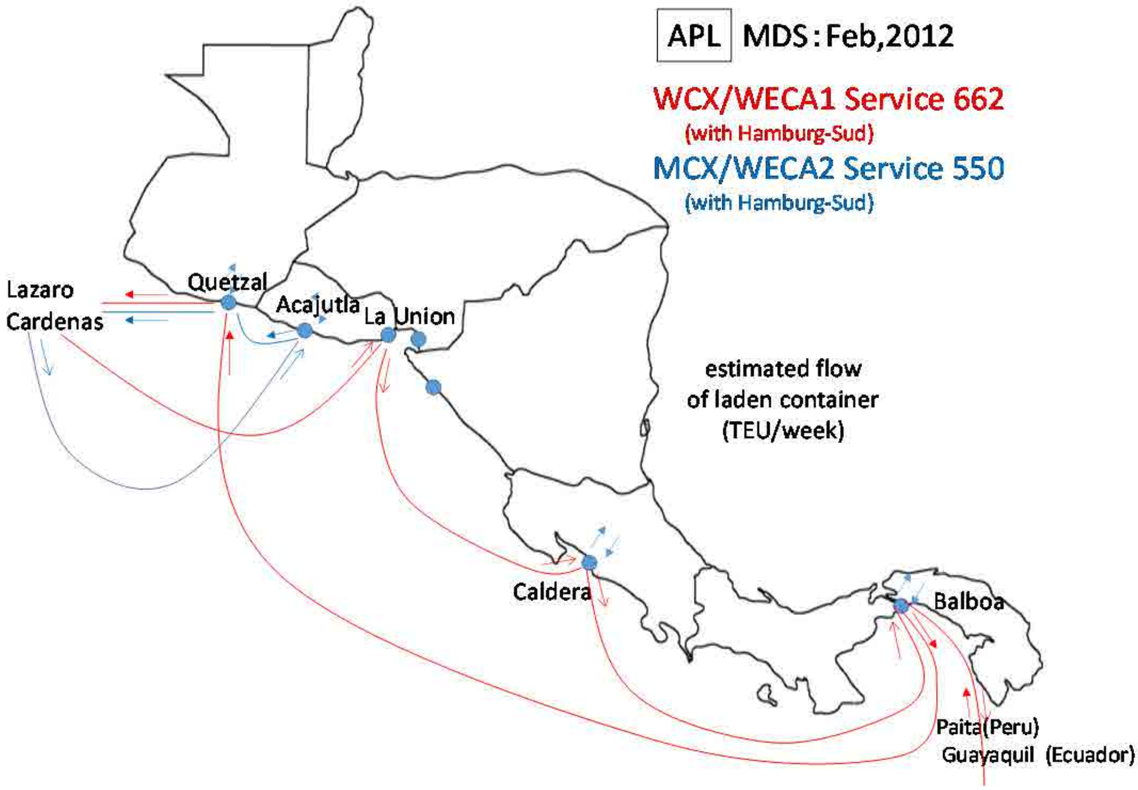


Figure 9.6 Service route operated by APL and Hamburg-Sud in 2012
(source: JICA Study Team made, based on information in the APL website)

The estimation result of model calculation in terms of container cargo throughput for each port is shown in Table 9.4. In the table, "base case (2010): S10-0" is the estimation result shown in 8.8.2(2) for reproducing the actual situation. The "simulation: S10-1" in the table shows the result when the additional liner service above mentioned is included.

The estimated amount of containers in La Union Port is 3,563 and 10,265 TEU for export and import respectively. Note that the model considers allocation only for the laden containers, not empty containers. The actual amount of container throughput in 2012 is 8,081 and 10,317 TEU in which empty containers are included. Considering that the empty containers often exist in order to coordinate the imbalance of import and export, it can be said that the model can accurately predict the amount of containers handled in La Union Port under the given condition.

Another finding from the table is that main cargo handled in La Union Port may shift mainly from foreign ports such as Corinto Port because in the case S10-1, the amount of containers handled in Acajutla Port is also estimated to increase slightly for both export and import.

Table 9.4 Estimation result of container cargo throughput in CA4 ports (TEU) considering a liner service to call at La Union Port

Port Name	Export		Import	
	Base Case (2010) S10-0	Simulation S10-1	Base Case (2010) S10-0	Simulation S10-1
Puerto Quetzal	100,406	96,888	121,403	116,255
Acajutla	30,479	31,637	60,621	65,136
La Union	0	3,563	0	10,265
Corinto	13,315	12,626	39,014	29,637
Puerto Cortes/ Puerto Castilla	202,477	194,281	198,855	207,297
Santo Tomas De Castilla/ Puerto Barrios	204,162	211,844	198,246	189,562

source: JICA Study Team's estimation

9.2.2 Scenario setting for future simulation (2020 and 2030)

(1) Container cargo OD

Future container cargo OD in year 2020 and 2030 are estimated by multiplying the 2010 container cargo OD estimated in 8.7.2 by multipliers which were estimated by CEPA for each CA4 country by year and by import/export. Note that the cargo shipping demand between any countries of the world other than CA4 countries is not changed from the amount in 2010.

(2) Level of service in each port

The level of service in La Union Port and other neighboring ports except for the depth of navigation channel to access to La Union Port are also considered to be somewhat improved for future. The settings in the future simulation of 2020 and 2030 are shown in Table 9.5. Some coefficients are subject to be changed due to some improvement as colored in the table. Some of the improvement is a reflection of our interview survey results such as a project for a new container terminal development in Puerto Quetzal. On the other hand, some of them are based on assumptions; for example, it is assumed that all CA4 ports except for Acajutla can accommodate a vessel with -12m draft at maximum in 2030 (i.e. a vessel of 3,350 TEU or less can berth at these ports from the relationship between vessel capacity and draft calculated using the correlation formula in (5) of 9.1.3), since the drastic increase in cargo demand expected in the CA region cannot be accommodated without introducing larger container vessels. Also, in Acajutla Port, the limitation of handling capacity for containers is considered.

Container handling charge is not changed during these periods for all ports, except for La Union Port in which a policy simulation on raising its tariff will be shown later.

Table 9.5 Future settings of level of service in each port
(colored columns are changed and improved from the previous period)

Port Name	2020				2030			
	Max. Draft	Lead Time		Transship-ment Time	Max. Draft	Lead Time		Transship-ment Time
		Export	Import			Export	Import	
	(m)	TPX_r (hours)	TPM_r (hours)	TR_r (hours)	(m)	TPX_r (hours)	TPM_r (hours)	TR_r (hours)
Puerto Quetzal	-14	48	24	24	-14	48	24	24
Acajutla	-11	60	48	48	-11	60	48	48
La Union	*	48	24	24	*	48	24	24
Corinto	-11	60	48	48	-12	48	24	48
Caldera	-11	48	24	48	-12	48	24	48
Puerto Cortes/ Puerto Castilla	-12	48	24	24	-12	48	24	24
Santo Tomas De Castilla/ Puerto Barrios	-11	48	24	48	-12	48	24	48
other ports	∞	48	24	*	∞	48	24	*

*: varied by port

source: forecasted by JICA Study Team

(3) Behavior of shipping companies

Each shipping company decides her level of service of liner shipping service including ports to call and their order, vessel size, frequency, transshipment port, etc. in order to maximize her profit or other corresponding principle. In this vessel calling model, future maritime shipping network including all liner shipping services of the world for the 28 shipping companies should be given as exogenous input. Since there is no limitation of the number of combinations of possible maritime shipping networks, alternatives of possible network are limited to the following rule, that is to say, i) modification of existing network, and ii) addition of new hub & spoke network.

1) Modification of existing network

As of May 2010, there are six liner shipping services which regularly call at Acajutla Port as shown in Table 9.6. Out of them, four services operated by single companies (i.e. Maersk, MSC, NYK, and APL) are feeder service from transshipment port(s) located in Mexico (Manzanillo or Lazaro Cardenas) and/or Panama (Balboa) using small vessels with a capacity of less than 1,700 TEU.

The other two services are “way-port” service using relatively larger vessels (around 2,500 TEU), coming from East Asia such as China and Japan or the east coast of North America to the west coast of South America including Columbia, Ecuador, Peru and Chile. Another characteristic of these “way-port” service is that they are co-operated by multiple companies or in case of the single company’s operation, alternately call (i.e. less than one calling per week) at a neighboring port (in this case, port of Caldera), in order to reduce the vessel capacity per week at the level to properly meet the actual demand.

Table 9.7 also shows a liner service operated in 2012 which called at La Union Port. This was also a feeder service connecting the port of Lazaro Cardenas, Mexico and Balboa, Panama to the trunk route.

Table 9.6 Existing liner shipping service call at port of Acajutla as of May 2010
(source: JICA Study Team based on MDS database and other sources)

Operator(s)	Average TEU capacity	Annual calls	Frequency
Maersk	1,695	104.0	twice a week (westbound and eastbound)
MSC	1,232	26.0	biweekly
NYK	1,610	52.0	weekly
APL	1,118	52.0	weekly
CMA-CGM/CSCL/CCNI	2,516	52.0	weekly
CSAV	2,599	23.1	4 times every 9 weeks (in other 5 times calling at Caldera instead of Acajutla)

Table 9.7 Existing liner shipping service call at La Union Port as on February 2012
(source: JICA Study Team based on MDS database and other sources)

Operator	Average TEU capacity	Annul calls	Frequency
APL/Hamburg-Sud	1,324	52.0	weekly

According to our interview survey to shipping companies, a shipping company has the following options when responding to an increase in demand;

a) increase frequency, for example, from biweekly to weekly, or from weekly to twice a week by calling in both directions (see the example of Maersk in Table 9.6).
b) increase the number of ports to call in the region, for example, calling at both Acajutla and La Union in El Salvador.
c) enlarge the vessel size. In case that a port does not have enough water depth, a vessel may shift to a neighboring port. On the other hand, if the area has large amount of cargo demand but there are no ports with sufficient water depth, a shipping company may introduce a small vessel.

From the above consideration, possible alternatives in the level of service which can be changed from the initial level for each company are summarized in Table 9.8.

Table 9.8 Possible alternatives in the level of liner service to be changed from the initial level by shipping company which call at Salvadoran ports at present

Operator	Average TEU capacity (draft)	Annual calls (Acajutla, La Union)
Maersk	1,240 (9m) 1,695 (10m, initial) 2,480 (11m) 3,350 (12m)*	(104, 0) (52(westbound), 52(eastbound)) (52(eastbound), 52(westbound)) (0, 104)
MSC	1,232 (9m, initial) 1,790 (10m) 2,480 (11m) 3,350 (12m)*	(26, 0) (52, 0) (52, 52)** (0, 52)
NYK	1,240 (9m) 1,610 (10m, initial) 2,480 (11m) 3,350 (12m)*	(52, 0) (52(westbound), 52(eastbound))** (52(eastbound), 52(westbound))** (0, 52)
APL(1)	1,118 (9m, initial)	(52, 0)

	1,790 (10m) 2,480 (11m) 3,350 (12m)*	(0, 52)
CMA-CGM/CSCL/CCNI	1,790 (10m) 2,516 (11m, initial) 3,350 (12m)*	(52, 0) (0, 52)
CSAV	1,790 (10m) 2,599 (11m, initial) 3,350 (12m)*	(23.1, 0) (0, 23.1)
APL(2)/Hamburg-Sud	1,324 (9m, initial) 1,790 (10m) 2,480 (11m) 3,350 (12m)*	(0, 0) (0, 52)

source: JICA Study Team's assumption
* only consideration in case of 2030 and only calling at La Union
** additional calling at La Union Port

2) Additional vessel-calling as a transshipment hub

In order to examine La Union Port's potential as a transshipment hub, one trunk route connecting East Asia including the port of Shanghai, Hong Kong and Shenzhen with the east coast of North America including the port of New York, Virginia, Savannah and Miami, with a vessel of 4,230 TEU (13m draft) co-operated by two companies is assumed to call at La Union Port as shown in Table 9.9. This service only calls at the port of Lazaro Cardenas (Mexico) in Central America at present.

In the eastbound direction after calling at and in the westbound direction before calling at the port of Lazaro Cardenas, additional call at La Union Port is assumed. Since these are additional calls to the existing service, it is assumed that a long waiting time (more than 0.2 hours) is not allowed when a vessel enters into the access channel to La Union Port due to maintain the schedule. Namely, the original vessel with the capacity of 4,230 TEU and 13m draft can berth at La Union Port only if the depth of navigation channel is -14m or more.

At the same time, a new feeder service connecting with the above trunk route in La Union Port by transshipment is additionally considered (see also Table 9.9). Based on preliminary trial results, the new service is assumed to operate between La Union Port and Balboa by way of Corinto and Caldera. The feeder service to the west from La Union Port connecting with Acajutla and Puerto Quetzal is not viable from the viewpoint of the amount of containers transported.

The shipping company A described in Table 9.9, which is one of operators of the trunk route and single operator of the feeder service, does not have any liner service in the Pacific coast of Central America at present (therefore, it is not included in Table 9.8). The reason why the shipping company A is selected as an example of a company which utilizes La Union Port as a transshipment hub is that the effect of its entry into the maritime shipping market in the Pacific coast of Central America can be clearly measured.

Table 9.9 Possible alternatives to be added as a transshipment service into La Union Port

Operator	Average TEU capacity (draft)	Annual calls and port to call
A/B	2,480 (11m)* 3,350 (12m) 4,230 (13m, initial)	104.0 (weekly, both direction) East Asia - Lazaro Cardenas - La Union - Miami - New York

A	2,480 (11m)* 3,350 (12m)**	52.0 (weekly) La Union, Corinto, Caldera, Balboa

source: JICA Study Team's assumption
* only in 2020, ** only in 2030

3) Scenario setting by combination of possible service

The scenario on the maritime shipping network for inputting into the container cargo assignment model is set by combining possible service of each shipping company as mentioned above. For each depth of access channel into La Union Port, there are set around 10 to 15 combinations with the maximum size of vessels which can berth at each port. At the same time, to meet the increasing shipping demand in CA4 countries, all the containerships navigating in this area are assumed to become larger, namely vessels of 2,480 TEU capacity with 11m draft will be introduced except in case where vessel size is assumed by each scenario. Figure 9.7 also shows a sample of maritime shipping network for model input around CA4 Pacific coastal ports.

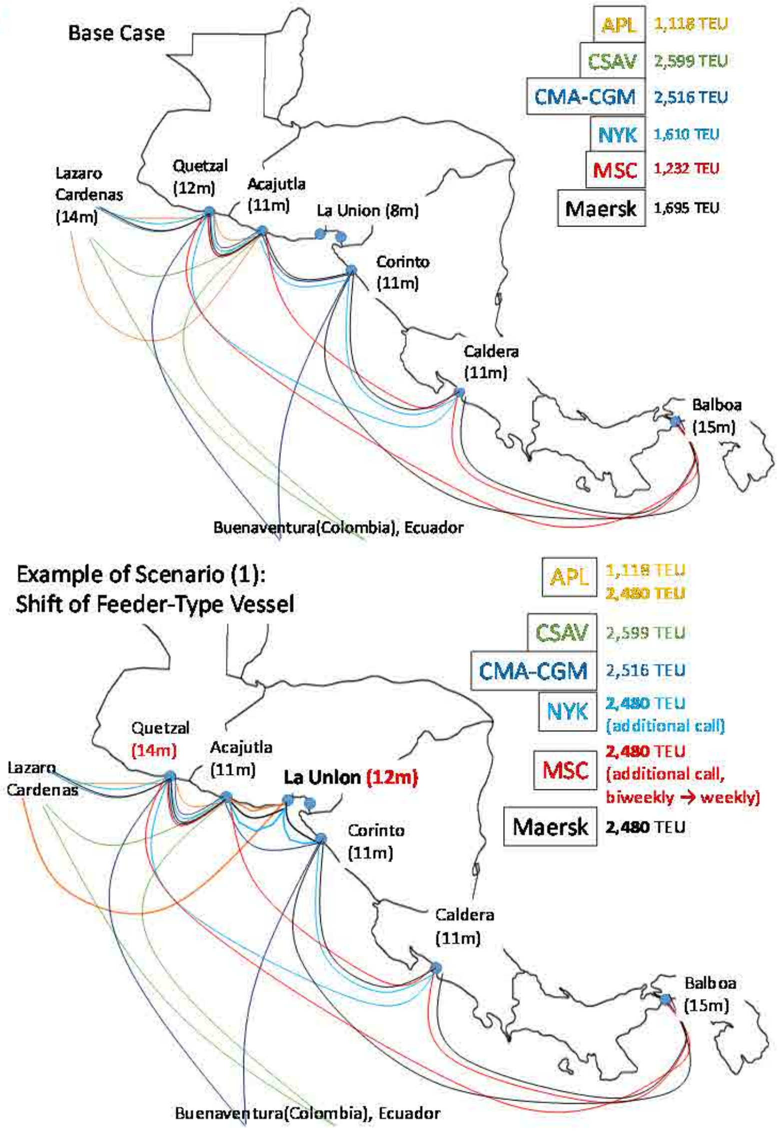


Figure 9.7 Base and example case of maritime shipping network (displayed only services to call at port of Acajutla or La Union)
source: made by JICA Study Team based on MDS database

9.2.3 Model calculation results

(1) Model calculation and result checking

For each scenario as prepared above, a model calculation is conducted. The number of calculations is around 100 times for each year. The calculation result is checked from the following viewpoints;

1) whether the model calculation is converged or not
2) whether each shipping company can collect enough cargo or not
3) whether a load factor of each service is too small or too large (for example, more than 100%)
4) whether the expected income is (although theoretically this cannot be calculated from the model) too small against the additional shipping cost or not

As a result, 23 scenarios (from -9m to -14m depth of navigation channel) out of 104 combinations in 2010 are selected as “feasible scenario” which is considered to be possibly realized, while 22 scenarios out of 121 combinations are selected as “feasible scenario” in 2030. Note that the possibility each scenario occurs is very different and that it is very difficult to predict which scenario is most likely to occur. Another point is that each scenario is set under a given depth of navigation channel with the maximum capacity of vessel that can navigate the access channel. In other words, if a scenario is judged “feasible” at some depth of channel, it is also automatically viable for any case with a deeper channel than originally envisioned.

(2) Example of calculation results: container cargo throughput for each feasible scenario

Figure 9.8 shows the amount of container cargo handled in La Union Port and Acajutla Port in 2020 for each feasible scenario with the depth of navigation channel. In the figure, the results in both scenarios i.e. 1) modification scenarios of existing feeder and way-port service network with -9m to -12m channel depth and 2) additional vessel-calling scenarios as a transshipment hub with -12m to -14m channel depth are shown. The result in “no-dredging scenario” with -8m channel depth is also shown in the figure.

It is found from the figure that the container cargo throughput in La Union Port increases in average as the depth of navigation channel increases, while the throughput in Acajutla Port tends to decrease as the depth of navigation channel in La Union Port increases.

Also, the same tendency in La Union Port can be observed in Figure 9.9 in which the same amount is shown in 2030, while the tendency in Acajutla Port is not clear. The constraint of handling capacity in Acajutla Port (additional lead time is considered if it is over 200,000 TEU) seems quite effective in the model calculation in 2030.

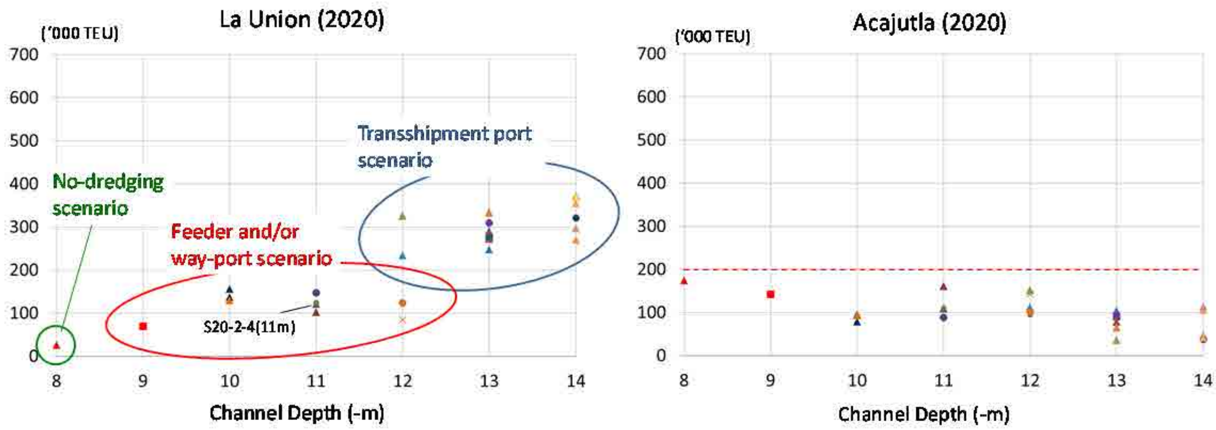


Figure 9.8 Container cargo throughput for each feasible scenario in La Union Port (above) and Acajutla (below) in 2020

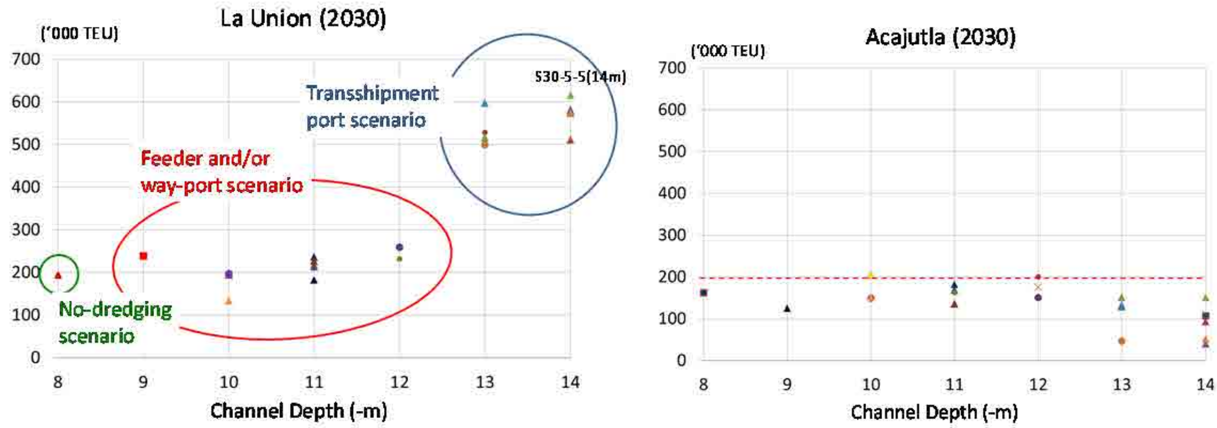


Figure 9.9 Container cargo throughput for each feasible scenario in La Union Port (above) and Acajutla (below) in 2030

(3) Policy simulation using the model: tariff increase and regional development in the eastern area of El Salvador

1) Tariff increase in La Union Port

After concluding the concession contract, the tariff for container handling in La Union Port is planned to increase. In order to measure the impact of the tariff increase, the model calculations are conducted again for all scenarios prepared in (1), inputting the new tariff (185.76 US$/TEU) for La Union Port instead of the existing tariff (65.79 US$/TEU).

Figure 9.10 shows the amount of container cargo handled in La Union Port and Acajutla Port in 2020 in the case of tariff increase in La Union Port. Compared with Figure 9.8 before the tariff increase, the container cargo throughput in La Union Port estimated in each scenario is slightly smaller for each channel depth, but the difference is not large. Also, the difference in the container cargo throughput in Acajutla Port is not significant. Figure 9.11 also shows the amount of container cargo handled in La Union Port and Acajutla Port in 2030 in the case of tariff increase in La Union Port. Compared with Figure 9.9 before tariff increase, the container cargo throughput in La Union Port estimated in each scenario is also slightly smaller for each channel depth, while the container cargo throughput in Acajutla Port is slightly larger and over the capacity of the container handling of the port (200,000 TEU) in a few scenarios.

These results imply that impact of the tariff increase in La Union Port on the container cargo throughput of the port is negative but not significant.

In order to consider the negative impact of the tariff increase, a simulation on the barrier at national border in land shipping is calculated. Figure 9.12 shows an example of the impact of the tariff increase on the container cargo throughput for each CA4 port in Scenario S30-5-5(14m) with -14m channel depth in 2030. In case that current level of national border is assumed, the change in the container cargo throughput in La Union Port after the tariff increase is very small; on the other hand, the impact of the tariff increase when any barriers at national border are removed is more significant.

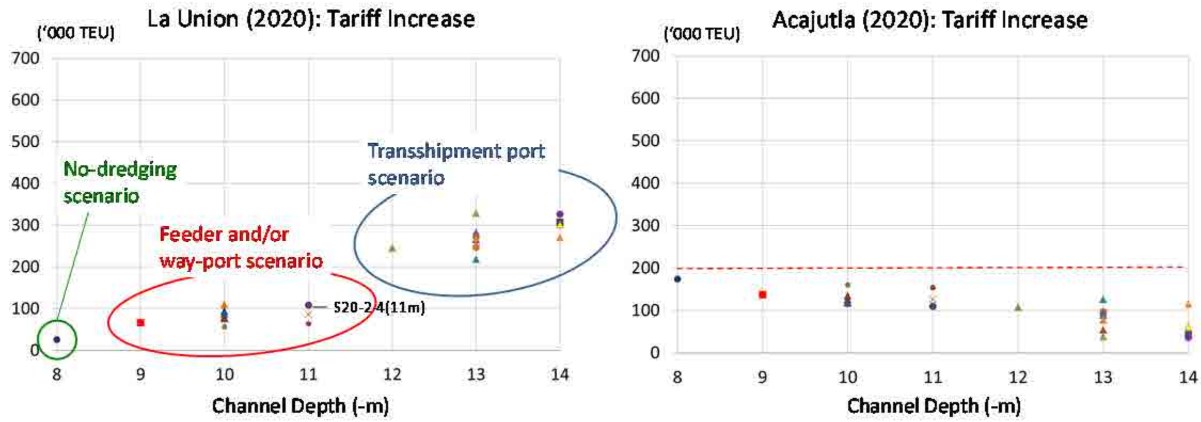


Figure 9.10 Container cargo throughput for each feasible scenario in La Union Port (above) and Acajutla (below) in 2020 (in case of tariff increase in La Union Port)

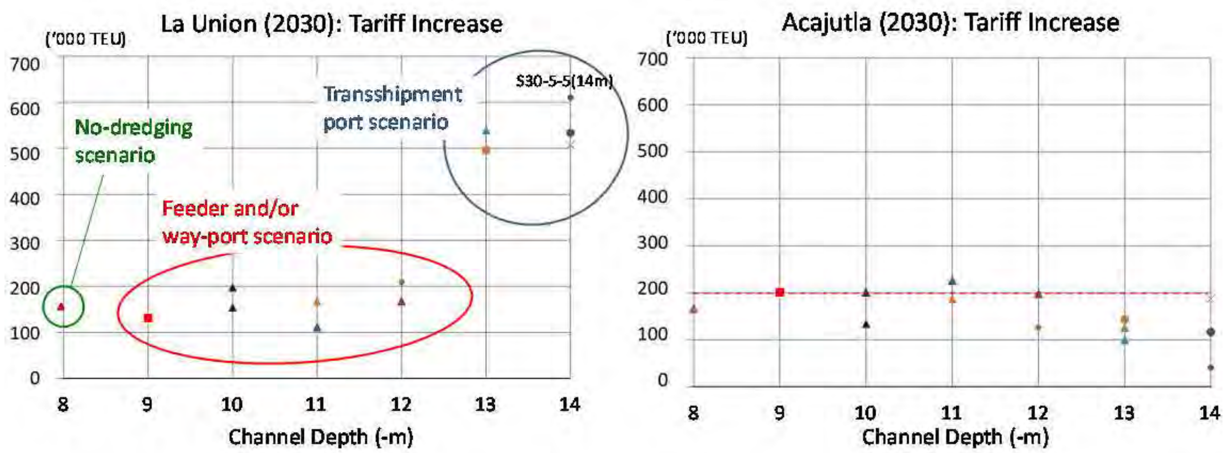


Figure 9.11 Container cargo throughput for each feasible scenario in La Union Port (above) and Acajutla (below) in 2030 (in case of tariff increase in La Union Port)

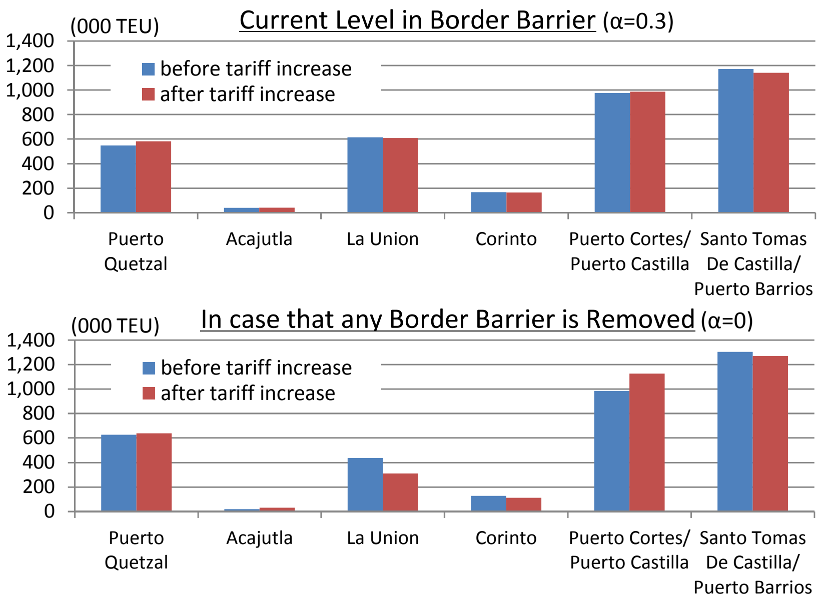


Figure 9.12 Difference of impact of tariff increase on container cargo throughput: current border barrier (above) and case that any border barrier is removed (below)
(in case of Scenario S30-5-5(14m) with -14m channel depth in 2030)

2) Regional development in Eastern El Salvador

The original development plan of La Union Port was integrated with the regional development plan of the hinterland in the eastern area of El Salvador. Reflecting this, a simulation to change the balance of the cargo originated from/destined into El Salvador between the West and East is conducted. Concretely, in the original OD, the share of container cargo between El Salvador West and East is assumed 94% and 6%; in this simulation, it is changed to 70% and 30% (in 2020) due to regional development in the eastern area. Note that the total amount of OD cargo is not changed from the original model.

Figure 9.13 shows the amount of container cargo handled in La Union Port and Acajutla Port in 2020 in the case of regional development in Eastern El Salvador. Compared with Figure 9.8 (original model), the amount of container cargo in La Union Port is expected to increase, especially in the feeder and/or way-port scenarios due to the extension of the hinterland of the port. However, the total amount of container cargo handled in La Union Port and Acajutla Port is almost not changed because the total amount of OD from/to El Salvador is not changed.

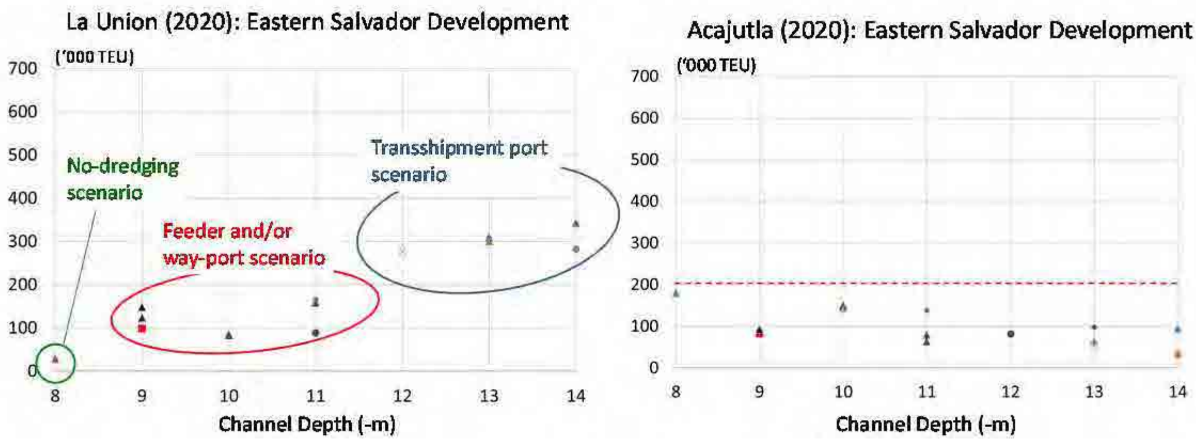


Figure 9.13 Container cargo throughput for each feasible scenario in La Union Port (above) and Acajutla (below) in 2020 (in case of regional development in Eastern El Salvador)

9.3 Economic and Financial Analysis in the Original Model

9.3.1 Definition and methodology

(1) Net income of La Union Port (except for dredging cost)

The optimum channel depth of La Union Port is identified by comparing the difference between dredging cost and the net income (except for dredging cost) derived from the container business of La Union Port by channel depth. The net income except for dredging cost of La Union Port is obtained by deducting container operation cost from the revenue obtained from container vessel use and container handling (see Table 9.10). The charges applied to vessels and containers were calculated based on the tariff of La Union Port (see Table 9.11). According to the tariff, the charges for ship accommodation and container handling depend on the number and size of vessels and the number of handled container boxes, which are obtained from the results of a model calculation. CEPA estimated container operation cost at La Union Port in the report on concession's tariff plan. According to this report, the cost consists of a fixed cost and a variable which depends on container handling volume. Container operation cost is estimated with the values of the above fixed cost and the values calculated based on a unit cost per box which is shown in the report (see Table 9.12).

Table 9.10 Revenue and expenditure of container business in La Union Port

Revenue		**Remarks**
	Charge for service to vessels	From Tariff of La Union Port (see Table 9.11)
	Charge for service to container handling	
Expenditure (except for dredging cost)		
	Container operation Cost	Estimated based on Financial Statements in the report on Concession's tariff Plan by CEPA (ESTRUCTURA TARIFARIA DE LA UNION) (see Table 9.12)
Net Income (except for dredging cost)		Revenue – Expenditure

Table 9.11 Tariff of La Union Port (related to containers)

Item		Remarks
a) Services Vessels		
	Access Channel Usage, navigation aids and pilotage	@(0.42$ * GT) MAX17,500GT
	Berthing/unberthing, towing, mooring/unmooring and first 24-hour stay of the vessel at the berth	@(0.08$ * GT) MAX17,500GT
	Stay. For each meter of length for each hour or fraction after the first 24 hours until the vessel leaves the berth.	@(0.35$ * LOA) per 24hour
b) Services for Container Handling		
	Loading/unloading at the pier, transfer, loading/unloading in yard, reception and dispatch	@($ 111.84*BOX)

Source：ESTRUCTURA TARIFARIA DE LA UNION

Table 9.12 Container terminal operation cost

Item	Annual Cost ($USD)	Remarks
Fixed cost	USD 2,683,832/year	Personnel expenses, Basic services, Use and consumption goods, Maintenance
Container volume depending cost	USD 15.52/box	Contracted services, Maintenance
Fixed and Container volume depending costs	USD 513,243/year USD11.47/box	Fuels and lubricants

Source: prepared from ESTRUCTURA TARIFARIA DE LA UNION

(2) Net income of port sector of El Salvador (except for dredging cost)

When considering the net income (except for the dredging cost) of the entire port sector of El Salvador, not only the net income of La Union Port, but also the net income of Acajutla Port should be considered as shown in Table 9.13.

Container terminal operation cost of Acajutla Port is assumed to be calculated by the same method as that of La Union Port. The tariff of Acajutla Port is shown in Table 9.14.

Table 9.13 Revenue and expenditure of container business in the Salvadoran port sector

Revenue		Remarks
	Revenue from container business of La Union Port (same as in Table 9.10)	See Table 9.10 and Table 9.11
	Revenue from container business of port of Acajutla	From Tariff of Acajutla Port (see Table 9.14)
Expenditure (except for dredging cost)		
	Container operation Cost of La Union Port(same as in Table 9.10)	See Table 9.10 and Table 9.12
	Container operation Cost of Acajutla Port	Same method as La Union Port
Net Income (except for dredging cost)		Revenue – Expenditure

Table 9.14 Tariff of Acajutla Port (related to containers)

Item		Remarks
a) Services to the Vessels		
	Berthing/unberthing in Quay	@(0.31$ * GT)
	Aid to Navigation	98.42 $ /vessel
	Stay in Quay	@(2.92$ * LOA) per 24hour
b) Services for Container Handling		
	Loading/Unloading Quay,Yarrd (Full/Empty),Transfer	@(124.92$ *BOX) (Full , Empty)

Source：CEPA

(3) Net benefit of Salvadoran economy (except for dredging cost)

Net benefit for Salvadoran economy produced by channel dredging is obtained by a summation of the increased amount of the net income for Salvadoran port sector (which is estimated in (2)) and the decreased amount of the shipping cost of Salvadoran container cargo, compared with the "no-dredging" scenario as shown in Table 9.15. The net income for Salvadoran port sector and shipping cost for Salvadoran shippers in the "no-dredging scenario" are obtained from the calculation result in case that the channel depth is 8m.

Table 9.15 Economic benefit and cost of dredging project of the channel in La Union Port (comparison to the "no-dredging" scenario)

Benefit		
	Increased/decreased revenue from container business of La Union Port	From Tariffs of the ports
	Increased/decreased revenue from container business of Acajutla Port	
	Increased/decreased shipping cost of Salvadoran export/import container cargo	Calculated by Model
Cost		
	Increased/decreased expenses of container operation of La Union Port	Same method as La Union Port
	Increased/decreased expenses of container operation of Acajutla Port	

9.3.2 Net income from container business of La Union Port and dredging cost by channel depth

The calculation results of the model indicate the amount of laden containers handled at La Union Port in TEU basis. The values have to be converted to those in boxes and the number of empty containers has to be added. The numbers of empty containers are derived from the empty container rate which is estimated in the previous section (in 10.2.1(2)). The amount of containers in TEU basis was converted to those in the number of containers (in box basis) using the conversion factor of 1.7 TEU/box which was calculated based on the numbers of 20 feet containers and 40 feet containers at Acajutla Port at present.

(1) Net income and dredging cost

The net income derived from container business of La Union Port is obtained by deducting container operation cost which is calculated based on Table 9.12 from revenue calculated based on Table 9.11. The estimated net incomes of La Union Port under several scenarios in 2020 and 2030 are shown in Figure 9.14 and Figure 9.15.

The dredging costs by channel depth are also displayed in the figures. Two values for dredging cost are prepared because siltation volumes were estimated by using an exponential model and a linear model as shown in Table 9.16. Note that in these dredging costs the cost of re-dredging is also included, not only the maintenance dredging cost with a contracted dredger. Since the maintenance dredging is assumed to last for ten years in Chapter 5, one-tenth of the re-dredging cost is added on the maintenance dredging cost for the average annual cost in the table.

The case of the maximum net income for each depth is the best scenario for CEPA from a financial viewpoint in the container business of La Union Port. Revenue and expenditures of such cases are shown in Table 9.17 and Table 9.18.

The maximum difference between the net income and dredging cost in 2020 and 2030 by channel is shown in Table 9.19 and Table 9.20. The optimum channel depth from a financial viewpoint of container business of La Union Port is the depth which provides the largest value obtained by deducting the dredging cost from the net income. The channel with depth of 8m yields the largest value (but negative) in both dredging cost functions in 2020. Also, the channel with depth of 8m yields the largest value in both dredging cost functions in 2030.

Table 9.16 Dredging cost by channel depth and model

Unit: 000 USD

Channel Depth	8m (no dredging scenario)	9m	10m	11m	12m	13m	14m
Modified exp. model	0	7,415	12,117	18,507	29,142	38,910	60,003
Linear model	0	7,415	12,117	18,507	27,998	36,563	44,541

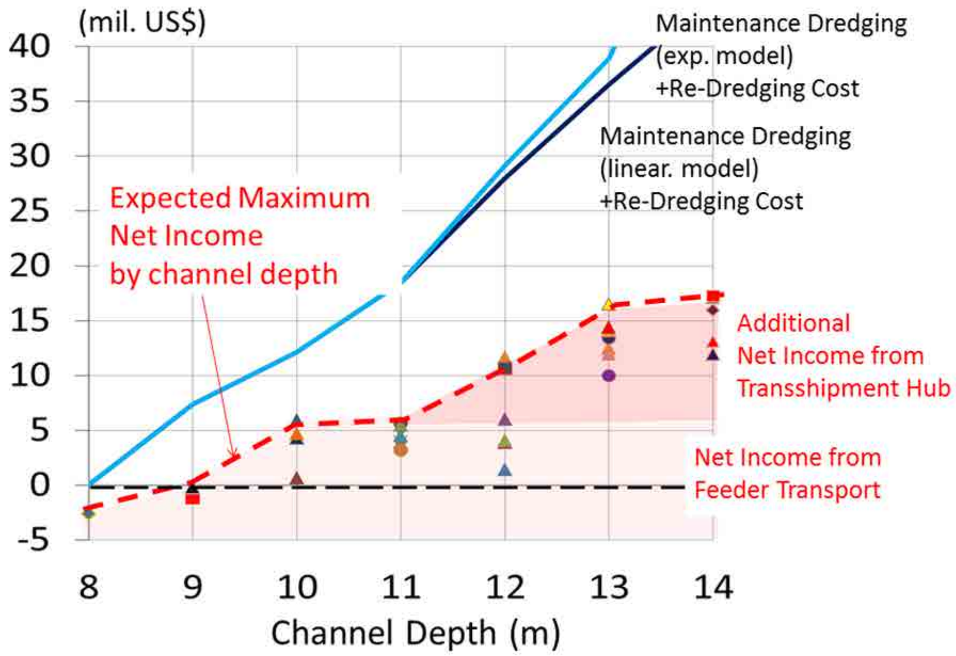


Figure 9.14 Estimated net income and dredging cost by channel depth in La Union Port (2020)

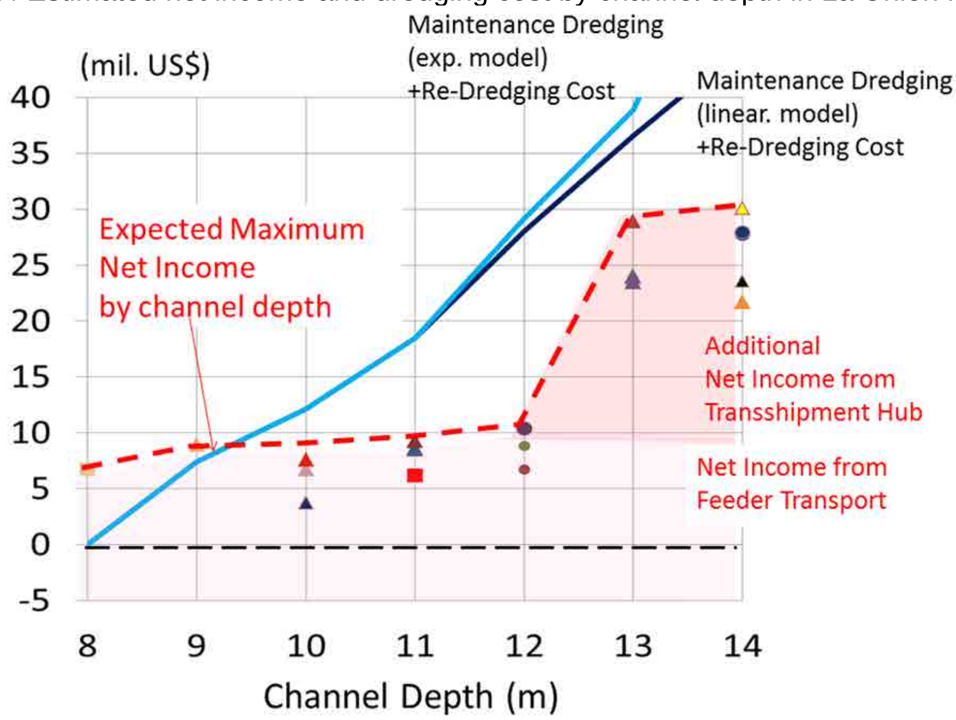


Figure 9.15 Estimated net income and dredging cost by channel depth in La Union Port (2030)

Table 9.17 Maximum net income from container business in La Union Port (2020)

Unit: 000 USD

Channel depth	8m (no dredging scenario)	9m	10m	11m	12m	13m	14m
Revenue	2,115	7,335	12,898	12,898	20,155	26,751	27,878
Expenditure	-4,755	-5,490	-6,983	-6,983	-8,525	-10,236	-10,626
Net Income	-2,641	1,845	5,917	5,917	11,630	16,515	17,253

Table 9.18 Maximum net income from container business in La Union Port (2030)

Unit: 000 USD

Channel depth	8m	9m	10m	11m	12m	13m	14m
Revenue	14,185	17,119	17,119	17,124	18,963	43,167	44,669
Expenditure	-7,489	-8,212	-8,212	-7,893	-8,596	-14,240	-14,565
Net Income	6,696	8,908	8,908	9,230	10,367	28,926	30,104

Table 9.19 Maximum difference between net income and dredging cost by channel depth in the La Union Port (2020)

Unit: 000 USD

Channel Depth	8m	9m	10m	11m	12m	13m	14m
Net Income	-2,641	1,845	5,917	5,917	11,630	16,515	17,253
Dredging Cost							
Modified exp. model	0	7,415	12,117	18,507	29,142	38,910	60,003
Linear model	0	7,415	12,117	18,507	27,998	36,563	44,541
Difference							
Modified exp. model	**-2,641**	-5,570	-6,200	-12,590	-17,512	-22,395	-42,750
Linear model	**-2,641**	-5,570	-6,200	-12,590	-16,368	-20,048	-27,288

Table 9.20 Maximum difference between net income and dredging cost by channel depth in the La Union Port (2030)

Unit: USD

Channel Depth	8m	9m	10m	11m	12m	13m	14m
Net Income	6,696	8,908	8,908	9,230	10,367	28,926	30,104
Dredging Cost							
Modified exp. model	0	7,415	12,117	18,507	29,142	38,910	60,003
Linear model	0	7,415	12,117	18,507	27,998	36,563	44,541
Difference							
Modified exp. model	**6,696**	1,491	-3,209	-9,277	-18,775	-9,984	-29,899
Linear model	**6,696**	1,491	-3,209	-9,277	-17,631	-7,637	-14,437

9.3.3 Net income from container business of Salvadoran port sector and dredging cost by channel depth

(1) Net income and dredging cost

The estimated net incomes (except for the dredging cost) of Acajutla Port and La Union Port under several scenarios in 2020 and 2030 are shown in Figure 9.16 and Figure 9.17 respectively. The dredging costs by channel depth are also displayed in the figures.

Revenue and expenditures of the best scenario from a financial viewpoint in the container business of Salvadoran port sector (i.e. the sum of Acajutla Port and La Union Port) are shown in Table 9.21 and Table 9.22 respectively.

The maximum difference between the net income and dredging cost in 2020 and 2030 by channel is shown in Table 9.23 and Table 9.24. The channel with depth of 8m is the optimum channel depth from a financial viewpoint of container business of Acajutla Port and La Union Port in both dredging cost models (i.e. the modified exponential model and linear model) in 2020. It is also the optimal channel depth in both dredging cost models in 2030.

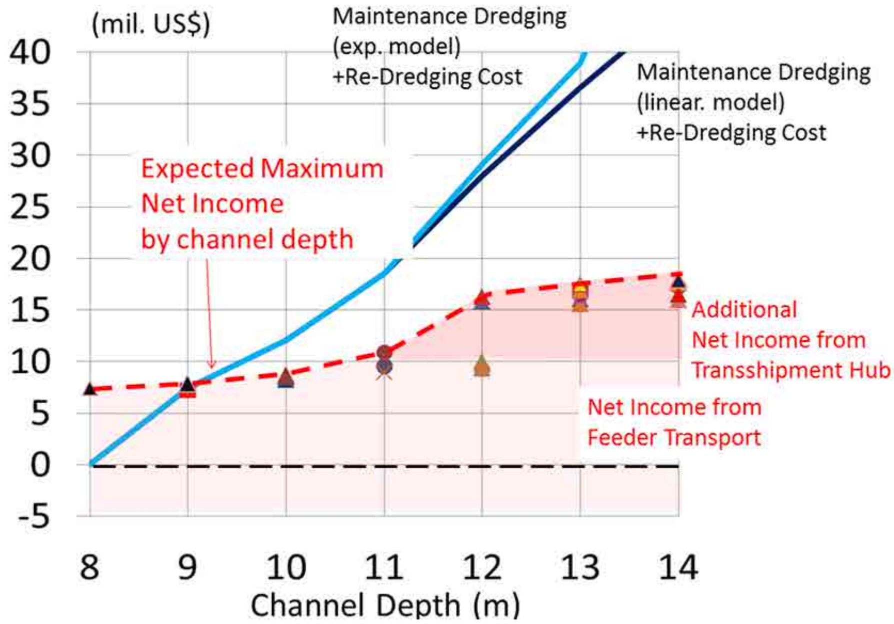


Figure 9.16 Estimated net income for Salvadoran port sector (sum of Acajutla Port and La Union Port) and dredging cost by channel depth in La Union Port (2020)

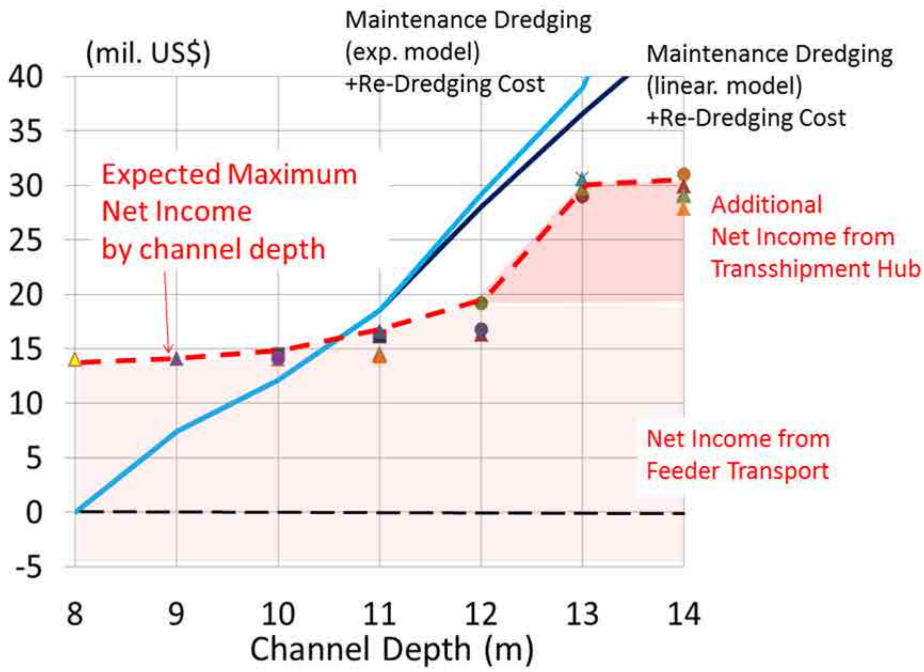


Figure 9.17 Estimated net income for Salvadoran port sector (sum of Acajutla Port and La Union Port) and dredging cost by channel depth in La Union Port (2030)

Table 9.21 Maximum net income from container business in Acajutla Port and La Union Port (2020)

Unit: 000 USD

Channel depth	8m (no dredging scenario)	9m	10m	11m	12m	13m	14m
Revenue	19,055	19,688	20,265	23,544	30,572	32,768	33,272
Expenditure	-11,625	-11,847	-12,064	-12,692	-14,336	-15,343	-15,416
Net Income	7,430	7,849	8,201	10,852	16,236	17,424	17,856

Table 9.22 Maximum net income from container business in Acajutla Port and La Union Port (2030)

Unit: 000 USD

Channel depth	8m (no dredging scenario)	9m	10m	11m	12m	13m	14m
Revenue	28,003	28,213	28,318	31,078	34,495	50,066	51,295
Expenditure	-13,999	-14,134	-13,851	-14,494	-15,314	-19,475	-19,332
Net Income	14,005	14,079	14,466	16,584	19,181	30,591	31,964

Table 9.23 Maximum difference between net income for Salvadoran port sector and dredging cost by channel depth in La Union Port (2020)

Unit: 000 USD

Channel Depth	8m (no dredging scenario)	9m	10m	11m	12m	13m	14m
Net Income	7,430	7,841	8,201	10,852	16,236	17,424	17,856
Dredging Cost							
Modified exp. model	0	7,415	12,117	18,507	29,142	38,910	60,003
Linear model	0	7,415	12,117	18,507	27,998	36,563	44,541
Difference							
Modified exp. model	**7,430**	426	-3,916	-7,655	-12,906	-21,486	-42,147
Linear model	**7,430**	426	-3,916	-7655	-11762	-19,139	-26,685

Table 9.24 Maximum difference between net income for Salvadoran port sector and dredging cost by channel depth in La Union Port (2030)

Unit: 000 USD

Channel Depth	8m	9m	10m	11m	12m	13m	14m
Net Income	14,005	14,079	14,466	16,584	19,181	30,591	31,964
Dredging Cost							
Modified exp. model	0	7,415	12,117	18,507	29,142	38,910	60,003
Linear model	0	7,415	12,117	18,507	27,998	36,563	44,541
Difference							
Modified exp. model	**14,005**	6,664	2,349	-1923	-9,961	-8,319	-28,039
Linear model	**14,005**	6,664	2,349	-1,923	-8,817	-5,972	-12,577

9.3.4 Economic benefit of El Salvador by container handling at La Union Port

Economic benefit of channel dredging is analyzed by comparing several cases of model calculation in 2020 and 2030 ("dredging scenarios") to a case without channel dredging ("no-dredging scenario").

La Union Port can accommodate larger vessels by deepening the channel. This could result in an increase of container volume through the ports of El Salvador and accordingly an increase in the net income of Salvadoran port sector. In addition, the shipping cost of Salvadoran import/export cargo would be expected to decrease. Channel dredging project is expected to produce such economic effect.

Difference of the sum of the net incomes of the ports of La Union and Acajutla and shipping cost of Salvadoran import/export cargo for dredging scenarios from those of the no-dredging scenario represents the economic benefit of the dredging project. Such values in 2020 and 2030 are shown in Figure 9.18 and Figure 9.19. Dredging cost is also displayed in the figures.

The case which shows the maximum economic benefit for each depth is the best scenario to El Salvador from an economic viewpoint. The values of increase of revenue and decrease of expenditures of the ports and decrease of shipping cost of Salvadoran cargo in 2020 and 2030 are summarized by channel depth in Table 9.25 and Table 9.26.

Economic benefit in 2020 and 2030 by channel depth and dredging costs are shown in Table 9.27 and Table 9.28. The optimum channel depth from an economic viewpoint of El Salvador is the depth which provides the largest value obtained by deducting dredging cost from economic benefit. The channel with depth of 12m falls into the above case for the costs by the modified model and the linear model in 2020 and the channel with depth of 13m in 2030.

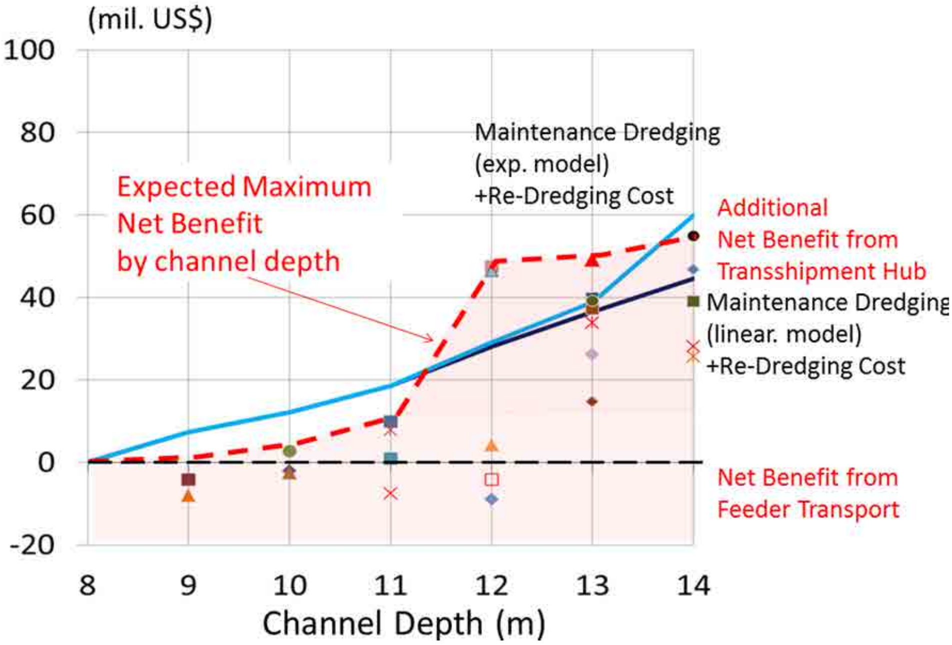


Figure 9.18 Estimated net benefit of dredging project for Salvadoran economy and dredging cost by channel depth (2020)

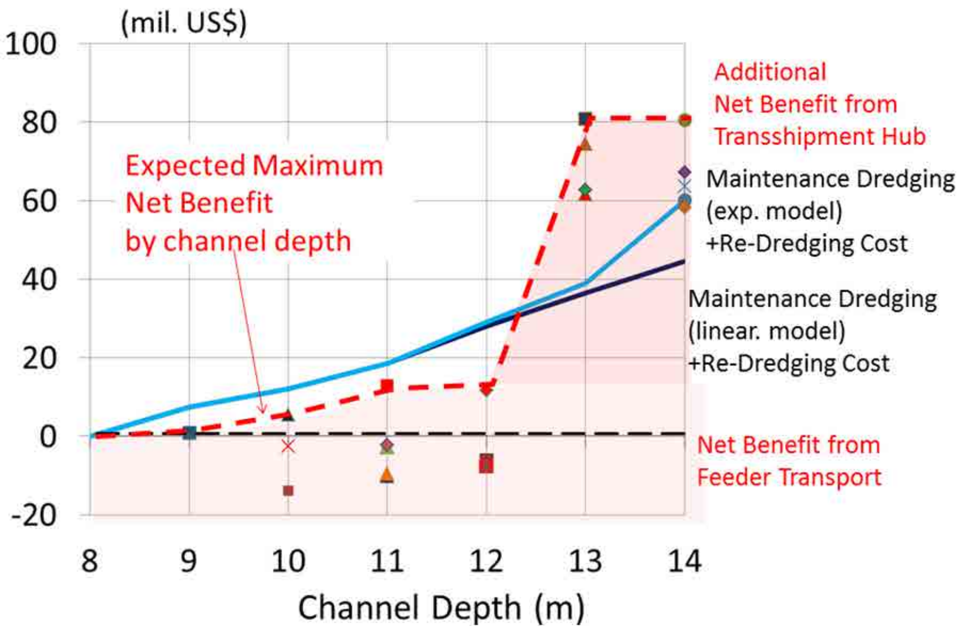


Figure 9.19 Estimated net benefit of dredging project for Salvadoran economy and dredging cost by channel depth (2030)

Table 9.25 Maximum net benefit of dredging project for Salvadoran economy by channel depth(2020)

Unit: 000 USD

Channel Depth	9m	10m	11m	12m	13m	14m
Increase of net income for Salvadoran port sector derived from container business	411	1,132	2,008	8,371	9,380	10,426
Decrease of shipping cost of Salvadoran cargo	-4,563	1,593	7,931	39,139	39,632	44,446
Net benefit	-4,152	2,726	9,939	47,510	49,012	54,872

Table 9.26 Maximum net benefit of dredging project for Salvadoran economy by channel depth(2030)

Unit: 000 USD

Channel Depth	9m	10m	11m	12m	13m	14m
Increase of net income for Salvadoran port sector derived from container business	74	462	523	523	16,587	16,587
Decrease of shipping cost of Salvadoran cargo	849	5,084	12,365	12,365	64,246	64,246
Net benefit	923	5,546	12,888	12,888	80,833	80,833

Table 9.27 Maximum economic benefit of dredging project for Salvadoran economy by channel depth (2020)

Unit: 000 USD

Channel Depth	9m	10m	11m	12m	13m	14m
Economic benefit	-4,152	2,726	9,939	47,510	49,012	54,872
Dredging cost						
Modified exp. model	7,415	12,117	18,507	29,142	38,910	60,003
Linear model	7,415	12,117	18,507	27,998	36,563	44,541
Difference						
Modified exp. model	-11,567	-9,391	-8,568	**18,368**	10,102	-5,131
Linear model	-11,567	-9,391	-8,568	**19,512**	12,449	10,331

Table 9.28 Maximum economic benefit of dredging project for Salvadoran economy by channel depth (2030)

Unit: 000 USD

Channel Depth	9m	10m	11m	12m	13m	14m
Economic Benefit	923	5,546	12,888	12,888	80,833	80,833
Dredging Cost						
Modified exp. Model	7,415	12,117	18,507	29,142	38,910	60,003
Linear. Model	7,415	12,117	18,507	27,998	36,563	44,541
Difference						
(Modified exp. Model)	-6,492	-6,571	-5,619	-16,254	**41,923**	20,830
(Linear. Model)	-6,492	-6,571	-5,619	-15,110	**44,270**	36,292

9.4 Economic and Financial Analysis on Policy Simulation

9.4.1 Net income from container business of La Union Port (in case of the tariff increase) and dredging cost by channel depth

(1) Net income and dredging cost

In case of tariff increase, the estimated net incomes of La Union Port under the feasible scenarios in 2020 and 2030 are shown in in Figure 9.20 and Figure 9.21. The new tariff assumed in this calculation is shown in Table 9.29.

Table 9.29 New tariff set in La Union Port

Item		Remarks
a) Services to the Vessels		
	Channel Usage	@(0.15$ * GT)
	Practical Pilot	@(701.79$ per call)
	Navigation Aids	@(263.18$ per call)
	Berthing and Unberthing	@(0.19$ * GT)
	Mooring and Unmooring	@(0.03$ * GT)
	Stay	@(0.09$ * LOA * hour)
b) Services for Container Handling		
	Dispatch	@(10.61$ * TEU)
	Wharfage	@(20.67$ * TEU(Full container))
	Loading/Unloading from Ship to Quay	@(82.88$ * TEU)
	Transfer from Quay to Yard	@(42.43$ * TEU)
	Loading/Unloading in Yard	@(29.17$ * Laden TEU+26.21$ * Empty TEU)

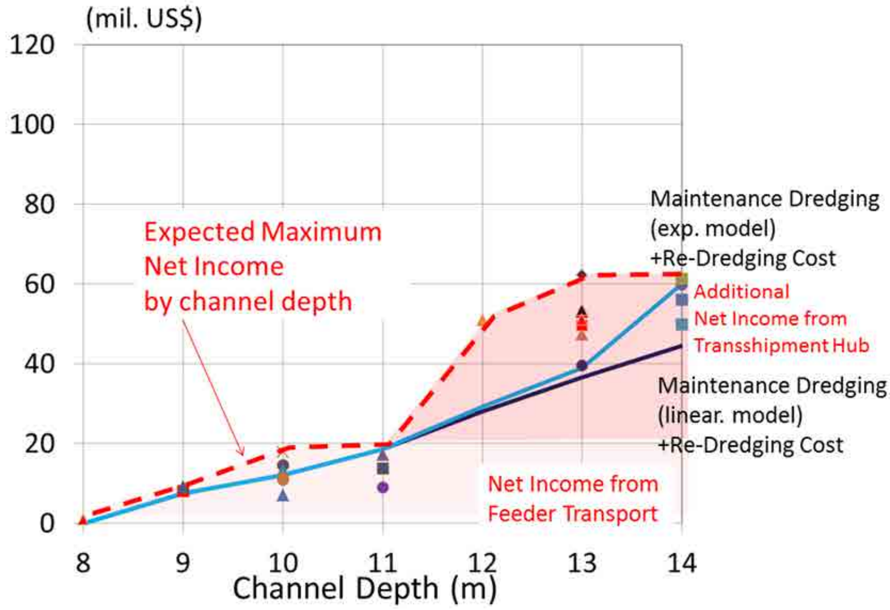


Figure 9.20 Estimated net income in case of the tariff increase and dredging cost by channel depth in La Union Port (2020)

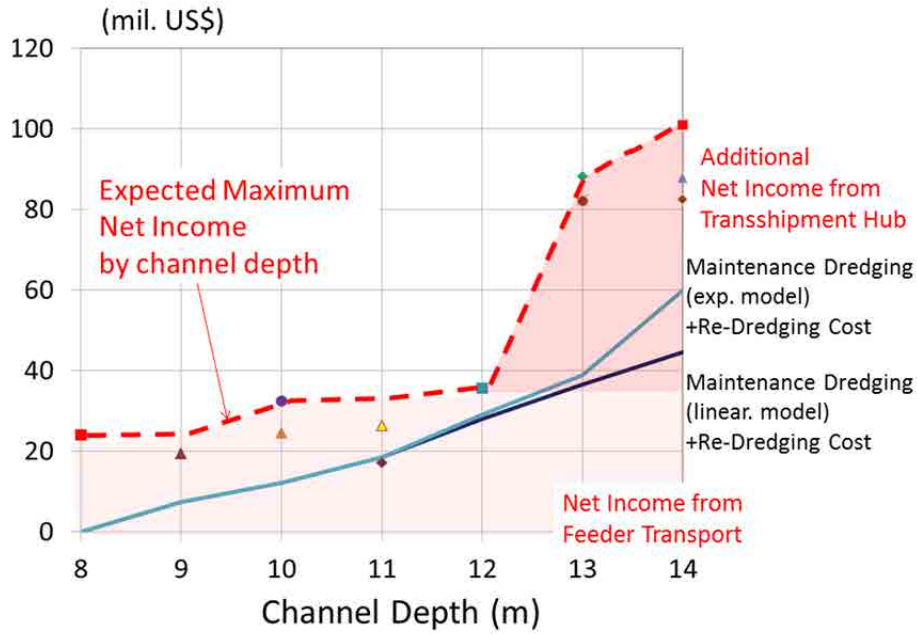


Figure 9.21 Estimated net income in case of the tariff increase and dredging cost by channel depth in La Union Port (2030)

The case of the maximum net income for each depth is the best scenario for CEPA from a financial viewpoint in the container business of La Union Port. Revenue and expenditures of such cases are shown in Table 9.30 and Table 9.31.

The maximum difference between the net income and dredging cost in 2020 and 2030 by channel is shown in Table 9.32 and Table 9.33. The optimum channel depth from a financial viewpoint of container business of La Union Port is the depth which provides the largest value obtained by deducting the dredging cost from the net income. The channel with depth of 13m yields the largest value in both dredging cost functions in 2020. Also, the channel with depth of 13m falls into the above case for the costs by the modified model and the channel with depth of 14m falls into the above case for the costs by the linear model in 2030.

Table 9.30 Maximum net income from container business in La Union Port in case of the tariff increase (2020)

Unit: 000 USD

Channel depth	8m (no dredging scenario)	9m	10m	11m	12m	13m	14m
Revenue	5,644	14,548	23,970	23,970	59,636	72,381	72,381
Expenditure	-4,755	-5,433	-6,199	-6,199	-8,730	-10,127	-10,127
Net Income	888	9,115	17,772	17,772	50,907	62,255	62,255

Table 9.31 Maximum net income from container business in La Union Port in case of the tariff increase (2030)

Unit: 000 USD

Channel depth	8m	9m	10m	11m	12m	13m	14m
Revenue	30,938	30,938	40,031	40,031	43,319	101,457	115,525
Expenditure	-6,914	-6,914	-7,574	-7,574	-7,683	-13,299	-14,465
Net Income	24,024	24,024	32,456	32,456	35,636	88,158	101,160

Table 9.32 Maximum difference between net income in case of the tariff increase and dredging cost by channel depth in La Union Port (2020)

Unit: 000 USD

Channel Depth	8m	9m	10m	11m	12m	13m	14m
Net Income	888	9,115	17,772	17,772	50,907	62,255	62,255
Dredging Cost							
Modified exp. model	0	7,415	12,117	18,507	29,142	38,910	60,003
Linear model	0	7,415	12,117	18,507	27,998	36,563	44,541
Difference							
Modified exp. model	888	1,700	5,655	-735	21,765	**23,345**	2,252
Linear model	888	1,700	5,655	-735	22,909	**25,692**	17,714

Table 9.33 Maximum difference between net income in case of the tariff increase and dredging cost by channel depth in La Union Port (2030)

Unit: 000 USD

Channel Depth	8m	9m	10m	11m	12m	13m	14m
Net Income	24,024	24,024	32,456	32,456	35,636	88,158	101,160
Dredging Cost							
Modified exp. model	0	7,415	12,117	18,507	29,142	38,910	60,003
Linear model	0	7,415	12,117	18,507	27,998	36,563	44,541
Difference							
Modified exp. model	24,024	16,609	20,339	13,949	6,494	**49,248**	41,157
Linear model	24,024	16,609	20,339	13,949	7,638	51,595	**56,619**

9.4.2 Net income from container business of Salvadoran port sector (in case of the tariff increase in La Union Port) and dredging cost by channel depth

(1) Net income and dredging cost

The estimated net incomes of Acajutla Port and La Union Port under the feasible scenarios in 2020 and 2030 are shown in Figure 9.22 and Figure 9.23. The dredging costs by channel depth are also displayed in the figures.

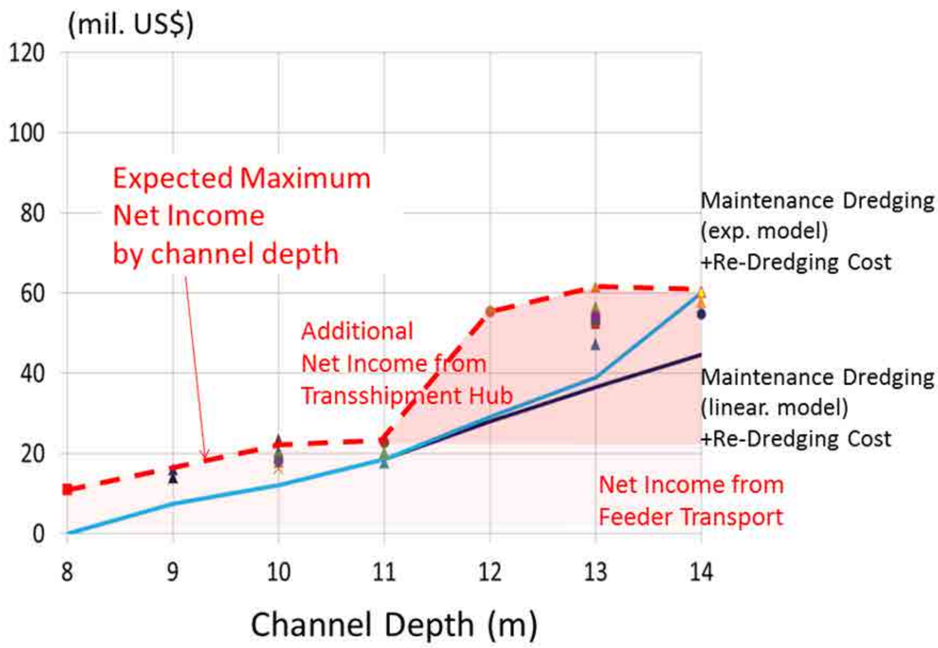


Figure 9.22 Estimated net income for Salvadoran port sector (sum of Acajutla Port and La Union

Port) in case of the tariff increase and dredging cost by channel depth in La Union Port (2020)

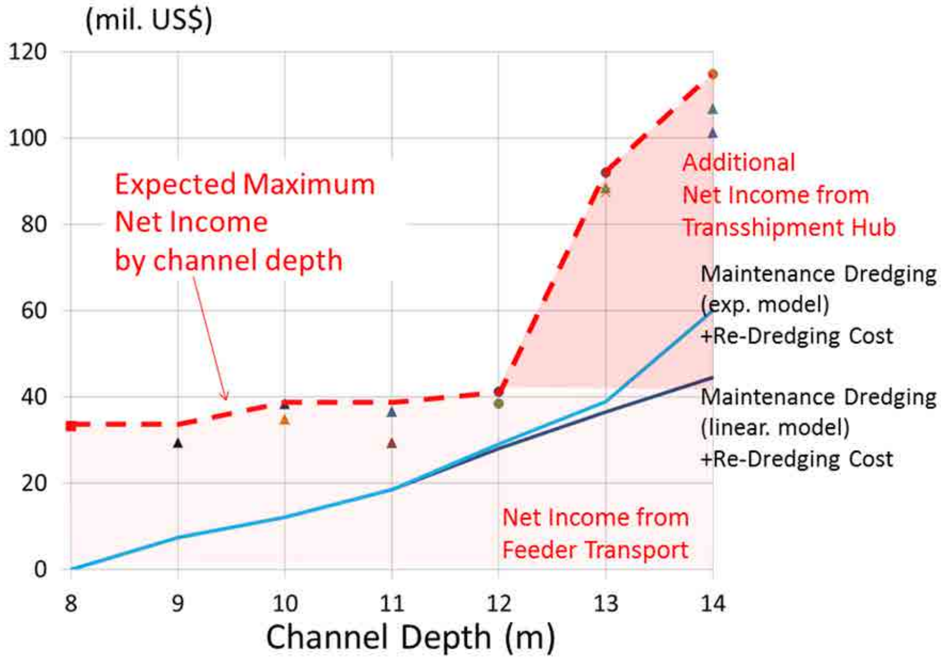


Figure 9.23 Estimated net income for Salvadoran port sector (sum of Acajutla Port and La Union Port) in case of the tariff increase and dredging cost by channel depth in La Union Port (2030)

Revenue and expenditures of such cases of the best scenario from a financial viewpoint in the container business of Salvadoran port sector (i.e. the sum of Acajutla Port and La Union Port) are shown in Table 9.34 and Table 9.35.

The maximum difference between the net income and dredging cost in 2020 and 2030 by channel depth is shown in Table 9.36 and Table 9.37. The channel with depth of 12m is the optimum channel depth from a financial viewpoint of container business of Acajutla Port and La Union Port in both dredging cost models (i.e. the modified exponential model and linear model) in 2020. The channel with depth of 13m is the optimum channel depth in both dredging cost models in 2030.

Table 9.34 Maximum net income from container business in Acajutla Port and La Union Port in case of the tariff increase in La Union Port (2020)

Unit: 000 USD

Channel depth	8m (no dredging scenario)	9m	10m	11m	12m	13m	14m
Revenue	22,583	27,602	35,630	35,630	69,796	76,092	76,092
Expenditure	-11,625	-11,676	-11,748	-11,748	-14,433	-14,640	-14,640
Net Income	10,958	15,926	23,883	23,883	55,363	61,452	61,452

Table 9.35 Maximum net income from container business in Acajutla Port and La Union Port in case of the tariff increase in La Union Port (2030)

Unit: 000 USD

Channel depth	8m	9m	10m	11m	12m	13m	14m
Revenue	46,778	46,778	51,948	51,948	54,832	110,810	111,936
Expenditure	-13,496	-13,496	-13,613	-13,613	-13,633	-18,783	-19,742
Net Income	33,282	33,282	38,335	38,335	41,198	92,027	92,194

Table 9.36 Maximum difference between net income for Salvadoran port sector in case of the tariff increase and dredging cost by channel depth in La Union Port (2020)

Unit: 000 USD

Channel Depth	8m	9m	10m	11m	12m	13m	14m
Net Income	10,958	15,926	23,883	23,883	55,363	61,452	61,452
Dredging Cost							
Modified exp. model	0	7,415	12,117	18,507	29,142	38,910	60,003
Linear model	0	7,415	12,117	18,507	27,998	36,563	44,541
Difference							
Modified exp. model	10,958	8,511	11,766	5,376	**26,221**	22,542	1,449
Linear model	10,958	8,511	11,766	5,376	**27,365**	24,889	16,911

Table 9.37 Maximum difference between net income for Salvadoran port sector in case of the tariff increase and dredging cost by channel depth in La Union Port (2030)

Unit: 000 USD

Channel Depth	8m	9m	10m	11m	12m	13m	14m
Net Income	33,282	33,282	38,335	38,335	41,198	92,027	92,194
Dredging Cost							
Modified exp. model	0	7,415	12,117	18,507	29,142	38,910	60,003
Linear model	0	7,415	12,117	18,507	27,998	36,563	44,541
Difference							
Modified exp. model	33,282	25,867	26,218	19,828	12,056	**53,117**	32,191
Linear model	33,282	25,867	26,218	19,828	13,200	**55,464**	47,653

9.4.3 Economic benefit of El Salvador by container handling at La Union Port in case of tariff increase

Difference of the sum of the net incomes of the ports of La Union and Acajutla and shipping cost of Salvadoran import/export cargo for dredging scenarios from those of the no-dredging scenario represents the economic benefit of the dredging project. Such values in 2020 and 2030 is shown in Figure 9.24 and Figure 9.25 respectively. Dredging cost is also displayed in the figures.

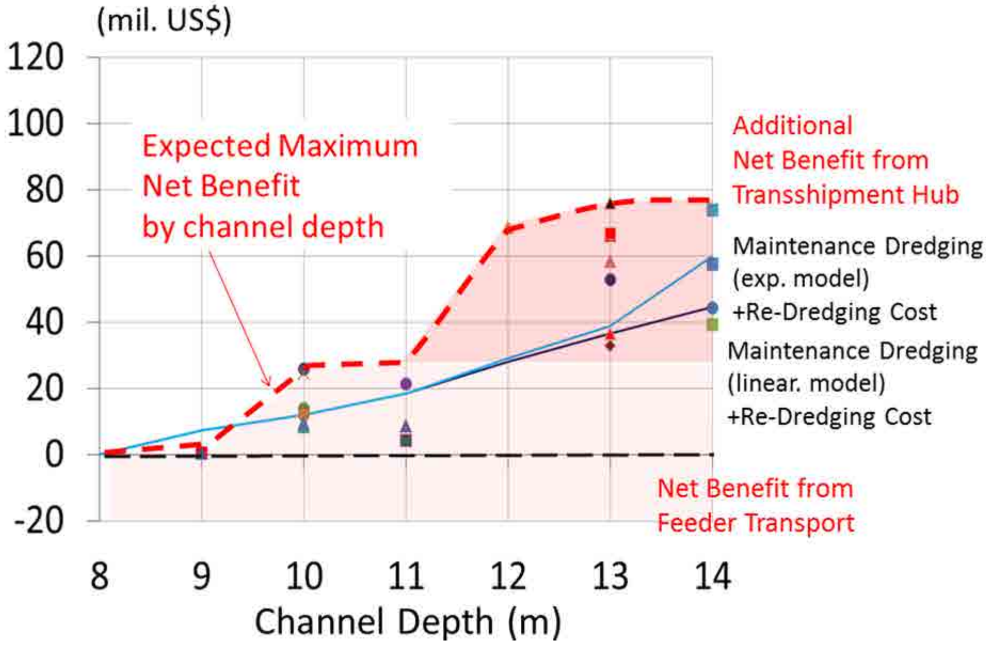


Figure 9.24 Estimated net benefit of dredging project for Salvadoran economy in case of the tariff increase and dredging cost by channel depth (2020)

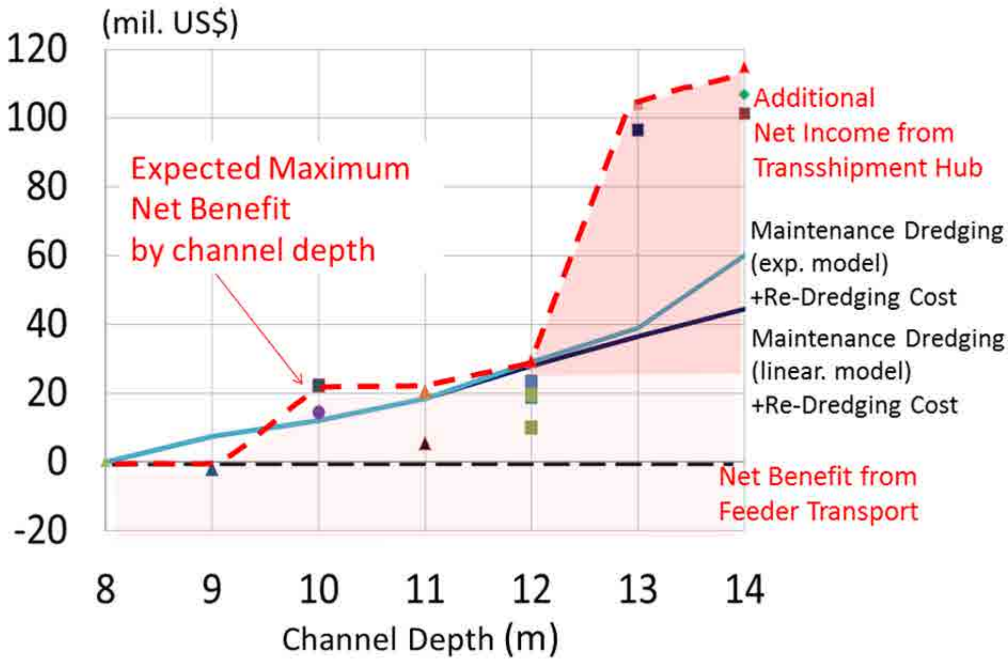


Figure 9.25 Estimated net benefit of dredging project for Salvadoran economy in case of the tariff increase and dredging cost by channel depth (2030)

The case which shows the maximum economic benefit for each depth is the best scenario to El Salvador from an economic viewpoint. The values of increase of revenue, decrease of expenditures of the ports, and decrease of shipping cost of Salvadoran cargo in 2020 and 2030 is summarized by channel depth in Table 9.38 and Table 9.39 respectively.

Economic benefit in 2020 and 2030 by channel depth and dredging costs is shown in Table 9.40 and Table 9.41 respectively. The optimum channel depth from an economic viewpoint of El Salvador is the depth which provides the largest value obtained by deducting dredging cost from economic benefit. The channel with depth of 12m falls into the above case for the costs by the modified model and the linear model in 2020. Also, the channel with depth of 13m falls into the above case for the costs by the modified model and the channel with depth of 14m falls into the above case for the costs by the linear model in 2030.

Table 9.38 Maximum net benefit of dredging project for Salvadoran economy by channel depth in case of the tariff increase (2020)

Unit: 000 USD

Channel Depth	9m	10m	11m	12m	13m	14m
Increase of net income for Salvadoran port sector derived from container business	4,968	9,495	9,495	44,404	43,503	43,503
Decrease of shipping cost of Salvadoran cargo	-4,387	16,471	16,471	24,261	32,467	32,467
Net benefit	581	25,966	25,966	68,665	75,970	75,970

Table 9.39 Maximum net benefit of dredging project for Salvadoran economy by channel depth in case of the tariff increase (2030)

Unit: 000 USD

Channel Depth	9m	10m	11m	12m	13m	14m
Increase of net income for Salvadoran port sector derived from container business	0	5,053	5,053	5,224	58,031	61,798
Decrease of shipping cost of Salvadoran cargo	0	17,114	17,114	24,107	45,732	53,072
Net benefit	0	22,168	22,168	29,332	103,764	114,871

Table 9.40 Maximum economic benefit of dredging project for Salvadoran economy by channel depth in case of the tariff increase (2020)

Unit: 000 USD

Channel Depth	9m	10m	11m	12m	13m	14m
Economic Benefit	581	25,966	25,966	68,665	75,970	75,970
Dredging Cost						
Modified exp. model	7,415	12,117	18,507	29,142	38,910	60,003
Linear model	7,415	12,117	18,507	27,998	36,563	44,541
Difference						
Modified exp. model	-6,834	13,849	7,459	**39,523**	37,060	15,967
Linear model	-6,834	13,849	7,459	**40,667**	39,407	31,429

Table 9.41 Maximum economic benefit of dredging project for Salvadoran economy by channel depth in case of the tariff increase (2030)

Unit: 000 USD

Channel Depth	9m	10m	11m	12m	13m	14m
Economic Benefit	0	22,168	22,168	29,332	103,764	114,871
Dredging Cost						
Modified exp. model	7,415	12,117	18,507	29,142	38,910	60,003
Linear model	7,415	12,117	18,507	27,998	36,563	44,541
Difference						
Modified exp. model	-7,415	10,051	3,661	190	**64,854**	54,868
Linear model	-7,415	10,051	3,661	1,334	67,201	**70,330**

9.4.4 Net income from container business of La Union Port (in case of the advancement of regional development in the eastern El Salvador) and dredging cost by channel depth

(1) Net income and dredging cost

The estimated net incomes of La Union Port under the feasible scenarios in 2020 are shown in Figure 9.26.

The case of the maximum net income for each depth is the best scenario for CEPA from a financial viewpoint in the container business of La Union Port. Revenue and expenditures of such cases are shown in Table 9.42.

The maximum difference between the net income and dredging cost in 2020 by channel is shown in Table 9.43. The optimum channel depth from a financial viewpoint of container business of La Union Port is the depth which provides the largest value obtained by deducting the dredging cost from the net income. The channel with depth of 8m yields the largest value in both dredging cost functions in 2020.

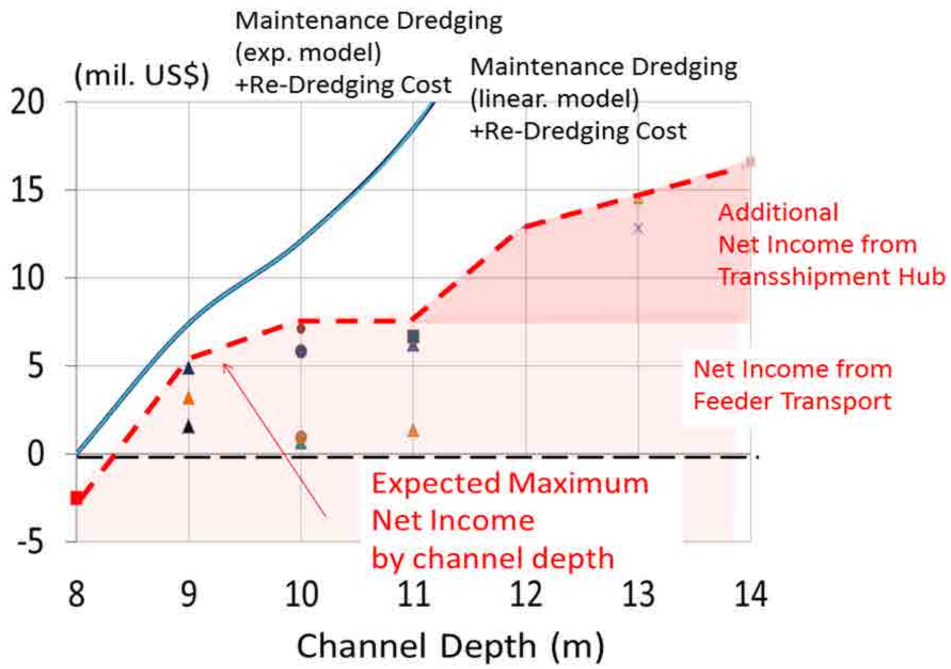


Figure 9.26 Estimated net income in case of the advancement of regional development in the eastern El Salvador and dredging cost by channel depth in La Union Port (2020)

Table 9.42 Maximum net income from container business in La Union Port in case of the advancement of regional development in the eastern El Salvador (2020)

Unit: 000 USD

Channel depth	8m (no dredging scenario)	9m	10m	11m	12m	13m	14m
Revenue	2,277	11,787	14,471	13,795	22,104	24,392	26,941
Expenditure	-4,795	-6,904	-7,374	-7,140	-9,246	-9,757	-10,337
Net Income	-2,518	4,883	7,097	6,655	12,858	14,635	16,604

Table 9.43 Maximum difference between net income in case of the advancement of regional development in the eastern El Salvador and dredging cost by channel depth in La Union Port (2020)

Unit: 000 USD

Channel Depth	8m	9m	10m	11m	12m	13m	14m
Net Income	-2,518	4,883	7,097	6,655	12,858	14,635	16,604
Dredging Cost							
Modified exp. model	0	7,415	12,117	18,507	29,142	38,910	60,003
Linear model	0	7,415	12,117	18,507	27,998	36,563	44,541
Difference							
Modified exp. model	**-2,518**	-2,532	-5,020	-11,852	-16,284	-24,275	-43,399
Linear model	**-2,518**	-2,532	-5,020	-11,852	-15,140	-21,928	-27,937

9.5 Conclusion of Chapter 9

In this chapter, the present status of navigation channel and rule are summarized and new navigation rule is proposed (9.1). The expected waiting time is calculated based on the new rule as well as on the existing rule. It is found that the existing rule may be effective under the current situation that a small ship navigates a shallow channel, but that difference from the new rule is not negligible when the channel is deepened and ships of various sizes are expected to call. Therefore, the new navigation rule is needed when the channel is deepened.

Many calculation scenarios on the future liner shipping network are prepared for each channel depth in La Union Port in 2020 and 2030, and several feasible scenarios (that have a possibility to realize) for each depth in both years are selected based on some criteria (9.2). Based on the container cargo throughput and other outputs estimated in the model, net income (except for the dredging cost) from container business of La Union Port, net income from container business of Salvadoran port sector (sum of Acajutla Port and La Union Port), and net benefit for Salvadoran economy of the dredging project in La Union Port are estimated and compared with the dredging cost by channel depth (9.3). From the financial aspect for La Union Port, if the tariff of La Union Port is kept at the present level, the net income will be always less than the dredging cost for each channel depth. If the tariff of La Union Port is increased, the net income (except for the dredging cost) may be larger than the dredging cost in the scenario that the expected net income is maximized by channel depth (9.4). Therefore, it is needed to increase the tariff in La Union Port to keep a sound financial condition. However, note that it may weaken the competitiveness of the port against neighboring ports resulting in a decreasing the amount of containers handled. In particular, it may be more critical as the shipping market is more liberalized such as decrease of the barrier at national border (9.2.3(3)).

The scenarios on the future liner shipping network are prepared not only for modification of the existing feeder and way-port network, but also for calling at the vessels of the trunk route. Some of these "transshipment hub" scenarios for La Union Port are considered to be feasible (9.2.3); in addition, if the transshipment hub is realized, it will be very beneficial to the economy of El Salvador (9.3, 9.4). However, an important point to keep in mind is that deepening the channel by dredging does not guarantee La Union will become a transshipment hub. To become a transshipment hub, considerable efforts to attract the vessels of the trunk line would have to be made.

An advancement of the regional development in the eastern El Salvador would contribute to increasing the amount of container cargo as well as the revenue in La Union Port (9.2.3(3)2) and 9.4.4). As originally planned, the integrated development of La Union Port with the hinterland in the eastern area of El Salvador is also one of important keys for the future development of La Union Port.

Chapter 10 Optimal Dredging Plan Considering Time-Series Changes on Demand and Costs

Chapter 10 Optimal Dredging Plan Considering Time-Series Changes on Demand and Costs

10.1 Concept

In the previous chapter, the net income and benefit (except for the cost related with dredging) estimated from the outputs of the vessel calling model are compared with the dredging cost in a single year (in 2020 and 2030) based on the results of Chapter 5. However, for the discussion of the timing of investment for dredging, time series analysis is needed to consider each year's income, benefit and dredging cost. The methodology of the time-series analysis and results of trial calculation are shown in this chapter.

The duration time for the evaluation of the dredging plan is set to be 20 years (from 2014 to 2033) in this report.

10.2 Dredging Cost

Dredging cost can be divided into two types in accordance with when it will be paid. The first type is the initial investment when the re-dredging is conducted and maintenance dredging is started. It includes not only the re-dredging cost, but also mobilization cost of dredgers and capital cost when the own-dredger is purchased. The second type is regular annual expense, including the maintenance dredging that is determined from the amount of soil dredged. A summary is shown in Table.10.1.

Table 10.1 Items of dredging cost summarized in terms of the timing when it is needed

Cost Type	Item	Description
Initial Cost (when the project starts)	Re-Dredging	- Depending on the target and existing depth of the access channel - Irrespective of the model to predict the change of water depth after the initial dredging
	Mobilization	- Mobilization cost of both dredgers for re-dredging and maintenance dredging should be considered - Mobilization cost is considered only for one way from the place where it is contracted to La Union Port, based on the conventional idea of the dredging industry
	Purchasing Dredger	- Needed only when CEPA will purchase her own dredger
Regular Cost (that should be paid every year)	Maintenance Dredging	- Depending on the target depth - Different between a contract-basis and own-basis dredging

Based on the methodology for the estimation of the dredging cost described in Chapter 5, the estimated costs by item shown in Table.10.1 are summarized as follows for the modified exponential model to predict the change of water depth after the initial dredging and for both cases of contract-basis and own-basis dredging.

10.2.1 Re-dredging cost

The re-dredging is assumed to be conducted by a leased dredger in all cases regardless of whether the maintenance dredging is conducted by another leased dredger or by an own dredger. Also, the amount of soil dredged is not changed in either of the models (i.e. either modified exponential and linear model) that predict the change of water depth after the initial dredging. The estimated amount of cost for each combination of existing and target depth is shown in Table.10.2.

Table 10.2 Re-dredging cost (US$) estimated for each combination of existing and target depth

Existing depth (-m) \ Target depth (-m)	9	10	11	12	13	14
8	11,455,845	16,455,908	26,256,770	32,762,463	50,747,583	64,652,814
9	0	9,967,799	18,772,670	29,136,071	41,940,063	61,271,406
10	-	0	13,913,678	24,120,906	37,825,632	55,014,013
11	-	-	0	17,685,342	30,798,126	50,189,111
12	-	-	-	0	21,348,500	34,729,346
13	-	-	-	-	0	25,188,008
14	-	-	-	-	-	0

10.2.2 Mobilization cost for re-dredging

The mobilization cost for re-dredging is also not changed among both types of maintenance dredging (whether the maintenance dredger is conducted by another leased dredger or by an own dredger) and both models that predict the change of water depth after the initial dredging. The estimated amount of cost for each combination of target and existing depth is shown in Table.10.3.

Table 10.3 Mobilization cost (US$) of re-dredging for each combination of existing and target depth

Existing depth (-m) \ Target depth (-m)	9	10	11	12	13	14
8	668,511	872,625	1,339,710	1,851,270	3,062,827	3,062,827
9	0	552,061	1,062,338	1,602,691	2,246,381	3,062,827
10	-	0	756,170	1,339,710	1,983,405	3,062,827
11	-	-	0	974,680	1,675,953	3,062,827
12	-	-	-	0	319,740	1,924,538
13	-	-	-	-	0	1,266,447
14	-	-	-	-	-	0

10.2.3 Cost for purchasing dredger (in case of own-basis dredging)

The cost of purchasing the dredger is considered only in case of the own-basis dredging. The cost in the modified exponential model to predict the change of water depth after the initial dredging is shown in Table.10.4.

Table 10.4 Cost for purchasing dredger by target depth for the modified exponential model

Target depth (-m)	Cost (US$)
8	0
9	15,800,000
10	20,200,000
11	33,400,000
12	51,000,000
13	81,800,000
14	139,000,000

10.2.4 Mobilization cost for maintenance dredger

Mobilization cost for maintenance dredger for the modified exponential model to predict the change of water depth after the initial dredging is shown in Table.10.5.

Table 10.5 Mobilization cost for maintenance dredger estimated by target depth for the modified exponential model

Target depth (-m)	Cost (US$)
8	0
9	450,006
10	552,061
11	872,625
12	1,266,447
13	1,851,270
14	3,062,827

10.2.5 Regular cost for maintenance dredging

The dredging costs introduced in 10.2.1 to 10.2.4 are only incurred in the year when the re-dredging is conducted and the maintenance dredging starts. The annual maintenance dredging costs are summarized in Table.10.6 for both cases in contract-basis and own-basis dredging for the modified exponential model. The cost of own-basis maintenance dredging is usually lower than the cost of contract-basis one. Note that some indirect costs for own-basis dredging are not included due to lack of information as discussed previously in Chapter 5.

Table 10.6 Regular cost for maintenance dredging (US$/year) for each target depth

Target depth (-m)	Contract-basis dredging	Own-basis dredging (Some indirect costs are not included)
8	0	0
9	6,120,185	3,615,751
10	10,283,006	5,756,123
11	15,623,243	8,818,581
12	25,474,352	14,336,801
13	33,215,909	21,618,484
14	52,793,877	34,759,302

10.3 Time-series estimation of container cargo throughput, net income and benefit, and dredging cost considering the timing of the dredging

10.3.1 Time-series estimation of container cargo throughput, net income and benefit

The future amount of container cargo throughput and net income except for dredging cost (which is acquired by subtracting income by operational cost) in La Union Port and Acajutla Port are estimated only in the year of 2020 and 2030 as shown in the previous chapter. Therefore, the container cargo throughput in years other than 2020 and 2030 (hereinafter, called "time-series throughput") is estimated based on some approximations and assumptions shown below. Also, from the estimated time-series throughputs in La Union Port and Acajutla Port as mentioned above, time-series income, operational cost (except for the dredging cost), and net income are estimated by the same manner described in the previous chapter.

(1) Calculating by hypothetical channel depth at the present OD (in 2010)

In order to carry out the following calculation, the amount of container cargo in 2010 for each channel depth other than the present depth (-8m) should be estimated as hypothetical scenarios. The estimated result for each channel depth in both cases before and after increasing the tariff of La Union Port is shown in Table.10.7. Please note that since a transshipment hub scenario in 2010 is not considered, the estimated throughputs with a channel deeper than -11m are assumed to be similar to that with a channel depth of -11m.

Table 10.7 Estimated container cargo throughput and other revenue/cost for each channel depth in 2010

- before increasing the tariff in La Union Port

	Acajutla				La Union				Shipping cost (000 US$)
depth (-m)	Laden (TEU)	Empty (TEU)	Trans-ship	Vessel Fee (000 US$)	Laden (TEU)	Empty (TEU)	Trans-ship	Vessel Fee (000 US$)	
8	96,774	40,876	0	1,804	13,828	4,603	0	262	827,116
9	76,869	32,675	0	1,334	44,132	14,341	0	1,081	815,026
10	77,439	34,531	0	1,334	44,569	15,319	0	1,081	809,976
11	74,666	36,515	0	1,334	52,352	11,353	0	1,081	827,406
12	74,666	36,515	0	1,334	52,352	11,353	0	1,081	827,406
13	74,666	36,515	0	1,334	52,352	11,353	0	1,081	827,406
14	74,666	36,515	0	1,334	52,352	11,353	0	1,081	827,406

- after increasing the tariff in La Union Port

	Acajutla				La Union				Shipping cost (000 US$)
depth (-m)	Laden (TEU)	Empty (TEU)	Trans-ship	Vessel Fee (000 US$)	Laden (TEU)	Empty (TEU)	Trans-ship	Vessel Fee (000 US$)	
8	88,679	37,263	0	1,804	12,073	2,911	0	262	815,026
9	74,834	35,688	0	1,334	32,065	9,687	0	1,081	842,194
10	77,220	37,081	0	1,334	36,107	9,853	0	1,081	829,592
11	75,566	39,211	0	1,334	44,040	11,694	0	1,081	838,967
12	75,566	39,211	0	1,334	44,040	11,694	0	1,081	838,967
13	75,566	39,211	0	1,334	44,040	11,694	0	1,081	838,967
14	75,566	39,211	0	1,334	44,040	11,694	0	1,081	838,967

(2) Deciding the representative results of container cargo throughput for each channel depth in 2020 and 2030

Out of many results on the container cargo throughput estimated from the vessel calling model as introduced in the previous chapter, it is necessary to select one result for each channel depth as a representative result. If the objective of the analysis is to know the best timing and depth of the dredging at the point that the maximum net income or benefit is expected, the result which constitutes an envelope line of the expected maximum net income or benefit in the figures shown in the previous chapter should be selected for each channel depth.

(3) Preparing the estimated amount of container cargo throughput by channel depth for each year by interpolating from the estimated results of the vessel calling model (2010, 2020, and 2030)

For example, the container throughput for both the port of Acajutla and La Union in 2014 with a channel depth of -8m is estimated by interpolating from the two throughputs for each port in 2010 and 2020 with a channel depth of -8m that are both estimated from the vessel calling model. Another example is that the throughput for both ports in 2027 with a channel depth of -13m is estimated by interpolating from the two throughputs for each port in 2020 and 2030 with a channel depth of -13m that are also both estimated from the vessel calling model. The revenue from vessel calling (vessel due) for each port and the total amount of shipping cost for Salvadoran cargo each year are also estimated in the same manner.

(4) Shifting from old channel depth to new channel depth

When the re-dredging (from -xm to -ym depth) is conducted in some year, time-series sequence of the container throughput estimated in (3) will shift from -xm to -ym in the next year that re-dredging is conducted. In the example shown in Figure.10.1, the first re-dredging is planned in 2017 in which depth will increase from -8m to -10m. Therefore, the amount of containers for each year is estimated based on a channel depth of -8m until 2017 and shifting to the line with -10m depth in 2018. Similarly, the second re-dredging is planned in 2027 (just ten years after the first re-dredging) in which depth will increase from -10m to -13m; therefore, the amount of containers for each year is estimated based on a channel depth of -10m until 2027 and shifting to the line with -13m depth in 2028.

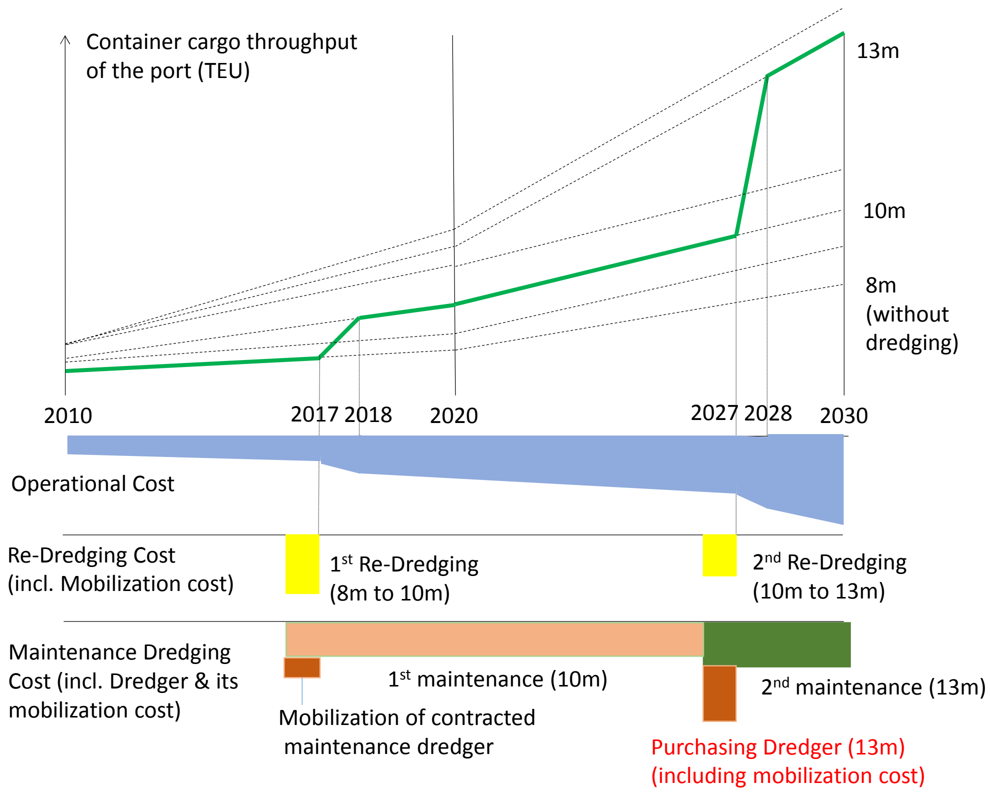


Figure 10.1 Typical example on framework of time-series income-cost calculation
(in case of contract-basis dredging for the first ten years)

10.3.2 Time-series dredging cost including the timing of the re-dredging

(1) Assumptions on the re-dredging and maintenance dredging

The objective of the time-series analysis of the dredging is to find the optimal timing to conduct the re-dredging and optimal target depth from the financial/economical viewpoint. To simplify the problem, it is assumed that the re-dredging is allowed twice during the evaluation period for twenty years. Also, the first and second re-dredging is assumed to be both optional and flexible in their timing, but the second re-dredging is limited to just ten years after the first dredging if conducted, reflecting that a contract-basis maintenance dredging cost calculated in Chapter 5 is premised on a contract for ten years.

Another important assumption is that once a dredger is purchased for an own-basis dredging, it could not be sold nor change its size during the evaluation period, although the salvage value of the dredger is calculated at the end of the evaluation period (i.e. as in 2033). Note that it is not necessary to utilize a dredger with full capacity, especially for the first ten years, and that the salvage value is also considered for the mobilization cost to maintain coherence of the calculation.

(2) Calculation of dredging cost

1) Contract-basis dredging scenario

Figure.10.1 also shows an example of the timing when each item of dredging cost introduced in 10.2 should be paid. In this example, the first and second re-dredging are planned in 2017 and 2027, respectively. Therefore, each re-dredging cost (from -8m to -10 depth for the first dredging, and from -10m to -13m depth for the second re-dredging) including the mobilization costs for the re-dredgers is recognized in each year.

The maintenance dredging for the first ten years has to be conducted every year to keep a -10m depth by a contracted dredger, while that for the second ten years has to be conducted every year to keep a -13m depth. Note that the maintenance dredging after the second re-dredging is assumed to be done by an own dredger, not by another contracted dredger, even in case that the "contract-basis dredging" is assumingly conducted for the first ten years. The reason is that a unit price for the maintenance dredging by an own dredger is always cheaper than that by a contracted dredger at the same target depth as shown in Chapter 5, if the salvage value of the dredger at the end of evaluation period is considered. In other words, a contract-basis dredging would be useful only if the maintenance dredger is expected to be renewed larger within the years that a salvage value of dredger is remained (concretely, twenty years in this calculation), according to the strategic plan to attract larger vessels in near future.

2) Own-basis dredging scenario

Figure.10.2 shows an example of the timing when each item of dredging cost introduced in 10.2 should be paid in case that a dredger is purchased when the first maintenance dredging is started. The re-dredging cost including mobilization of the re-dredger and their timing are not changed from those estimated in a contract-basis dredging scenario shown in Figure.10.1. Since in this example the target depth of channel is different among the first and second ten years, the maintenance dredging for the first ten years to keep a -10m depth is assumed to be conducted without utilizing the full capacity of a dredger, which is purchased with the capacity to keep a depth of -13m (i.e. the target depth after the second re-dredging) in the year at the first re-dredging. Note that if the target depth is not changed between the first and second ten years, the second re-dredging is not necessary.

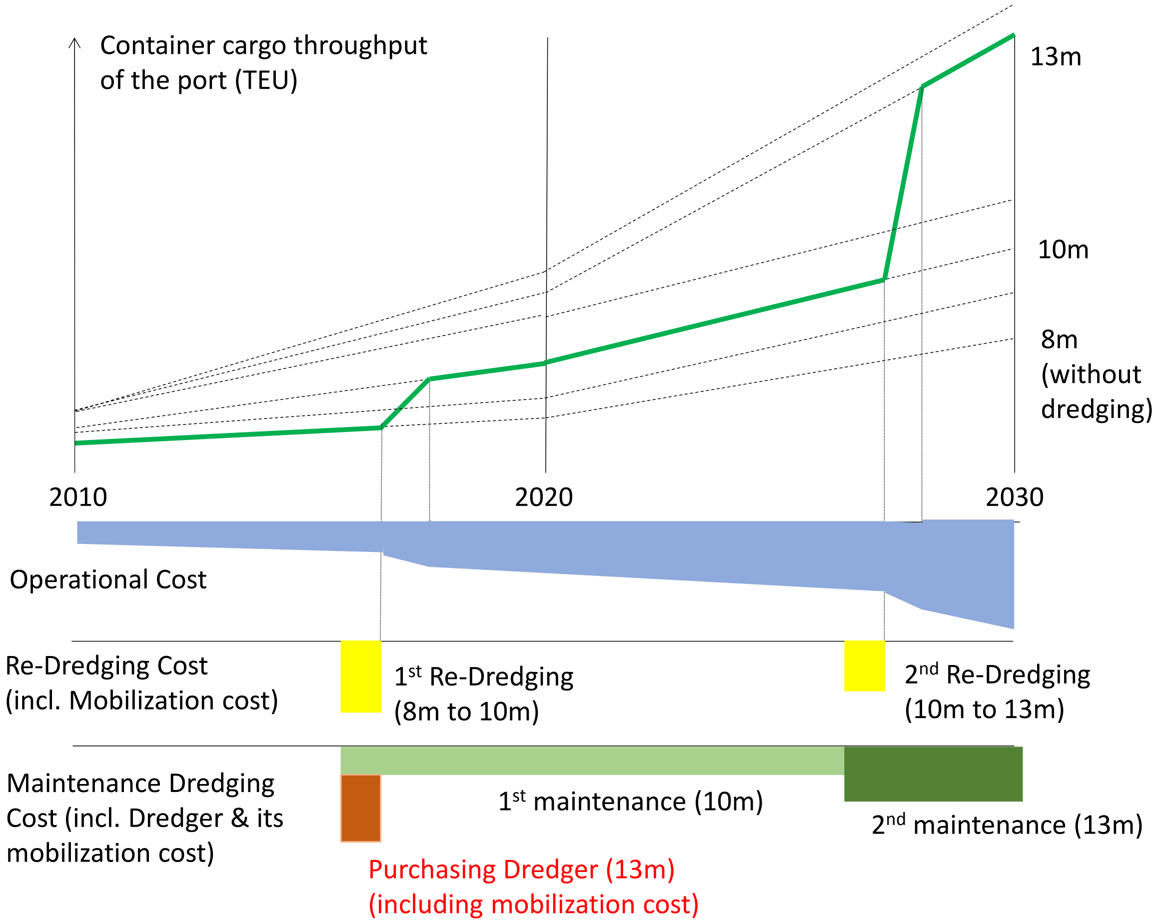


Figure 10.2 Typical example on framework of time-series income-cost calculation (in case of own-basis dredging)

10.4 Methodology and example results of time-series financial and economic analysis considering the timing of the dredging

10.4.1 Making a calculation sheet for time-series estimation

Based on the framework of the time-series calculation of container cargo throughput, revenue, operational cost, cargo shipping cost for Salvadoran shippers and dredging cost described in 10.3, an excel-basis calculation sheet is developed.

The calculation sheet is prepared separately for each type of dredging scenario (i.e. contract-basis and own-basis dredging scenario) and their results are compared. An excel file is prepared for each model (i.e. modified exponential and linear model) that predicts the change of water depth after the initial dredging. Also, a different excel file is prepared when the tariff system has been changed; for example, the latest change of the tariff system in La Union Port from the system based on the number of containers to that in a TEU-basis.

10.4.2 Obtaining the optimal timing of re-dredging and combination of target depth

By changing the year that the target depths after the first re-dredging is realized and target depths for both re-dredging (which are yellow-colored in the upper-left in Figure.10.4), the estimated net income and benefit could be changed.

JICA study team provides a macro to obtain the optimal year to maximize the net benefit (which is estimated by summing up the difference of net income and shipping cost for Salvadoran shippers between “dredging scenario” and “no-dredging scenario”) throughout the evaluation period for each combination of the target depths after first and second re-dredging. The optimal year is obtained by changing the input year that the target depth after the first re-dredging is realized, with a range between 2015 and 2024.

The example of the calculation result by the macro on the optimal year and net benefit in the year for each combination of target depth after the first and second re-dredging is shown in Table.10.8 (before increasing the tariff) and Table.10.9 (after increasing the tariff). These tables also show a comparison of the results between a contract-basis and own-basis dredging. The findings from the table are as follows

1) The optimal year when the target depth should be realized in order to maximize the expected net benefit is different among a combination of the target depth after the first and second re-dredging and among the type of dredging (i.e. whether contract-basis or own-basis dredging). Also, which expected net benefit is larger among the contract-basis and own-basis dredging (that are green-colored in Table.10.9) is different among a combination of the target depth. Generally, when the difference of the target depths after the first and second dredging is zero (i.e. the second re-dredging is not conducted) or small, an own-basis dredging is advantageous rather than a contract-basis dredging. On the other hand, when the difference of the target depths is relatively large, a contract-basis dredging is more advantageous to maximize the expected net benefit.

2) Before increasing the tariff in La Union Port, in most cases of a combination of the target depth, the expected maximum net benefit is less than zero; i.e. the “without dredging scenario” (do-nothing case) is better than any cases with dredging (see Table.10.8). Out of a few combinations in which the expected maximum net benefit is positive in Table.10.8, a combination that the first re-dredging with -12m is conducted in 2014 and the second re-dredging with -13m in 2024 with purchasing an own dredger for maintenance dredging in 2014 is to maximize the expected maximum net benefit, although this result is based on the assumption that the “transshipment hub” scenario shown in Chapter 9 is realized; in other words, this strategy for the dredging has a significant risk. The second best strategy with relatively smaller risk is that the first re-dredging with -10m is conducted in 2014 and the second re-dredging with -13m in 2024 with a contracted dredger at least for the first ten years.

3) On the other hand, after increasing the tariff in La Union Port, in most cases of a combination of the target depth, the expected maximum net benefit is positive (see Table.10.9). Out of them, the combination in which the first re-dredging for a depth of -13m is conducted in 2016 and maintained for twenty years together with purchasing an own dredger for maintenance dredging in 2016 maximizes the expected benefit, although this strategy for the dredging has a significant risk as well as the case before increasing the tariff mentioned in 2). The second best strategy with relatively smaller risk is, as well as the case before increasing the tariff mentioned in 2), that the first re-dredging for a depth of -10m is conducted in 2014 and the second re-dredging for a depth of -13m in 2024 with a contracted dredger at least for the first ten years.

Table 10.8 Example of calculation result in optimal year and net benefit for each combination of target depth after the first and second re-dredging and each type of dredging (before increasing the tariff in La Union Port)

Target Depth		Contract-basis Dredging (000 US$)				Own-basis Dredging (000 US$)			
First re-dredging	Second re-dredging	optimal year	Net benefit (NPV)	Net Income for Salvadoran Port Sector	Decrease amount of Shipping Cost	optimal year	Net benefit (NPV)	Net Income for Salvadoran Port Sector	Decrease amount of Shipping Cost
8	8	2015	0	0	0	2015	0	0	0
8	9	2024	-1,347	-1,347	0	2024	-7,963	-7,963	0
8	10	2024	-2,086	-2,086	0	2024	-10,545	-10,545	0
8	11	2024	-3,226	-3,226	0	2024	-17,213	-17,213	0
8	12	2024	-4,956	-4,956	0	2024	-26,316	-26,316	0
8	13	2015	111,724	-89,254	200,978	2015	61,139	-139,839	200,978
8	14	2015	35,513	-167,775	203,287	2016	-49,976	-227,444	177,468
9	9	2024	-33,314	-32,310	-1,005	2024	-29,649	-28,644	-1,005
9	10	2024	-34,212	-33,207	-1,005	2024	-32,377	-31,373	-1,005
9	11	2024	-35,325	-34,321	-1,005	2024	-39,019	-38,014	-1,005
9	12	2024	-37,164	-36,159	-1,005	2024	-48,230	-47,225	-1,005
9	13	2015	53,198	-140,087	193,286	2015	21,434	-171,851	193,286
9	14	2015	-26,187	-221,782	195,595	2023	-91,324	-107,444	16,120
10	10	2024	-35,364	-52,047	16,683	2024	-25,265	-41,947	16,683
10	11	2024	-36,641	-53,324	16,683	2024	-32,055	-48,737	16,683
10	12	2024	-38,476	-55,159	16,683	2024	-41,262	-57,945	16,683
10	13	2015	57,280	-176,775	234,055	2015	40,715	-193,340	234,055
10	14	2015	-21,149	-257,514	236,364	2015	-73,129	-309,493	236,364
11	11	2024	-34,864	-78,623	43,759	2024	-20,951	-64,710	43,759
11	12	2024	-36,941	-80,700	43,759	2024	-30,376	-74,135	43,759
11	13	2015	36,163	-212,367	248,530	2015	36,717	-211,814	248,530
11	14	2019	-32,862	-186,969	154,108	2019	-64,304	-218,412	154,108
12	12	2016	14,955	-230,303	245,258	2015	64,475	-198,937	263,412
12	13	2015	155,315	-255,279	410,595	2015	188,432	-222,163	410,595
12	14	2016	79,605	-301,560	381,165	2015	76,256	-336,648	412,904
13	13	2018	155,091	-224,720	379,811	2017	182,474	-219,912	402,386
13	14	2021	112,445	-190,567	303,012	2020	106,577	-222,843	329,421
14	14	2024	25,047	-204,861	229,908	2020	49,384	-294,631	344,015

Table 10.9 Example of calculation result in optimal year and net benefit for each combination of target depth after the first and second re-dredging and each type of dredging (after increasing the tariff in La Union Port)

Target Depth		Contract-basis Dredging (000 US$)				Own-basis Dredging (000 US$)			
First re-dredging	Second re-dredging	optimal year	Net benefit (NPV)	Net Income for Salvadoran Port Sector	Decrease amount of Shipping Cost	optimal year	Net benefit (NPV)	Net Income for Salvadoran Port Sector	Decrease amount of Shipping Cost
8	8	2015	0	0	0	2015	0	0	0
8	9	2024	-1,347	-1,347	0	2024	-7,963	-7,963	0
8	10	2015	34,996	-21,379	56,375	2015	22,552	-33,823	56,375
8	11	2015	13,028	-43,347	56,375	2015	-7,567	-63,942	56,375
8	12	2015	20,181	-59,737	79,918	2015	-11,300	-91,218	79,918
8	13	2015	190,403	57,847	132,556	2015	139,818	7,262	132,556

8	14	2015	138,908	-26,985	165,893	2015	52,908	-112,985	165,893
9	9	2024	-38,131	-39,832	1,701	2024	-34,466	-36,167	1,701
9	10	2019	-33,230	-45,435	12,206	2019	-29,062	-41,268	12,206
9	11	2024	-40,143	-41,843	1,701	2024	-43,836	-45,537	1,701
9	12	2024	-41,981	-43,682	1,701	2024	-53,047	-54,748	1,701
9	13	2015	105,959	30,183	75,776	2015	74,196	-1,581	75,776
9	14	2015	51,291	-57,822	109,113	2016	-14,576	-117,475	102,899
10	10	2016	81,517	-50,110	131,626	2016	101,245	-30,382	131,626
10	11	2017	62,926	-65,158	128,083	2017	74,034	-54,049	128,083
10	12	2016	59,429	-92,228	151,657	2015	61,729	-94,331	156,059
10	13	2015	231,876	23,178	208,698	2015	215,311	6,613	208,698
10	14	2015	178,163	-63,871	242,034	2015	126,184	-115,851	242,034
11	11	2019	24,891	-88,849	113,740	2018	48,451	-71,689	120,140
11	12	2018	13,979	-119,945	133,923	2017	28,812	-111,661	140,473
11	13	2015	174,807	-21,841	196,647	2015	175,360	-21,287	196,647
11	14	2016	120,286	-100,846	221,133	2016	86,376	-134,757	221,133
12	12	2016	124,597	-63,526	188,123	2016	172,355	-15,768	188,123
12	13	2015	288,408	47,496	240,911	2015	321,524	80,613	240,911
12	14	2015	236,363	-37,885	274,248	2015	234,064	-40,183	274,248
13	13	2017	335,524	55,258	280,266	2016	367,391	78,474	288,917
13	14	2018	293,989	2,426	291,563	2017	291,982	-15,689	307,671
14	14	2019	187,758	-103,410	291,168	2018	220,141	-87,189	307,330

10.5 Conclusion of Chapter 10

In this chapter, a methodology of the time series analysis considering each year's income, benefit and dredging cost is introduced and example results of calculation are shown in order to contribute to the discussion on the optimum time to conduct dredging. The calculation is based on many assumptions (e.g., the re-dredging is allowed only twice and the second re-dredging must be carried out precisely ten years after the first dredging); in addition, the examples of which the calculation results are shown in this chapter are very limited to those based on the liner which service network to generate the expected maximum net benefit for each channel depth.

The example results imply that the best strategy to maximize the expected maximum net benefit is to purchase a dredger for annual maintenance dredging within a few years and maintain a channel depth of around -12m or -13m, although there is a significant risk because this strategy will only be successful if the transshipment hub" scenario is realized. On the other hand, the second best strategy with relatively smaller risk is that the first re-dredging for a depth of around -10m is conducted with a contracted dredger and the second re-dredging for a depth of -13m. This kind of "step-wise" strategy is very useful for avoiding huge financial risks.

Chapter 11 Conclusions and Recommendations

Chapter 11 Conclusions and Recommendation

11.1 Conclusions

Conclusions of the Study are summarized as follows.

(1) Present state of siltation in the access channel

La Union Port has an access channel with total length of 22.3 km and had been dredged to a depth of DL.-14 m. At present, however, the entire passage has been filled to almost the original elevation and the depth when it was completed has not been maintained.

(2) Thickness of fluid mud layer

Judging from the Team's experience in the field, it is considered that the echo sounder of 200 kHz in frequency detects the top surface of the fluid mud layer. The depth navigable for vessels is considered to be deeper than the depth measured by the echo sounder of 200 kHz, with the thickness of the fluid mud layer.

The fluid mud layer in the channel continues in existence for relatively long period. This indicates a possibility to reduce maintenance dredging volume by making a maintenance dredging plan taking the fluid mud layer into account.

From the analysis of mud sampled at about two years after capital dredging, it is confirmed that fluid mud layer, the wet density of which is less than 1,200 kg/m^3, is formed with the thickness of about 0.5 m in the outer channel and about 1.0 m in the inner channel.

(3) Mechanism of siltation and prediction models for water depth in the channel

In the La Union Port, a phenomenon of siltation is a result of the movement of fluid mud layer as a density current. Wherever there is the elevation difference on the seabed such as across a dredged channel, fluid mud flows into the lower elevation by gravity.

A trend analysis of the temporal variation of the mean channel depth at traverse survey lines has enable to establish an empirical prediction model for siltation speed as a function of the difference in the depths inside and outside the channel and the time elapsed from completion of capital dredging (see Eq.(4.1)).

The prediction model for siltation speed is integrated for deviation of a prediction model of the depth difference Δh as Eq.(4.2), which is named as the original Exponential Model.

The bathymetric data of the Inner Channel obtained in December 2008 is unnaturally shifted downward, which is probably due to some systematic error such as inappropriate correction for the tide level or a mistaken of datum level. This data is corrected and at the same time the coefficient of the original Exponential Model has been modified for the Inner Channel (see Eq.(4.3)).

Outside of Outer Channel, the sea bottom did not changed in the western area in the process of channel siltation, while in the eastern area the sea bottom was eroded. The water depth in the channel was usually equal to or deeper than that of eastern bank. In other words, the channel water depth of full-siltation is deeper than that of before dredging. By taking the effect of eastern bank into the consideration, which is introduced concept of "final depth", the original

Exponential Model has been modified for the outer channel (see Figure 4.27)).

The rapid siltation occurred just after the completion of dredging, which might be the bound phenomenon only once in the newly excavated channel. If this be so, the rapid siltation does not occur in the case that the maintenance dredging is continuously conducted. Based on this hypothesis, another new prediction model has been established. That is to say, the speed of siltation is constant (Eq.(4.4)) and the water depth in the channel changes linearly with time (see Eq.(4.5)). This model has been named the Linear Model. Since the Linear Model has been formulated based on the hypothesis, we must refrain from the use of the Linear Model until the hypothesis is verified with the bathymetric data, or an applicability of Linear Model is confirmed with it.

Unfortunately in the harbor basin, since there is no available data which is necessary for formulating an empirical prediction model, the Modified Exponential Model for the Outer Channel is applied to the harbor basin.

(4) Volume of re-dredging

The harbor basin, Inner channel and Outer channel need to be re-dredged at first. The total volumes of the re-dredging for six target navigation depths of 9 to 14 m varying by 1 m has approximately estimated based on the latest survey result in July 2013. The estimated re-dredging volumes by depths are summarized in Table 5.1.

(5) Volume of maintenance dredging

The maintenance dredging volume is calculated for six levels of the target depth: i.e., 9, 10, 11, 12, 13, and 14m. The cycle time, or the time interval of successive maintenance dredging, is set at 3, 4, 6, or 12 months. The volume of maintenance dredging at a specified cycle time and a target depth is estimated by the Modified Exponential Model and the Linear Model. In the calculation, the fluid mud thickness is taken into account. The result of estimation is shown in Figure 5.7.

(6) Appropriate dredging method

As a result of comparison of four types of dredger, TSHD (Trailing Suction Hopper Dredger) is regarded appropriate for the re-dredging and maintenance dredging in La Union Port, because TSHD has the lowest impact on “other vessels traffic” with the highest “productivity” and “cost efficiency”.

(7) Vessel calling model

A vessel calling model is developed in order to analyze La Union Port from the financial and economic viewpoint. The whole structure of the model is shown in Figure 8.5. Major input variables into the model are level of service in each port including channel depth of La Union Port and container cargo shipping demand (container cargo OD). The model is divided into two parts; consideration of behavior of shipping companies to decide each liner service network and a container cargo assignment model. Every combination of liner service network is respectively input into the container cargo assignment model, which is developed to include both land and maritime shipping networks. Based on the results of the container cargo assignment model, each combination of liner service network is examined from the viewpoint of whether each shipping company would consider it reasonable to call at La Union Port.

The calculation results of the container cargo assignment model are examined from the viewpoint of the model reproducibility by several benchmarks such as container cargo throughput in Section 8.8. The sensitivity of the model to the estimated unknown parameters is also examined. As a result, the container cargo assignment model well describes the actual container cargo shipping market in CA4 countries and reasonably behaves against the change of the model input. Also, by inputting many scenarios on the future liner shipping network for each channel depth in La Union Port in 2020 and 2030, several feasible scenarios for each depth in both years are selected based on the criteria shown in Section 9.2.

The estimated results (e.g. Figure 9.8 and Figure 9.9) show that the "transshipment hub" scenario in which vessels of the trunk route call is one of the feasible scenarios on the future liner shipping network. Also, the model can simulate the effects of tariff increases and regional development near La Union Port (in eastern El Salvador).

The Vessel Calling Model developed in this project aims to exhaustively list the container flow patterns which are possibly realized, reflecting that various kinds of patterns of future liner shipping network are considered in the Pacific Coast of Central America including La Union Port. Therefore, the multiple results are estimated to be realized under the same channel depth. Note that, even if the operation and procedure in La Union Port are effectively implemented as supposed in the model, the lowest value out of all feasible scenarios could be realized in the worst case.

(8) Financial and economic analysis of La Union Port and policy simulation

Based on the container cargo throughput and other outputs estimated from the vessel calling model, net income (which is acquired by subtracting the expected revenue from port and handling charges by expenditure such as container operation cost except for the dredging cost) from container business of La Union Port, net income from container business of Salvadoran port sector (sum of Acajutla and La Union Port), and net benefit for the Salvadoran economy of the dredging project in La Union Port are estimated and compared with the dredging cost by channel depth.

From a financial aspect, if the tariff of La Union Port is kept at the present level, the net income will always be less than the dredging cost for each channel depth as shown in Figure 9.14 and Figure 9.15. On the other hand, if the tariff of La Union Port is increased, the net income may be larger than the dredging cost in the scenario that the expected net income is maximized by channel depth as shown in Figure 9.20 and Figure 9.21.

Another policy simulation focuses on an advancement of the regional development in eastern El Salvador. It would contribute to increasing the amount of container cargo (see Figure 9.13) as well as the revenue in La Union Port (see Figure 9.26).

(9) Optimal dredging plan considering time-series changes

The methodology of the time series analysis considering each year's income, benefit and dredging cost is developed as described in Chapter 10. Also, example results of calculation are shown in order to contribute to the discussion on the optimum time to conduct dredging. The calculation is based on many assumptions (e.g., the re-dredging is allowed only twice and the second re-dredging must be carried out precisely ten years after the first dredging); in addition, the examples of which the calculation results are shown in Chapter 10 are very limited to those based on the liner which service network to generate the expected maximum net benefit for each channel depth.

(10) Navigation rule of access channel

The present status of navigation channel and rules are summarized and a new navigation rule is proposed in 9.1. The expected waiting time is calculated based on the new rule as well as on the existing rule. It is found that the existing rule may be effective under the current situation that a small ship navigates a shallow channel, but when the channel is deepened and ships of various sizes are expected to call the new rule needs to be introduced.

11.2 Recommendation

(1) Applicability of a empirically formulated prediction model

Both the Modified Exponential Model and the Linear Model are formulated empirically based only on the bathymetric data without considering the physical characteristics of siltation. These models can predict the siltation process under the same condition as in the past. However, they cannot predict those under a new condition.

For example, among the bathymetric data used for formulating these models, the maximum water depth in the channel is around 15 m. Then, a precision of prediction by these models is guaranteed to a certain degree when the channel depth is shallower than 15m. Please note that it becomes worse when the water depth becomes deeper than 15m because the models have no experience in such a deep depth.

Another example, when some structure will be constructed nearby the channel to reduce the siltation, which is a new condition, these models cannot be used. In this case, another model must be developed based on the bathymetric data obtained under the new condition.

(2) Applicability of the Linear Model

The Linear Model has been formulated base on the hypothesis that the rapid siltation just after the dredging might be the bound phenomenon only once in the newly excavated channel. It must be stressed again that we must refrain from the use of the Linear Model until the hypothesis is verified with the bathymetric data, or the applicability of the Linear Model is confirmed with the data.

(3) Appropriate dredging framework

The dredging cost by own dredger is estimated smaller than contract base because the indirect cost is estimated cheaper than by contract base while direct costs are similar. Indirect cost of contract base includes mobilization cost, insurance cost, costs related with contingency and so on. On the contrary, indirect cost of dredging by own dredger include only mobilization, insurance cost and contingency as other cost is difficult to estimate. However, it is not appropriate to discuss about the dredging framework only with a comparison of dredging costs by contract base and own dredger, for the following reasons.

If CEPA owns a dredger, CEPA would have to bear considerable cost more than the cost estimation. And, dredging works could not be functioned without long experience and the accumulation of know-how. Aside from the cost, CEPA would have to handle training and education for dredger’s crew.

Furthermore, accurate prediction of the siltation volume is necessary to design the size or capacity of the dredger before its procurement. But prediction models of siltation volume developed in this report is not reliable enough and necessary to be revised through monitoring of channel siltation for a certain period.

In addition to above, in case of change of target channel depth, the flexible response is extremely difficult if CEPA owns its dredger. This problem will remain unchanged for future as well.

Judging from the above all, “dredging by contract base” for the channel maintenance dredging for a certain period is strongly recommended.

(4) Necessity of monitoring channel depth

The two models empirically established are based on the bathymetric data which is not always sufficient both in quality and in quantity. In particular, the Linear Model is developed on an unverified hypothesis. The monitoring of channel depth by bathymetric survey is the only way for improving the precision of prediction and enhancing the applicability of the Linear Model to the maintenance dredging. This is the first purpose of monitoring. The second one is to confirm the phenomenon of rapid siltation just after the dredging.

The monitoring plan is set up in Chapter 6, subject to the condition that the bathymetric survey will be conducted by CEPA’s personnel themselves with their own equipment.

(5) Use of dual frequencies of echo sounder

Whenever the bathymetric survey is conducted, the water depth should be measured with the sonic waves of 38 kHz and 200 kHz at the same time. High frequency signals reflect near the water-mud interface, while low frequency waves penetrate into the sediment deposit and yield a large water depth value. There have been many arguments on the acoustic response of fluid mud layer to the low and high frequency sonic waves, but no quantitative conclusion has been obtained yet. Anyway, the difference between the water depths measured with low and high frequency waves is an indication of the thickness of fluid mud layer.

(6) Tariff Setting

Increasing the tariff in La Union Port is necessary for the financial soundness of the port. If the tariff of La Union Port is kept at the present level, the net income will always be less than the dredging cost for each channel depth as already mentioned. Therefore, it is necessary to increase the tariff in La Union Port to keep a sound financial condition.

However, this may weaken the competitiveness of the port against neighboring ports resulting in a decrease in the amount of containers handled. The level of the tariff will be a crucial issue when the shipping market becomes more liberalized such as when the barriers at national borders are removed as shown in Figure 9.12.

(7) Transshipment hub scenario

Becoming a transshipment hub is one of the feasible scenarios for La Union Port according to the calculation of the vessel calling model as shown in Figure 9.8, Figure 9.9 as well as other figures in Section 9.2. It would be also very beneficial to the economy of El Salvador as shown in Figure 9.18, Figure 9.19 as well as other figures in Section 9.3.

However, an important point to keep in mind is that simply deepening the channel by dredging does not guarantee that the port will become a transshipment hub. To become a transshipment hub, considerable efforts to attract the vessels of the trunk line would need to be made. As stated in (8) of the previous section, the estimated values (e.g. container cargo throughput) from the

Vessel Calling Model spread across a broad range depending on the scenario. In order to realize the highest value out of all feasible scenarios by attracting the most favorable liner shipping network to La Union Port, it is very important to implement more effective, strategic port sales by focusing on the appropriate targets based on a scientific approach as shown in this report. The importance of strategic port sales would not change at all even if CEPA becomes a landlord-type port authority after the concession contract. Port sales needs to be strategically implemented with the cooperation of the concessionaire.

(8) Regional development in eastern El Salvador

An advancement of the development project for East Salvadoran region would contribute to increasing the amount of container cargo as well as the revenue in La Union Port as already mentioned. Therefore, the integrated development of La Union Port with the hinterland in the eastern area of El Salvador is also one of important keys for the future development of La Union Port as originally planned.

(9) Importance of step-wise investment plan for dredging to avoid huge financial risks

The example results as shown in Table 10.8 and Table 10.9 on the time series analysis considering each year's income, benefit and dredging cost imply that the best strategy to maximize the expected maximum net benefit is to purchase a dredger for annual maintenance dredging within a few years and maintain a channel depth of around -12m or -13m. However, there is a significant risk because this strategy will only be successful if the "transshipment hub" scenario is realized.

On the other hand, the second best strategy with relatively smaller risk is that the first re-dredging for a depth of around -10m is conducted with a contracted dredger and the second re-dredging for a depth of -13m. This kind of "step-wise" strategy is very useful for avoiding huge financial risks.

(10) Necessity of new navigation rules for access channel of La Union Port

Existing rule for navigation is adequate under the current situation that a small ship navigates a shallow channel as mentioned in Section 9.1. However, new navigation rules need to be introduced when the channel is deepened and ships of various sizes are expected to call.