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著者(和文)	KavirathnaChathumi Ayanthi
Author(English)	Kavirathna Chathumi
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COOPETITION MODELING AND APPLICATIONS FOR THE INTRA-PORT AND INTER-PORT LEVELS

A Dissertation

Submitted to the Department of Transdisciplinary Science and Engineering

In Partial Fulfillment of the Requirements of the Degree of

Doctor of Engineering

Kavirathna Chathumi Ayanthi

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Department of Transdisciplinary Science and Engineering

School of Environment and Society

Tokyo Institute of Technology

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ABSTRACT

The increasing complexity of the liner-shipping industry emphasizes the significance of having effective interactions among key market players to enhance the efficiency of the port value chain. Owing to the disadvantages of extreme competition and cooperation, this study proposes the coopetition among market players considering both the intra-port and inter-port levels. The coopetition refers to the simultaneous presence of both competition and cooperation, thus having a strategic implication for those engaged in the same market to focus on a win-win strategy. Moreover, this study analyzes the coopetition with different ownership types and significant implications of coopetition are discussed and tested with numerical analysis and case study applications.

Firstly, this study proposes the coopetition for the intra-port level, which simultaneously presences both competition and cooperation among terminal operators in a port when competing with external ports and terminals. As the coopetition strategy, terminals cooperate with each other to enhance the entire port competitiveness although they simultaneously make competitive efforts on price adjustment, operation cost reduction or time efficiency improvement at individual terminals. Thus, we analyze the willingness of terminal operators towards competition and cooperation, and the coopetition model is formulated as a multi-periods non-linear optimization problem incorporating a generalized cost function and considered both public and private terminals together with their objectives such as social surplus or profit maximization. As per the numerical analysis, incentives of terminal operators depend on the terminal ownership types and the private terminal indicates a free-riding behavior when the public terminal focuses on enhancing the entire port competitiveness. However, coopetition enables a win-win situation for terminals in one port to erode demand from external competitors.

Secondly, the intra-port coopetition is proposed for sharing terminal facilities in congested circumstances to reduce berthing delays and to enhance the entire port competitiveness. As per the proposed strategy, terminals have competitive interactions during the contract stage when negotiating with shipping lines. However, their cooperation with a vessel transfer policy during the operational stage enables vessel transfers between two terminals if one terminal has idle berths and the other has excess vessel calls, simultaneously. The effectiveness of coopetition is compared with an extreme competition case, where terminals have only competitive interactions during both contract and operational stages. A mixed-integer programming model is formulated incorporating a game-theoretical decision-making approach and then tested with the Port of Colombo. The occurrence of vessel transfers and berthing delays are significantly different depending on the port authority’s policy on collecting terminal fees and the objectives of terminal operators. However, the intra-port coopetition strategy enhances port competitiveness than the extreme competition strategy.

Finally, the coopetition is analyzed considering both the intra-port and inter-port levels, which incorporate decision-making behaviors of a global terminal operator who has terminals in two competing ports and a port authority who has both the public terminal operated by the port authority and the private terminal operated by a global terminal operator in the same port. As for the case study, initially, the potential competition between Colombo and Hambantota ports in Sri Lanka is discussed with both the domestic and transshipment cargo flow analysis. Thereafter, a terminal pricing scenario is developed considering a range of objectives associated with the port authority and a global terminal operator. Both the port and terminal levels are considered in the analysis where the pricing decisions for the terminals in the same port, and for the terminals owned by the same global terminal operator are analyzed with a multi-period non-linear optimization model. As per the results, the attractiveness of Colombo port for the domestic container handling and that of Hambantota for the transshipment container handling are revealed and the policy implications on the port development aspects are discussed. The terminal pricing decisions of the port authority and the global terminal operator change significantly based on their objectives and their decision-making behaviors try to balance the interests on both competing ports especially when having the profit maximization objective.

This study has significant contributions by analyzing the coopetition for both the intra-port and inter-port levels and considering the different ownership types of ports and terminals. Moreover, the decision-making behaviors of the key market players with a range of objectives are analyzed while discussing related policy implications. By effectively channeling both competition and cooperation with the modeling and application of coopetition, this study speaks to the very pertinent challenges in ports and container terminals. In the liner shipping industry where progressively in need of such solutions, this study creates immense value for every actor involved, policymakers, and academia.

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CHAPTER 1: INTRODUCTION

1.1 Background

As the most economical and cost-effective mode of transportation, maritime transportation plays a significant role in international freight distribution. Especially the advantages of containerization such as standardization, flexibility, economies of scale, less turnaround time, convenience in warehousing, and safety and security of cargo (Rodrigue, 2017), among others, accelerate the growth of the liner shipping industry. A seaport plays an important role as a logistic node to connect the maritime transportation with the other transportation modes while facilitating economic space to carry out a wide range of activities focusing on its main customers such as shipping lines, shippers, consignees, freight forwarders and other transport and logistics companies (Montwill, 2014). Therefore, the key stakeholders such as container ports, terminal operators, shipping lines, and stevedoring companies, among other have growing significant roles in the liner shipping industry, which emphasizes the importance of having effective interactions among these parties for increasing the efficiency of the entire port value chain (Song and Panayides, 2008).

As an industry with significant growth potential, several strategic changes can be observed in the liner shipping industry in the current context. Especially, the challengers given with the intense competition motivate market players such as ports and terminal operators to embrace new strategies to sustain in the market (Heaver et al., 2001; Notteboom et al., 2019). Besides, the cost-driven approaches such as strategic alliances among shipping lines, and enlargements of container vessel size, among others encourage port service providers to appropriately balance the interactions among each other in both horizontal and vertical levels in the port value chain. Although a majority of seaport functions were previously carried out by the public sector, the intense competition in the industry encourages the port authorities to accommodate the private sector in the port operation especially with container terminals, to enhance operational efficiency (Saeed and Larsen, 2010). Therefore, the public port authorities in many seaports act as a planner, facilitator, developer, and a regulator of the port activities and also focus on enhancing port connectivity with its hinterlands and forelands (World Bank Port Reform Toolkit, 2007). However, there is a growing involvement of the private sector in the terminal operation, to carry out cargo handling functions (Baltazar and Brooks, 2001). Thus, the administration and governance structures of seaport are being transformed from traditional public service ports, where the public sector directly involves in cargo handling functions, to a contemporary model such as landlord port model, with the involvement of private sector in container terminal operations. However, as per Galvao et al. (2016), there can be possible conflicts of interests owing to the private sector involvement in the port operation especially when the port authority tries to regulate and oversees the activities of a private terminal, who usually focus on maximizing individual profit. Therefore, with these strategic changes, the interactions among port service providers have become multifaceted because of the different objectives and interests associated with them.

This situation becomes even more complicated when a single port has terminals, which are operated by both the public and private sectors. According to Brooks and Pallis (2012), the ports in several countries including Sri Lanka, Pakistan, Finland, India, Germany, Greece, and Turkey, simultaneously have both the public terminals and the private terminals in the same port. Therefore, the differences in objectives and operating principles of the public and private terminals and their interactions could have a significant influence on the overall port performance. However, the interactions among terminal operators are not limited to a single port, because of the possible competition and cooperation among terminal operators located in different ports, which are serving to the same market (Notteboom and Yap, 2012). Thus, considering the challenges given by the contemporary liner shipping industry, this study proposes different strategies and approaches for the ports and terminal operators to withstand in a competitive market setting.

1.1.1 Port Value Chain and Interactions among Market Players

Since this study focuses on the strategies and approaches for effective interactions among port service providers, it is important to understand the contemporary nature of their interactions considering the port value chain. As per the Vitsounis and Pallis (2012), the port value chain can be defined as the system of regionalized units, which are interacting both functionally and spatially. Therefore, when considering the value chain, the implications are different from those related to the individual market players, such as terminals, warehouse, and trucking companies, among other that operate in an isolated basis. Effective interactions among market players in the port value chain are significant because they all are in the need of services offered by each other. For instance, it is not possible to provide a complete service to a container vessel at a port without incorporating services offered by many different parties such as terminal operators, port authorities, and transport companies, among others. Owing to the growing competition in the liner-shipping industry, the market players even at the same horizontal level (e.g. among the terminal operators) are required to have effective interactions among each other.

Figure 1.1 illustrates a simplified approach to understand the levels of functional integration within the port value chain considering the changes in ownership and management of its different components such as the port authority, terminal operators, logistics companies, and shipping lines, among others. First, a high level of functional integration can be observed when the majority of port service providers are belonging to the same conglomerate, as represented by the same color code. Such situations can be observed when a global logistics provider has different sub-business units focusing on port operation, liner shipping business, and liner-owned terminals, among others, under the same conglomerate (Heaver et al., 2001). However, the level of functional integration can be reduced when the different components of the port value chain are belonging to individual companies, as represented by different color codes. This can happen not only at the vertical level but also at the horizontal level, which increases the complexity of their interactions. Despite the high level of functional integration resulted from having a majority of port service providers from the same conglomerate (Notteboom et al., 2019), such a situation can lead to several disadvantages due to the monopolistic behavior of port service providers. On the contrary, despite the high operational efficiency gain with the presence of competition among players in the port value chain due to the different ownership types, such a situation can lead to the congestion and other negative externalities. Thus, balancing the level of integration among the players in the port value chain is important to facilitate effective port functions, because the port is a critical node in the global supply chain.

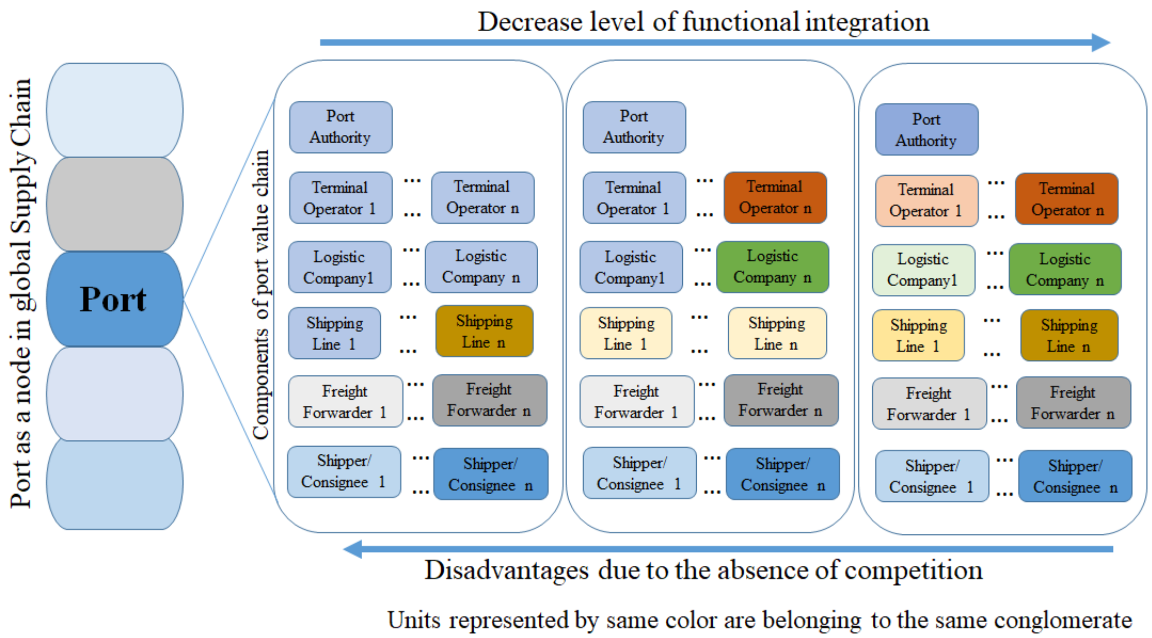

Figure 1.1. Functional Integration with the Port Value Chain

(Source: made by author)

Since this study focuses on container ports and terminals, it is significant to understand the basic functions at a port in terms of container vessel handling as illustrated in Figure 1.2. Accordingly, after arriving on a container vessel at the port, the vessel waits at the anchorage area until a terminal operator makes the required preparations on vessel handling. In some instances, vessels are required to wait for several hours and days until an idle container berth becomes available at its target terminal. Then, the vessel's navigation functions are initiated after the pilot gets onboard the vessel and the vessel is navigated to the respective berth of the terminal operator. Subsequently, the vessel operation is commenced, and the loading and unloading of containers to/from the vessel are taken place. Therefore, each container terminal is equipped with required gantry cranes and other superstructures for container vessel operations. Simultaneously, the back and forth movements of containers between the yard stacking areas and quay areas are taken placed to ensure a smooth operation of the vessel. After loading/ unloading functions are completed, the pilot gets onboard for confirming the vessel clearance and navigates the vessel back to the anchorage area. Then, the vessel is permitted to sail to its next port of call. However, the actual operation of a vessel at a container port requires more complicated functions and documentation, although they are not described here in detail. Besides the cargo handling, vessels may demand some husbandry services from the port, such as bunkering, repairs, spares parts supply, and crew changes, among others, which are facilitated by different logistics service providers as approved by the port authority.

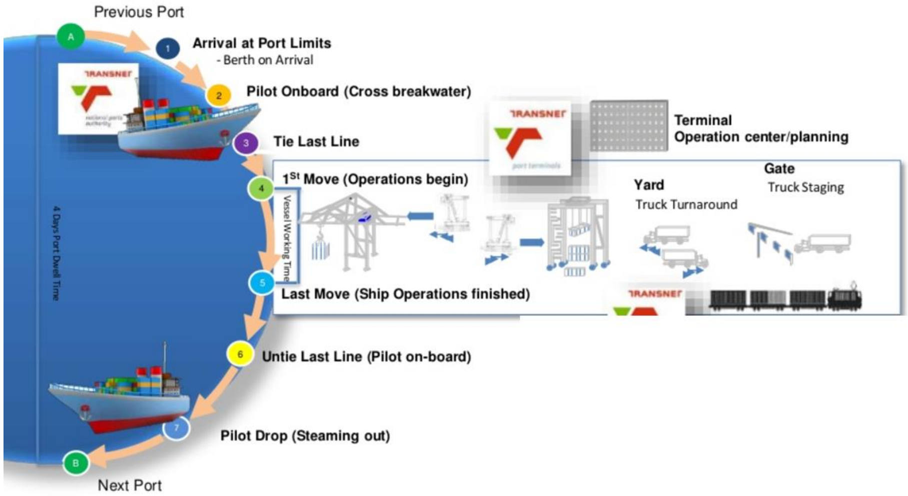

Figure 1.2. Container Vessel Handling at a Port

(Source: Willie, 2017)

Although multiple parties are involved in the port value chain, this study mainly focuses on the interactions among the port authorities, terminal operators as well as the shipping lines, which are considered as the key players in the liner shipping business (Heaver et al., 2001). The basic interactions among these market players are summarized in Figure 1.3 to better understand the model developments in the later chapters of this dissertation. Since we focus on different combinations of terminal ownership types, such as public and private terminals operated within a given port, the explanation is given here considering both the public and private terminal cases. In this study, the port authority is assumed to be involved in the planning, monitoring and regulating of port activities (World Bank Port Reform Toolkit, 2007). However, in the case of public terminals, the port authority or it's subsidiary business units directly involved in the terminal operation functions. Therefore, the public terminals and the port authority are assumed to be represented by the same economic entity (Brooks and Pallis, 2012; Munim et al. 2018; Saeed and Larsen, 2010). Thus, apart from maximizing the direct operating profits, the public terminals can have non-profit objectives as well, thereby the operating principles of the public terminals could be different from those of the private terminals (Heaver et al., 2001).

The private terminals in this study are considered as the concession terminals, which are operated based on a concession agreement with the port authority. As per Olivier et al. (2007), there is a growing trend of having concession terminals in container ports. Apart from enhancing the terminals' operating performance, the need of large investments on developing container terminals would be another major reason for port authorities to consider the private sector involvement in container terminal operation (Pallis et al., 2010), especially aligned with the concession agreements such as build–operate–transfer. A concession terminal can be operated by an individual private terminal operating company or a global terminal operator (GTO), who has a number of container terminals in different parts of the world. Usually, the concession terminals are granted for a specific time period could be 30-40 years depending on the strategies of the port authority as defined with the port master plan. Therefore, after constructing general port infrastructure such as port access roads, and the main portland, among others, a private terminal operating company is awarded the concession agreement to build the necessary superstructure for vessel operation including berths, cranes, and yards, among other and to operate the terminal for a pre-defined time period. Thus, as per the concession agreement, the port authority receives a terminal fee from the private terminal operator depending on the number of containers handled at the private terminal (Pallis et al., 2010). Moreover, some port authorities may receive an annual terminal rent, which is usually a pre-agreed value in the concession agreement, in addition to the terminal fee (Saeed and Larsen, 2010). Besides the collecting terminal fees from the private terminals, the port authority enforces the rules and regulations and oversees the operation performance of these private terminals, considering its role as the landlord of the entire port.

Next, we discuss the interactions between the terminal operators and the shipping lines, because shipping lines are considered as the direct users of container terminals in this study. As per the Kavirathna et al. (2018.b), to carry out a vessel operation, initially, a shipping line and a terminal operator come up with a service contract after negotiating handling charges and operation terms. The terminal operators facilitate the main container loading and unloading functions of the vessels at the port, thus, in return, shipping lines are required to pay container handling charges to the terminal operators, depending on the number of containers handled, although the shipping lines transfer this container handling cost to the ultimate shippers and consignees when making service contracts with shippers and consignees or freight forwarders. Thus, to attract more vessel calls, the terminal operators should provide efficient vessel handling functions, especially due to the intense market competition with the multiple terminal operators available in the same market.

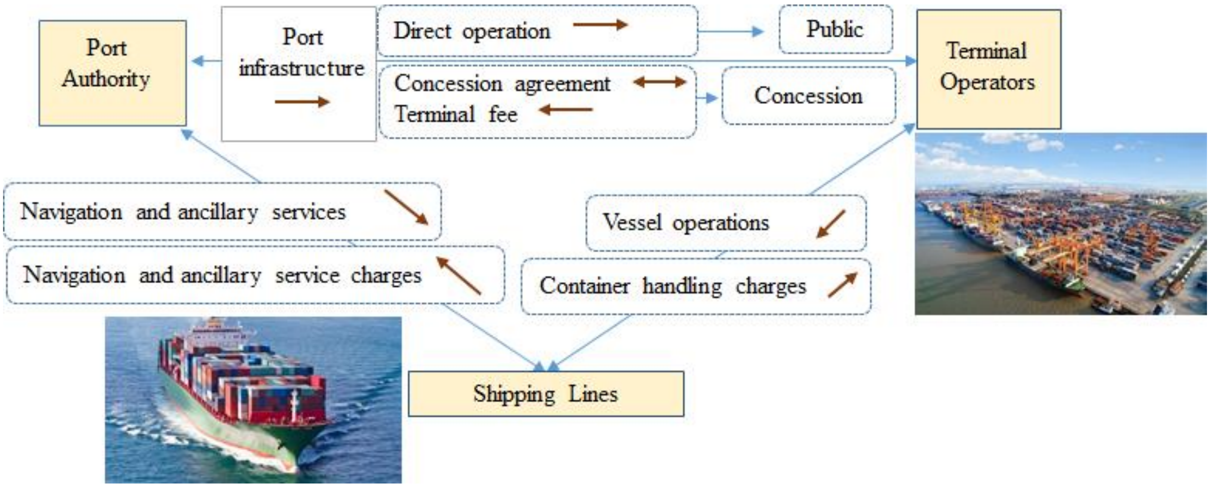

Figure 1.3. Interactions among Market Players

(Source: made by author)

Lastly, when considering the interactions between the port authority and the shipping lines, apart from enforcing rules and regulations and monitoring activities of shipping lines inside the port territory, the port authority manages and oversees a range of ancillary services provided for the vessels at the port. However, depending on the operating principles of a port, the port authority may authorize private or public third-party service providers to facilitate these ancillary services under the supervision of the port authority. As per the industry practices, the relevant charges associated with these navigation and ancillary services are determined and published by the port authority in the form of the port tariff document. Thus, shipping lines are required to pay charges related to these services to the port authority, depending on their usage of such services. Besides, the port authority can have interactions with the shipping lines as a part of the port marketing and promotion functions as well.

1.1.2 Intra-port and Inter-port Levels

Since this study focuses on the coopetition for both the intra-port and inter-port levels, it is important to understand the difference between intra-port and inter-port levels. As per Van de-Voorde and Winkelmans, (2002) and De Langen and Pallis (2006), the interactions at the intra-port level means that the interactions among the terminal operators within the same port. However, when considering the inter-port level, the inter-port interactions can be taken placed at both the operator level and the port authority level as illustrated in Figure 1.4. As one of the main focuses of this study, we consider the inter-port interactions occurred at the operator level such as interactions among terminal operators, who locate in different ports but compete for the same traffic category (Van de-Voorde and Winkelmans, 2002). Although an extensive number of previous studies focus on the inter-port level analysis, only a limited number of studies focus on the intra-port level analysis. Besides, even in case of inter-port level, not many studies consider the operator level interactions because most previous studies consider only the port authority level interactions. However, the analysis of both the intra-port and inter-port levels is significant owing to the different implications associated with them.

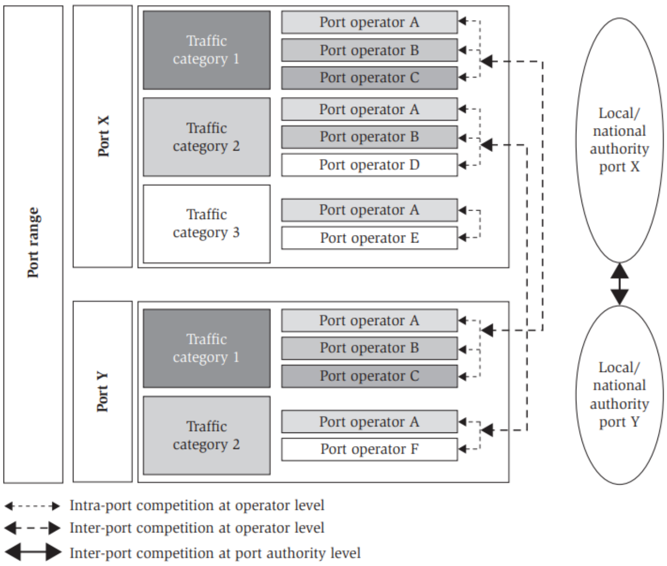

Figure 1.4. Inter-port and Intra-port Interactions

(Source: Van de-Voorde and Winkelmans, 2002)

1.2 Coopetition

1.2.1 Theoretical Framework of Coopetition

As the fundamental concept of this study, the coopetition can be defined as the **"mixture of both competition and cooperation, therefore it derives strategic implications on the players, who compete in the same market to come up with a win-win strategy rather than maintaining their win-loss strategies"** (Song, 2003). The coopetition was first introduced by Brandenburger and Nalebuff (1996) and they emphasized the objective of coopetition as "**to create a bigger business pie while competing to divide it up"**. Owing to the simultaneous presence of both competition and cooperation, which are the most prominent types of interactions among market players, the coopetition can incorporate the advantages and minimize the disadvantages associated with both the extreme competition and cooperation situations. Therefore, the implications associated with the coopetition would be different from those associated with pure competitive and cooperative approaches. Due to the advantages of coopetition, it has been applied in several industries including ports and shipping, automobile, aviation, and tourism, among others (Dong, 2015). For introducing the coopetition, previous studies incorporate two main concepts namely; **value creation** and **value appropriation (capture)** (Brandenburger and Nalebuff, 1996; Ritala and Tidström, 2014). The value creation considers as the common benefit created by cooperation among market players and the value appropriation is the individual benefit attained by one market players while competing with others, and the simultaneous presence of value creation and value appropriation is recognized as the coopetition (Ritala and Tidström, 2014). Thus, although the market players create a common value by their cooperation, they should simultaneously maintain their own value appropriation strategies to remain competitive as individual entities.

Although this study follows different optimization approaches in modeling coopetition strategies in individual chapters, the main principles and concepts of game theory are used here to better understand the coopetition among market players, which helps authors to describe the mechanisms and ideas related to following chapters. Since the coopetition requires simultaneous competition and cooperation among market players, we assume strategies of market players on different business processes such as product development, marketing, selling, and pricing among others. Thus, when considering competing market players, they can have different ways of interactions in terms of individual business processes. Hence, if we consider a set of alternative strategies in terms of different combinations of competitive and cooperative approaches, these alternative strategies influence the payoff of individual market players. In some cases, market players choose to compete in terms of all business processes which is considered a pure competition strategy. On the contrary, market players can choose to cooperate in terms of all business processes, which can be considered as a pure cooperation strategy. However, there is a possibility that market players choose to compete in terms of one business process (ex: selling) but simultaneously cooperate in terms of a different business process (ex: procurement) due to the advances associated with those approaches. Due to the possibility of generating mutual benefits, the payoff generated when market players choose to compete in one business process but cooperate in another business process can be higher than their payoff associated with pure competition and cooperation strategies. In such scenarios, market players should consider this appropriate mixture of competitive and cooperative interactions rather than focusing on extreme competition or cooperation, which is defined as the coopetition in this study. Due to the simultaneous presence of competition and cooperation, such a coopetition strategy may generate more benefits to the entire market cluster.

Since the coopetition requires simultaneous competition and cooperation among market players, we assume two market players, player 1 and player 2, their strategies and associated payoffs as illustrated in Figure 1.5. The pair of values in each cell, from left to right represents the payoff of player

1, and player 2, respectively. Accordingly, the strategy of a market player is described as a combination of competitive and cooperative approaches given in terms of different business processes such as procurement, marketing, selling, etc. Thus, market players can choose to compete in terms of one business process but cooperate in terms of a different business process. Hence, if we consider a set of alternative strategies in terms of different combinations of competitive and cooperative approaches represented by x and y, respectively, the payoff matrix of market players with their alternative strategies can be represented as in Figure 1.5. Accordingly, the strategy options of Player 1 and Player 2 are represented in columns and rows of the strategy matrix. Assuming the x^1 and y^1 represent the competitive and cooperative approaches given by Player 1 and x^2 and y^2 represent the competitive and cooperative approaches given by Player 2, the first most row ($x^1 = 0,\ y^1 = M$) and first most column ($x^2 = 0,\ y^2 = M$) represent the extreme levels of cooperation because both market players have only cooperative approaches without any competitive approach. In contrary, last row ($x^1 = M$, $y^1 = 0$) and last column ($x^2 = M$, $y^2 = 0$) represent the extreme competition approaches of two players because they have only competitive approaches without any cooperative approach. Thus, in terms of coopetition, market players can choose different levels of x and y given for individual business processes which influence on their individual π^1 and π^2.

		Player 2							
		$x^2 = 0$, $y^2 = M$				$x^2 = ?$, $y^2 = ?$			$x^2 = M$, $y^2 = 0$
Player 1	$x^1 = 0$, $y^1 = M$								
	$x^1 = ?$, $y^1 = ?$					π^1, π^2			
	$x^1 = M$, $y^1 = 0$								

Figure 1.5. Coopetition with Simultaneous Competition and Cooperation

Following this explanation, when considering value creation and value appropriation with coopetition, the business processes related to cooperative interactions may focus on the common value creation and the business processes related to competitive interactions may focus on the individual value appropriation. In terms of model development in individual chapters, we consider different alternative scenarios in which market players can maintain these competitive and cooperative interactions simultaneously considering different objective functions associated with their decision-making. Thus, market players choose an appropriate combination of competitive and cooperative interactions as the coopetition strategy. However, the models developed in individual chapters are associated with multiple decision-making periods with repetitions in decision-making by market players, therefore details of the model development are given in individual chapters focusing on the specific case under consideration by them.

Therefore, it is possible that two firms simultaneously have both competitive and cooperative interactions in terms of two different business processes, which influence their payoffs. Such kind of situations can be observed in several industries, where few market players or players in a market cluster have an opportunity to create a common value by cooperating on specific business processes such as joint marketing campaign, outsourcing, and joint procurement, among other although they simultaneously compete with each other in terms of another strategy such as pricing, and product development, among other. Focusing on the coopetition behaviors among the firms in the software industry, Ohkita and Okura (2014) analyze the situation where legal software firms make a cooperative investment for excluding illegal software firms while simultaneously deciding the number of software produced by each firm in a competitive approach. Moreover, Volschenk et al. (2016) discuss different approaches on coopetition with industry examples such as joint destination marketing by competing luxury hotels to attract more tourist to Cape Town, joint logistics network used by competing furniture companies for cost-saving, and collaborative glass recycling process by competing wine-producing companies in South Africa, among other. Besides, considering the real industrial practices related to the industry-wide training of insurance agents apart from the training given by individual insurance firms, Okura (2012) discusses the coopetition among insurance firms. Accordingly, insurance firms have both the cooperative training of insurance agents and the competitive sales systems, simultaneously.

However, the coopetition does not always emerge with voluntary actions. This happens because the market players may not choose the different combination of competitive and cooperative interactions in all situation as they tend to follow the extreme competition or cooperation strategies. Therefore, in such situations, a coordinator can play a significant role in directing firms on appropriate strategies by communicating information between firms as discussed by Okura and Carfi (2015). In some cases, a coordinator may enforce some rules, incentives, penalties, etc to direct market players on appropriate competitive or cooperative interactions depending on the different business processes and market environments. Since this dissertation focuses on coopetition among ports and container terminals in the liner-shipping industry, it is possible to observe opportunities to have similar interactions among ports and terminals. Therefore, as an example, the port authority as the main regulator and policymaker of the port may act as a coordinator for encouraging appropriate competitive and cooperative interactions among terminal operators in the same port for effectively balancing both value creation and value appropriation among them. This study considers different approaches to introducing coopetition in each chapter with various strategies to achieve specific objectives associated with individual chapters.

Next, an analytical framework of the coopetition can be simply explained with the following example scenario illustrated in Figure 1.6. If we consider a pure competitive approach with a pricing strategy among market players, individual market players may decide the optimal price level considering their individual payoff. However, in the case of a pure cooperative or coalition approach in the pricing decision, the market players may decide the price level considering the combined payoff of all members in the coalition (Saeed and Larsen, 2010). Since we consider the simultaneous presence of both competition and cooperation, we assume that the value creation made by cooperation among all market players has a positive influence on their payoffs while the value appropriation generated for the individual market player can be decided with a competitive strategy such as pricing strategy. Therefore, even in the case coopetition situation, a market player may decide an individual price level with a competitive approach as a strategy for value appropriation in coopetition to maximize individual payoff. However, the individual payoff is also positively affected by the value creation made by cooperation among market players in terms of a different strategy.

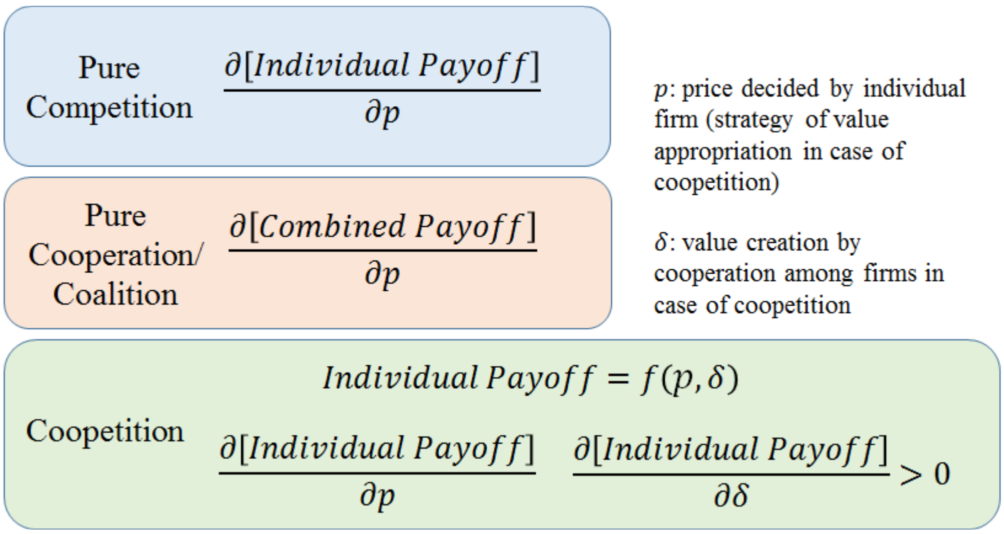

Figure 1.6. Analytical Framework for the Model Development on Coopetition

Therefore, in order to decide strategies and develop models on coopetition, this study defines a necessary condition for executing a coopetition strategy among market players as the **"possibility of creating a common value by a group of competing market players, such that the created common value can make a positive impact for all of them"**. Accordingly, when a group of competitive market players or market players within a particular market cluster have the possibility for creating a common value, which has a positive impact on all market players, they can have coopetition interaction with simultaneously competition and cooperation. Therefore, their cooperative interactions should focus on creating the common value and their competitive interactions focus on individual value appropriation.

1.2.2 Coopetition for the Ports and Terminals in the Liner-shipping Industry

The competition in the liner shipping industry, enlargement of vessel sizes, and the formation of shipping lines alliances, among others create more challengers for port services providers (Notteboom et al., 2019). Therefore, focusing on a new form of interaction such as coopetition would be advantageous for these market players to sustain in the competitive market. Moreover, as suggested by Notteboom (2007), the focus on the right balance between the competition and cooperation attitudes is significant for the current cargo handling industry, because it enables port customers including shipping lines to experience best possible deals with service providers, without jeopardizing their possibilities on enhancing the infrastructure and services.

A conceptual model for the coopetition among ports is proposed by the Song (2003) as illustrated in Figure 1.7 to withstand against the high bargaining power of customers, market environment forces such as the larger size of vessels and inter-modality as well as the high competition given from the market. Due to these market challenges, the market power of individual port can be threatened if they continue to act as isolated entities. Therefore, port operators synergize all of their competitive advantages to create a stronger position in the market, which can enhance the market power of each port operator (Song, 2003). Moreover, such an arrangement enables all ports to quickly respond to market changes.

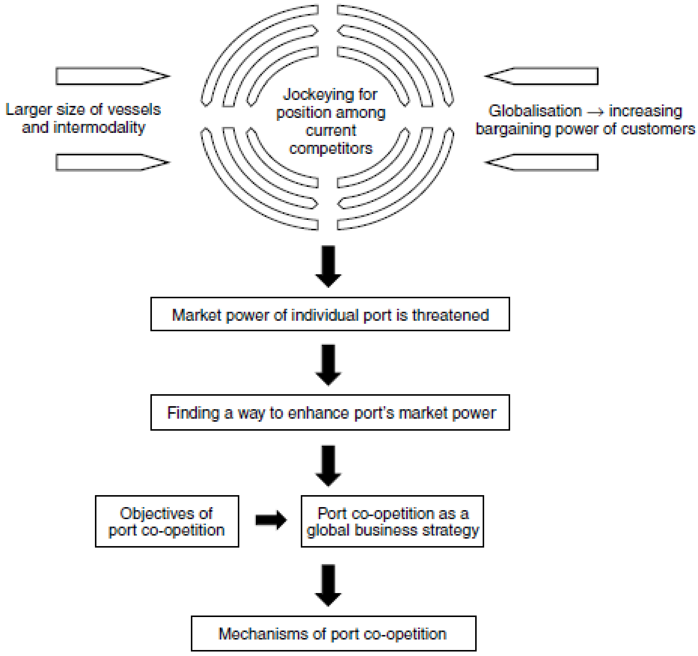

Figure 1.7. Conceptual Model on Port Coopetition

(Source: Song, 2003)

Although a conceptual model for the coopetition among ports is discussed by Song (2003) with Figure 1.7, we focus on the coopetition among terminal operators. When comparing to the port level, the intra-port level has more advantages from the coopetition because all terminals in the same port have common interests such as the competitiveness of entire port, same geographical and market advantages, same external competitors, possibilities of sharing facilities, and some positive externalities as well. Moreover, they have individual interests in profits and demand for own terminals due to the different ownership types. Thus, the intra-port coopetition may generate more advantages and implications on the liner-shipping industry than the port coopetition discussed by Song (2003). Thus, to clarify the motivation for this study, a conceptual model for the intra-port coopetition is given with Figure 1.8.

Accordingly, with the external market challengers such as liner alliances, hub-hopping nature of shipping lines, vessel enlargement, and new entrance in the market, among others, the market power of individual ports can be negatively affected (Notteboom et al., 2019). The Panel (a) of Figure 1.8 illustrates the situation when the terminals in one port adopt either pure competition approach focusing only on individual terminals aspects or pure cooperation approach focusing only on entire port aspects, which lead to the reduction of the market power of the entire port and those of individual terminals in that port. Therefore, it considers as a loss-loss situation. This happens due to the disadvantages of pure competition at the intra-port level such as extreme price competition, high bargaining power of shipping lines, congestion, and underutilization of facilities, among other and the disadvantages of pure cooperation among terminals, such as monopolistic high average price of the entire port, less motivation on innovation and specialization, and less operational efficiencies, among others (De Langen and Pallis, 2006; Saeed and Larsen, 2010). However, Panel (b) of Figure 1.8 illustrates a situation where terminal operators in one port adopt coopetition, which enables the entire port and its terminal operators to enhance their market power and performances even with the challengers given from the market environment. Accordingly, the terminals within a given port can be effectively incentivized to have cooperative interactions to increase the competitiveness of the entire port. Simultaneously, they can compete with each other to enhance the performance of individual terminals, which allows them to obtain a larger share from the expanded port market. Thus, the intra-port coopetition can reduce the disadvantages of extreme competition and cooperation. This study discusses different coopetition strategies and modeling approaches with related implications on market players, while various aspects such as terminals' objectives, ownership types, and market conditions are taken into consideration.

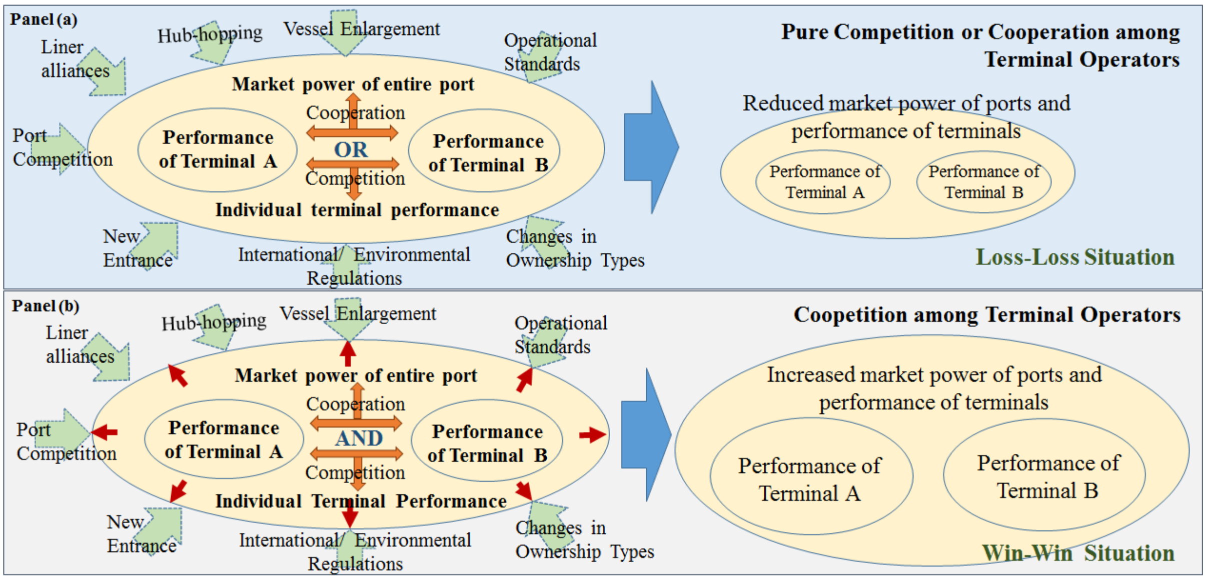

Figure 1.8. Conceptual Model on the Intra-port Coopetition

1.3 Motivations for the Study

In general, the motivations for this study can be discussed considering the significance of port competitiveness due to the strategic changes and various challengers observed from the liner-shipping industry and the possible implications drawn from this study by addressing them. The competitiveness is generally considered as the ability to over-perform the competitors. Thus, our three main analysis chapters focus on enhancing port competitiveness with various strategies related to coopetition. First, Chapter 3 focuses on high port competitiveness by lowering the cost of port users with different improvements made in port facilities such as single-window systems, and inter-terminal transfer systems, etc, which can increase the port attractiveness to the users. Besides, the reduction of handling charges, operation cost and handing time are considered in individual terminals, which in return enhance the port competitiveness. Chapter 4 focuses on high port competitiveness by minimizing port congestion and delays, which are detrimental to the shipping lines' port choices. By minimizing these operational issues, a port can perform better than external competitors, implying higher port competitiveness. Finally, due to the significance of port charges on the port competitiveness, the reduction of average port charges is considered to enhance the port market share when competing with other ports in the region. These cost and time factors are considered for enhancing port competitiveness because of their significance in port and terminal selection decisions of shipping lines as discussed in previous studies in Chapter 2.

1.3.1 Intense Competition in the Liner-shipping Industry

The current competitive nature of the liner shipping industry can be considered as the main motivation for this study. As discussed in Chapter 2, the competitive dynamics in the liner-shipping industry have significantly changed the roles and positions of individual ports in the international maritime network (Heaver et al., 2001; Notteboom, 2010). Therefore, to withstand the market competition, the port service providers, especially the terminal operators and port authorities should embrace new strategies and approaches. As per the Notteboom et al. (2019), the market competition has a higher influence on the transshipment ports, than the gateway ports because the market share of transshipment ports are highly volatile. This happens due to the possibility that shipping lines can easily shift from one transshipment port to another when compared to a gateway port that has a captive cargo base. Therefore, both Chapter 4 and Chapter 5 focus on the Port of Colombo, which is a main transshipment hub in the South Asian region (Kavirathna et al., 2018a). Besides, Chapter 3 discusses the ports and terminals competition aspects, Chapter 4 discusses the port competitiveness, and Chapter 5 analyzes the port competition considering both the domestic and transshipment container handling.

1.3.2 Changes in Administrative and Ownership Models of Ports

The restructuring of the port administration and ownership models from the traditional public service port to contemporary private or landlord port models (World Bank Port Reform Toolkit, 2007) is another motivation for this study because such strategic changes greatly influence on the performance of market players. Besides, these different ownership structures and administrative models increase the complexity in the market owing to the differences in objectives and operating principles of market players. According to the UNCTAD review of maritime transport published in 2017, 80% of the global port capacity is controlled by the private sector, while the remaining 20% is controlled by the state. As highlighted by World Bank Port Reform Toolkit (2007), due to the stake owned from the public terminal as well as in the provision of ancillary services in the Port of Colombo, the port authority in Sri Lanka may have conflict of interests, which compromise its role as a neutral landlord of the entire port. Therefore, such aspects are analyzed as case studies in Chapter 4 and Chapter 5 with different policy scenarios. Moreover, even within the same horizontal level, the behavior of market players could be different depending on their ownership structure. For instance, the behavior of a dedicated terminal, a public terminal, and a global terminal operator could be varied significantly (Heaver et al., 2001), which gives motivation for analyzing their interactions in Chapter 3 and Chapter 5 of this study.

1.3.3 Challengers Given by the Shipping Lines

As another motivation for this study, the formation of strategic alliances can be considered as illustrated in Figure 1.9. As a result of liner alliances, the bargaining power of shipping lines, who are the major customers of ports and terminals has been increased, which allows them to demand high standards and operating performance from the port service providers. Thus, the synergistic effect among terminal operators is significant to fulfill the requirements given by the shipping lines. Moreover, the high market power of shipping lines allows extreme price competition among port service providers, which leads to the reduction of the average port charges in the market and hub-hopping nature, owing to the availability of multiple service providers. Thus, an effective arrangement among port service providers helps to minimize these negative consequences. Besides, the enlargement of container vessel sizes and cascade effect can be observed in the liner-shipping industry as a strategy of shipping lines to obtain economies of scale advantages. However, this creates various operational challengers to the port operators because large vessel sizes require them to upgrade port infrastructures such as deep-water terminals, longer berths, and large terminal areas and also requires more efficient handling equipment (Heaver et al., 2001; Notteboom et al., 2019). Due to the limitations of capacities and operational capabilities at individual terminals, effective interactions among terminals are important to create a win-win solution, while sharing equipment and resources collaboratively as discussed in Chapter 4 of this study.

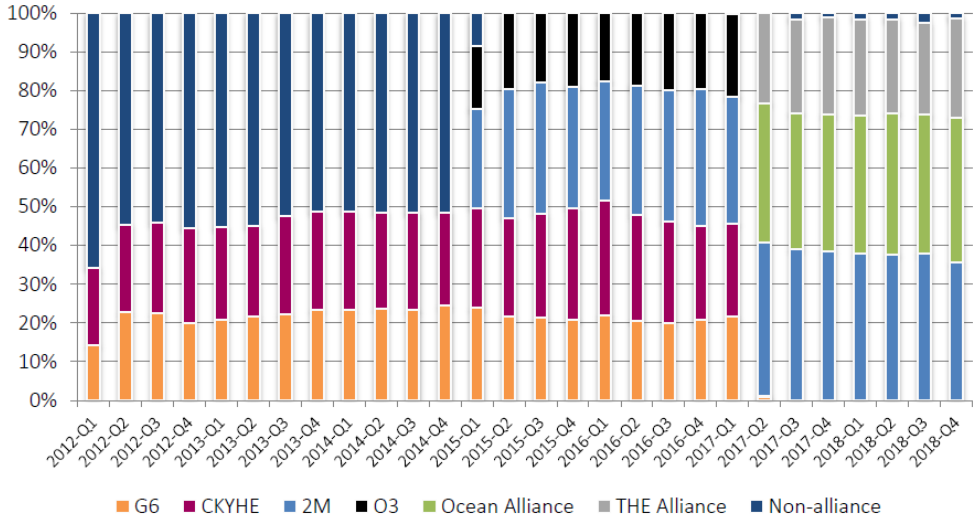

Figure 1.9. Market Shares of Alliances on Asia-North Europe Trade Lane

(Source: International Transport Forum, 2019)

1.3.4 Significant Role of the Global Terminal Operators

The significant role of the global terminal operators (GTO) can be considered as another motivation for this study because their behavior and interactions among other market players could have a significant influence on the liner-shipping industry, as discussed in Chapter 5. As per the Drewry Maritime Research (2016), GTOs control about 60% of the world container handling capacity in 2015 and a significant portion of the world container port volumes, mainly represented by the top 40 container ports are handled by the GTOs. The regional shares of the major GTOs from their portfolio are illustrated in Figure 1.10 in terms of terminal areas (hectares) in 2018, which highlights the strategic approaches of most GTOs in balancing interests on multiple geographical markets while reducing investment risk. However, due to the profit-oriented approach of GTOs, they are usually confronted when balancing their own interests and the interests of the port, where their terminals are belonging to. Thus, it motivates us to analyze the behavior of GTOs and their interactions with the port authority. Such analysis is significant when a GTO has own terminals in two competing ports in the same market as discussed in Chapter 5. Besides, due to the competitive advantages of GTOs such as economies of scale with multiple terminals, and extensive research and development, among others, a GTO can create significant threats to other individual private or public terminal operators in the same market (Heaver et al., 2001). Thus, various strategies and approaches should be adopted by other individual terminal operators to withstand the competition given by GTOs, as proposed in later chapters of this study.

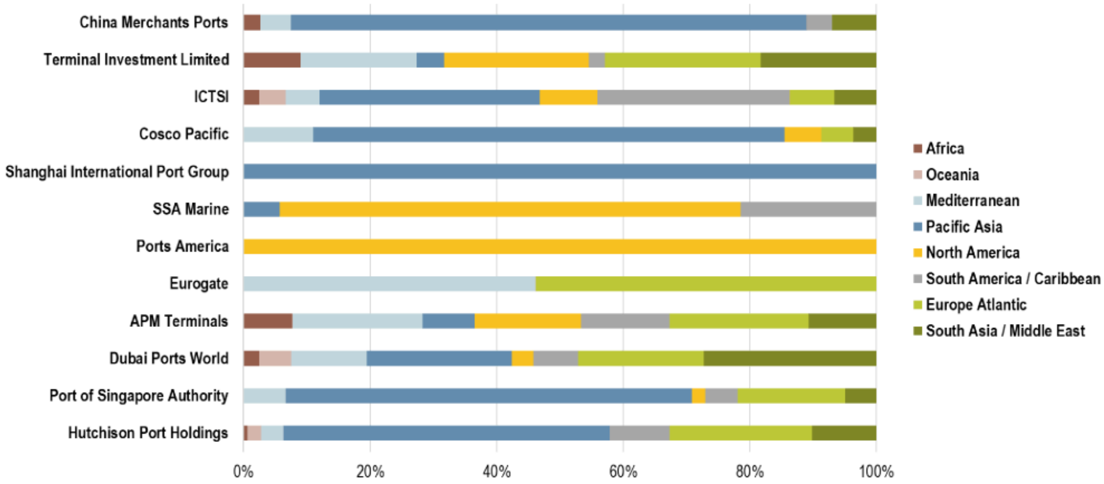

Figure 1.10. Regional Share of the Major Global Terminal Operators

(Source: Rodrigue, 2017)

1.3.5 Exiting Research Gap

Besides, the summary of previous literature discussed in Chapter 2 highlights the existing research gap on coopetition among terminal operators. Moreover, Chapter 2 also emphasizes the lack of previous studies on analyzing ports and terminal interactions considering different ownership types, behaviors of private terminals, public terminals, and GTOs, among others, which motivate us in conducting this study. Besides, the available case studies related to the port competition and cooperation highlight the lack of previous studies on ports in the South Asian region, especially on Colombo port, as focused by Chapter 4 and Chapter 5 of this study. Moreover, the lack of previous studies on optimizing terminal facilities with a collaborative approach among different terminals in a single port highlights the motivation for conducting such analysis in Chapter 4. Finally, previous studies emphasize the complexity in ports and terminals selection and the need for considering the distinct roles of ports, which are discussed in Chapter 5 of this study.

1.3.6 Existing Issues Related to Case Studies under Consideration

In addition to the model formulation on coopetition, this study discusses their application on case studies considering their practical significance. The main motivation for the proposed coopetition strategy in Chapter 4 comes from the recent joint initiative among container terminal operators in the Port of Colombo to enhance the overall port competitiveness (Mudugamuwa, 2018; Nanayakkare, 2018), which is the case study under consideration of this chapter. Therefore, the significance of the results from Chapter 4 on the relevant market players and policymakers in the Port of Colombo clarity the motivation for conducting such analysis. Moreover, the current issues associated with the port development in Sri Lanka, especially the development of Hambantota port with the involvement of

China Merchant Port Holdings, which is a GTO, and the impacts from the potential competition between Colombo and Hambantota ports on the Sri Lankan economy clarity the motivation for conducting such analysis as a part of the Chapter 5. Thus, apart from the motivation that comes from the existing research gap and the challenges given by the contemporary liner shipping industry, the practical significance of focused case studies and the implications derived for the relevant policymakers further motivate for conducting this study.

1.4 Research Objectives

Before discussing the individual chapters in detail, it is important to clarify the aim of this whole dissertation as well as the objectives associated with each chapter.

Aim of the Dissertation

To enhance the performance of ports and terminals by coopetition at both the intra-port and inter-port levels with model formulations and their applications while clarifying the implications on market players.

In order to achieve this aim, the dissertation consists of three main analysis chapters, focusing on two main objectives from each chapter as follows.

Chapter 3: Impacts of intra-port coopetition on external competitors

Objective [3.1]: To understand the coopetition behavior of a single terminal operator with changing market dynamics

Objective [3.2]: To analyze the intra-port coopetition strategy between two terminal operators considering different mixtures of terminal ownership types

Chapter 4: Intra-port coopetition strategy with a vessel transfer policy among container terminal operators in a single port

Objective [4.1]: To analyze the effectiveness of intra-port coopetition strategy to reduce berthing delays and idle berths at container terminals considering different mixtures of terminal ownership types

Objective [4.2]: To understand the coopetition behavior among terminal operators in one port with the objective of minimizing total berthing delays or maximizing total profit of the port considering policy scenarios

Chapter 5: Impacts of ports and terminals coopetition at the inter-port level

Objective [5.1]: To analyze the potential competitive scenario between Colombo and Hambantota ports in Sri Lanka

Objective [5.2]: To understand the coopetition at the inter-port level considering the involvement of a global terminal operator and the port authority with Colombo and Hambantota ports in Sri Lanka

1.5 Dissertation Framework

This section explains the structure of this dissertation in chapters-wise as illustrated in Figure 1.11. Accordingly, Chapter 1 introduces the background, basic concept of coopetition, objectives of the study, dissertation framework as well as the motivations, contributions, and limitations of the study. Thereafter, Chapter 2 explains the summary of the literature review to emphasize the existing research gap and the positioning of the current study. Subsequently, we have three main analysis chapters, each focusing on different aspects of the coopetition at the intra-port and inter-port levels as summarized below. Finally, Chapter 6 provides the conclusion with a summary of significant findings, policy implications and the directions for future research.

Chapter 3: Impacts of intra-port coopetition on external competitors

Chapter 3 proposes an intra-port coopetition strategy, which simultaneously characterizes both competition and cooperation among terminal operators in a port when competing with operators from external ports. Terminal operators make cooperative efforts to increase the entire port competitiveness, while simultaneously making competitive efforts for the price adjustment, operation cost reduction and time efficiency improvement at individual terminals. Numerical analysis is performed considering private and public terminals characterized by different extents of profit and social surplus maximization objectives. A multi-periods non-linear optimization model is formulated to analyze the coopetition strategy between two terminal operators in a given port. The Objective [3.1] analyzes the coopetition decision of a single terminal operator with various market dynamics and the Objective [3.2] discusses the coopetition strategy between two terminal operators considering different combinations of terminal ownership types associated with them. Thus, significant implications associated with the proposed intra-port coopetition strategy are discussed considering the variations in resulting price, cost, profit, and marketing share, among other, of terminal operators and ports with eleven different cases under consideration.

Chapter 4: Intra-port coopetition strategy with a vessel transfer policy among container terminal operators in a single port

Chapter 4 focuses on enhancing the port competitiveness with minimizing berthing delays and congestion at container terminals with a coopetition strategy proposed to the intra-port level. As per the proposed strategy, terminals have competitive interactions in the contract stage, where they initially negotiate with shipping lines to obtain more vessel calls toward own terminal. However, their cooperation with a vessel transfer policy in the operational stage enables vessel transfers between two terminals if one terminal has idle berths and the other has excess vessel calls, simultaneously. The effectiveness of coopetition is assessed in comparison to an extreme competition case, where terminals have only competitive interactions during both contract and operational stages. As the Objective [4.1], the effectiveness of the coopetition strategy is evaluated with a game theoretical decision-making approach in the context of individual rationality and as a case study for the Port of Colombo. The minimum satisfying condition for executing the coopetition strategy is derived from the different combinations of terminal operators. As the Objective [4.2], the coopetition behaviors of terminals are analyzed with two alternative objectives, "minimizing total penalty cost related to berthing delays" and "maximizing total profit" of terminals in one port. Thus, a mixed-integer programming model is formulated and different policy scenarios are analyzed considering the port authority and terminal operators in the Port of Colombo. The reductions in the occurrences of berthing delays and the total delay hours are discussed as the results from the coopetition strategy while emphasizing the benefits of coopetition strategy on enhancing port competitiveness.

Chapter 5: Impacts of ports and terminals coopetition at the inter-port level

Chapter 5 aims to expand the coopetition into the inter-port level considering the involvement of a GTO and a port authority with two competing ports. Therefore, Objective [5.1] focuses on analyzing the potential competition between Colombo and Hambantota ports in Sri Lanka considering only the port level analysis. Both the domestic and transshipment container cargo flows are analyzed, using two different generalized cost functions associated with them while discussing the directions for Sri Lanka's port developments and policy implications. The impacts from limiting slot capacity from liner services at Colombo, transport infrastructure development for Hambantota port, and ports' charges and efficiencies are discussed by considering local shippers and consignees, shipping lines, and the port authority. The Objective [5.2] discusses the involvement of a GTO with Colombo and Hambantota ports, considering the availability of its own terminals in both ports. Besides, the behavior of the port authority who has both the own public terminal and the private terminal, operated by a GTO in the same port is analyzed. Significant implications are discussed considering a terminals' pricing strategy of a GTO and port authority, while the impacts on both the terminal and port levels are analyzed with a multi-period decision-making model.

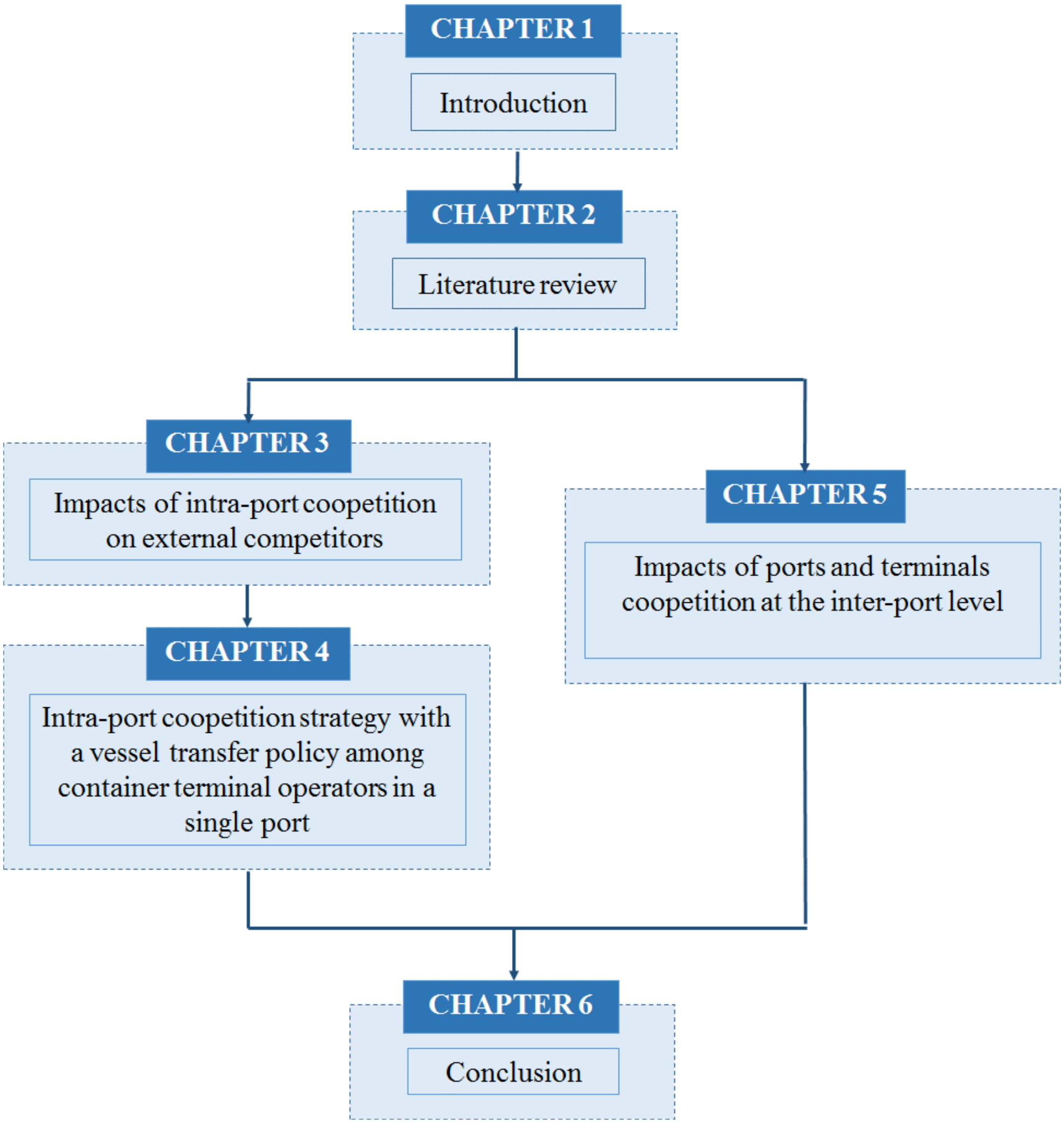

Figure 1.11. Dissertation Framework

1.6 Scope and Limitations of the Study

This study focuses on both the intra-port and inter-port levels analysis considering the interactions among ports and terminals. However, Chapter 3 mainly focuses on the theoretical contribution since it is one of the very first studies to propose the intra-port coopetition. Therefore, we employ a hypothetical budget allocation scenario with numerical analysis to understand the simultaneous competitive and cooperative interactions among terminals, which may not fully represent the current industry practices. Besides, the model development in each chapter follows several assumptions to eliminate the influences from complicated industrial practices related to the inter-organizational relationships such as dedicated terminals given for shipping lines (Haralambides et al., 2002), behavior of liner-owned terminals, and nature of shipping lines alliances, among others, because the scope of this study is limited to a competitive market setting, where terminals and ports are competing to attract more vessel calls from shipping lines towards themselves. Owing to the same reason, the shipping lines are assumed to choose a port service provider based on their generalized cost without considering any inter-organizational relationships, therefore the total market demand is distributed among its competing ports/terminals based on the choice model. Besides, to eliminate the impacts from external market changes, several analyses are done assuming fixed total market demand with multiple periods implying a stable market size. However, market growth and decline scenarios and sensitivity of market size are analyzed only in a few cases to discuss significant implications. Since a major contribution of this study lies in the model development and applying by proposing the coopetition, it is not possible to estimate some parameters with the real industrial data because these proposed strategies are not yet being practiced in the current industry. Besides, considering the novelty of the study with the conceptual framework of coopetition, we derive conclusions based on the variations of significant results drawn from a similar exact optimization tool/algorithm applied for multiple cases rather than developing new heuristic optimization algorithms.

Besides, since Chapter 4 and Chapter 5 discuss the implications associated with the proposed models based on the data collected from relevant case studies, these findings are highly applicable for those case studies under consideration. However, the proposed models and strategies can still be applied in another context or case study with similar circumstances. Moreover, the models are analyzed with a simplified market setting to eliminate the impacts from external competitors that are located beyond the case study area under consideration. Apart from the data collected during the interviews and questionnaire survey, some policy scenarios are analyzed with several assumptions to understand the related implications.

1.7 Contributions of the Study

The contributions of this study can be discussed in two aspects, such as contributions to the literature and academia related to the liner-shipping industry and the contributions to the industry, policymakers, and practitioners. First, this study makes a significant contribution to the literature on ports and terminal operators and their interactions by proposing different coopetition strategies as a new way of interaction. Moreover, this study fulfills the research gap on interactions among port operators with different ownership types, multiple objectives, behavior of global terminal operators, decision-making with multiple periods, and simultaneous considering of port and terminal levels analysis, among others, which can be considered as vital additions to the literature due to the lack of previous studies on these aspects.

Secondly, this study has significant contributions to the practitioners and the industry owing to the detail discussions on the implications associated with coopetition by considering very compelling case studies. Moreover, several analyses are done with actual vessel handling data of container terminals, perception-based survey data with shipping lines, and the interviews with the port authorities and terminal operators as well to enhance the applicability of the results in the practical context. Besides, this study proposes new strategies and approaches for the port service providers considering the challengers given by the industry, thus the results are significant for port service providers to withstand in the market. To this end, this study is a vital addition to describe on how to respond to the globally mounting challenge of port usage. In a world that is progressively in need of such solutions, this study creates immense value for every actor involved: policymakers, port service providers, port customers as well as all agents engaged in vessel operation at ports and terminals.

CHAPTER 2: LITERATURE REVIEW

2.1 Changes in Port/ Terminals Administration and Ownership Structures

Since this study considers the different ownership types of ports and terminals when analyzing the coopetition, the previous studies related to the similar contents are summarized here. A port can be governed by a public or private organization and the objectives and operating principles of a port could be varied depending on its ownership type (Fawcett, 2007). As per the Baltazar and Brooks (2001), governments in several countries tend to transfer their responsibility for port operation and management from the public sector to the private sector. Moreover, Baltazar and Brooks (2001) discuss a port devolution matrix, which categorizes the port governance into three groups such as public, mixed and private governance. Besides, they categorize functions related to a port into two groups namely; regulatory functions and port functions. First, the regulatory functions include licensing, monitoring, customs, policy formulations for security and environmental protection, among others. Second, the port functions are further grouped into two sub-categories such as the landlord port functions including maintaining waterside, port access, port security, and acquisition of land, among others, and the operator function including cargo handling, marketing, and pilotage, among others. However, depending on the ownership and governance structure of a particular port, these regulatory, landlord and operator functions can be transferred from one party to another (Brooks, 2004).

However, the port administration and governance can be influenced by multiple factors such as socioeconomic aspects of the country, location of the port, port's history and development, and the cargo type, among others (The World Bank, 2007). Thus, an alternative approach to the port administration models is proposed by the World Bank (2007) with its port reform toolkit. They discuss four different models on the port administration namely; public service port, tool port, landlord port, and fully privatized port, while considering the changes in port governance over time. The governance and operation functions of a public service port are carried out by the public entities. In the case of a tool port, although the majority of port functions are carried out by the public entities, a tool port utilizes private labors as the main difference from a public service port. However, both the public service port and the tool port usually aim to satisfy the public interests as their main objective rather than focusing only on individual commercial interests. Alternatively, a landlord port model aims to balance the interests of public and private (industry) sectors by focusing on both the profit and non-profit objectives. Although a public port authority still acts as the regulator and policymaker of the landlord port, the cargo handling functions are carried out by the private terminal operators. Therefore, the port authority offers the port infrastructures to the private companies, who will build and maintain their own superstructures to carry out port operation functions. Mostly, there is a concession agreement such as built-operator-transfer between the port authority and the private terminal operator, which usually requires a private operator to pay a fixed annual rent based on the concession agreement and a variable terminal fee depending on the cargo volume handled at the terminal, to the port authority. However, the landlord port model is considered as the most dominant port governance model in the current context, and most of the public service ports and tool ports are transforming into the landlord port model. Lastly, the fully privatized port model is considered as an extreme level of privatization, where all infrastructure, superstructure and port labors are provided by the private sector. Thus, a fully privatized port usually focuses on maximizing profit as the main objective. However, this study mainly focuses on the landlord port governance model considering its high applicability in the current industrial context and the advantages of having both the profit and non-profit objectives. Apart from that, the public service ports and fully privatized ports are also considered in several scenarios in later chapters of this dissertation to understand the implications from different ownership structures to the coopetition concept. Moreover, the transformation of port governance models from public service ports to contemporary land-lord or private ports encourages the multifaceted interactions among the market players especially owing to the different terminal ownership types co-existed in the same port. However, the lack of previous studies on analyzing these terminals and ports interactions with their different ownership types, emphasizes the significance of this study.

Considering the terminal operator aspects, Ng et al. (2019) analyze the relationship between the space and institutional changes as a case study on Hong Kong International Terminal. They investigate the development of Hong Kong International Terminal as a global player in container terminal operation by accessing its evolution with the time, regional expansion and also the changes in institutional, operational and management factors. Moreover, Munim et al. (2018) analyze the impacts from port governance models, and the possible outcomes with the transformation to the landlord port from the tool port, as a case study on two selected ports in Bangladesh; Chittagong and Mongala. As per the results, the port authority obtains the highest profit while creating a high user surplus by privatizing only one container terminal, although a low level of user surplus is generated by privatizing both terminals.

2.2 Competition and Cooperation at the Inter-Port Level

Since this study focuses on the coopetition, which characterizes both competition and cooperation, the perspectives given by previous studies on competition and cooperation at the inter-port level are discussed here. Accordingly, Van de-Voorde and Winkelmans, (2002) discuss the inter-port competition at the operator level and at the port authority level, with the aim of achieving individual targets of the ports as a whole while competing with other ports in the same market. Although previous studies analyze the inter-port competition at the port authority level, most of them do not quantitatively analyze the interactions at the operator level. Chapter 3 of this study analyzes the impacts of coopetition on the external competitors that are located in different ports, considering interactions at the terminal operator level and Chapter 5 analyzes the interactions at the inter-port level considering both the port authority level and the terminal operator level.

In terms of previous studies on the inter-port competition at the port level, the competition between the Port of Colombo and the major ports in Southeast Asia is analyzed by the Kavirathna et al. (2018.a). They incorporate a discrete choice model to estimate the market share of hub ports in transshipment container handling from the Indian sub-continent feeder market and competition is analyzed for hub and spoke and relay networks, separately, to understand the significant role of hub ports in terms of both network types. Besides, Twrdy and Batista (2014) discuss competition/ cooperation among Northern Adriatic ports while incorporating three different container throughput characteristics given as relative growth, market share and container shifts among ports. They analyze port container throughputs from 1990 to 2013 and develop a model to estimate their expected growth. As per the results, different absolute growth factors of container throughput and container shifts among the Northern Adriatic ports are observed and also asymmetric cooperative/competitive relationships are identified among several ports. The competition between two ports; Busan and Kobe with the effect of changing port charges and port capacities is analyzed by Ishii et al. (2013) with a game-theoretical approach. The results emphasize the significance of port charges on a competitive market, which has a high demand elasticity because a loss of the profit and the market share by one market player is observed due to the setting of its port charges higher than the equilibrium level. Besides, Hoshino (2010) discusses the competition and collaboration among ports and suggests strategies for minor ports in Japan to sustain the huge competition placed by ports in China and Korea. Accordingly, the study discusses the significance of collaboration among minor ports with their neighboring ports rather than competing with each other for better survival, if they are located close to the regional hub centers. According to the Oliveira and Cariou (2015), who apply a truncated regression with a parametric bootstrapping model with 200 container ports, the port efficiency is decreased when increasing the inter-port competition at the regional level (400-800km), but not significant at the local (less than 300km) or global (more than 800km) level. As per the previous studies, both the competition and cooperation approaches can be adopted by the ports depending on the market dynamics.

Incorporating different analysis tools such as correlation analysis and logistics regression model, the competition and cooperation between Shanghai and Ningbo-Zhoushan ports are discussed by Li and Oh (2010). As per the results, the competition among ports is observed not only within the domestic context but also with the counterparts in other countries and it is difficult for ports to cooperate with each other due to the unique competitive advantages associated with them. Further, to identify the competitive dynamics among major East Asian ports with the trade development in China, Yap et al. (2007) analyze the growth of ports' market share, vessel sizes, slot capacities, and investment, among others. Moreover, their analysis of liner services data from 1995 to 2001 implies the nature of increasing attractiveness of Chinese ports as direct calling ports for mainline services than the ports in Japan and Taiwan. As per the Bae et al. (2013), a monopolistic nature of the market created with a port coalition scenario may result in a theoretically infinite port price and the port of call decision of a shipping line attempts to minimize the operation and congestion cost at the port while maximizing the profit of shipping lines. By analyzing the liner services and their calling patterns within the Pearl River Delta in South China, Lam and Yap (2011) discuss the existence of complementary relationships at the inter-port level in addition to the competitive relationship. Veldman and Buckmann (2003) discuss the competition among hub ports in the Western European region while quantifying port's routing choices with a logit model. The cost, transit time, frequency and quality of service, among others are used as explanatory variables and the traffic forecasting and economic and financial evaluation of container ports' projects are done with the derived demand function while describing the routing choices and port choices under a large decision-making framework.

The port competition and network polarization in the East Asian maritime corridor are analyzed by Ducruet et al. (2011) from the maritime network perspectives. The study incorporates the network indicators such as maritime degree, and betweenness centrality, among others to understand the polarization and interdependencies among the East Asian ports. Further, focusing on Southeast Asian ports, Lam and Yap (2008) conduct the slot capacity analysis using the shipping trade routes data from 1999 to 2004. As per the results, the transshipment performance of Singapore port has been negatively affected by the competition given by the port Keland and Tanjung Pelepas. Despite that, the dominant position is still maintained by the Singapore port as the primary transshipment hub in the region. The impact of the growth of Chinese ports on the port of Singapore is analyzed by Tongzon (2011) with an ordinary least squares analysis, which utilizes data from 1995 to 2007. As per the results, although the Shanghai port has overtaken the position of Singapore port by being the world busiest port, the performance of the Singapore port has not been negatively affected. Importantly, the positive impact on the Singapore port from the growth of Chinese port is observed from the results, although such complementary relationship may turn into a competitive relationship in the future depending on the changes in port selection factors. Do et al. (2015) apply the game theory and uncertainty theory for analyzing competition between Hong Kong and Shenzhen ports by considering their competitive strategies in terms of long-term investments in port capacities. As per the results, the dominant position of Shenzhen port in capacity investment is revealed, thus it will continuously develop container cargo throughput and possibly surpass the Hong Kong port in the near future. Thus, previous studies emphasize the changes in the role and position of individual ports in the global maritime network with time.

Focusing on regional port integration as a case study on Ningbo-Zhoushan port, Dong et al. (2018) apply a game-theoretical approach such that each port sets its container throughput considering the port integration effort in the multiport region. As per the results, the lower handling charges and larger container throughputs result from a higher degree of port integration. Moreover, Yang et al. (2019) analyze the integration among ports in a multiport gateways region while discussing the industry transformation and upgrades of ports with overcapacity. Moreover, they suggest the optimal scale for the port cluster with a proposed model. The modified hoteling model is utilized by Zhou (2015) for understanding the ports' motivation for the formation of alliances, which allow them to capture a greater market share. Ignatius et al. (2018) utilize a game-theoretical approach to analyze the possible ways of competition or cooperation among major ports in Malasia; Kelang and Tanjung Pelepas and the Singapore port, which can generate a higher benefit on the entire port region. According to the results, the cooperation between Singapore and Tanjung Pelepas ports derives higher profitability and it is not advisable for either Singapore or Tanjung Pelepas ports to have such cooperation with the Port Kelang. Considering the cross-border transportation issues to serve two landlocked countries in South Asia, Nepal and Bhutan, the competition and cooperation among ports in Bangladesh and India are analyzed by Munim and Haralambides (2018). As per the results from their mixed-integer linear programming optimization model, the port users can be benefited from the ports' cooperation owing to the transportation cost reduction despite the revenue loss experienced by the Kolkata port authority in India. Thus, the cooperation or integration among ports may create positive impacts on different market players but it may not possible to generate higher benefits for all stakeholders of ports, simultaneously.

Focusing on the East Asian region, the competitive dynamics among ports are analyzed by Yap and Lam (2006), which also discuss the impacts of China's development in terms of ports and shipping industry. The study utilizes the container throughput data from 1970 to 2001 for a time series analysis and the long-term relationships among ports are examined with co-integration tests while determining short-term dynamics among ports with error correction models. Incorporating cost components associated with both the hinterland shipments and transshipments, the competition between two ports is analyzed by Song et al. (2016). They incorporate a transport chain perspective into the competition analysis while including port charges, transport costs associated with the deep-sea segment, hinterland segment, as well as the feeder segment of the entire network. A non-cooperative game model is formulated to discuss the optimal decision on port charges and port of calls of shipping lines and the results of the developed model are discussed as a case study with Southampton and Liverpool ports, which highlights the possibility of each port in attracting a fraction of market demand. Moreover, Notteboom (2010) discusses the concentration among ports and the formation of multi-port gateway regions focusing on the European container port system. Accordingly, regardless of the gradual de-concentration trend, the container handling market has a comparatively higher level of concentration than the other cargo handing segments in Europe, owing to the strong market-related incentives given for maintaining a high level of cargo concentration in the container business. Thus, depending on the geographical context, the effect of port competition and cooperation can be changed.

Besides, considering the shipping lines context, Song et al. (2002) analyze the rationale behind the formation of liner shipping alliances by incorporating cooperative game theory. According to the results, the possibility of pursuing the benefits from an economic point of view is considered significant for the survival of most liner shipping companies and alliances. Moreover, the instability of alliances is discussed when shipping lines give high significance on the individual revenues. The competition between shipping lines is analyzed by Wang et al. (2014) incorporating a game-theoretical approach. Their results highlight the benefits of expanding vessel capacity to meet the required capacity provision rather than increasing service frequency owing to the economics of scale advantages with low marginal cost. However, these cooperative strategies discussed in previous studies such as the formation of alliances and expanding vessel capacities by shipping lines, among others create significant challengers on the port service providers (Notteboom et al., 2019).

Therefore, previous studies discuss the advantages and disadvantages of both inter port competition and cooperation depending on the different market settings. As the main advantages of inter-port competition, it can increase the port efficiencies because ports are motivated to have high operational performances to attract a greater number of customers. However, when ports are located close proximity to each other especially in the case of ports in a multi-port gateway region, cooperation among ports may create advantages because they can increase the competitiveness of the entire region with an effective cooperative arrangement. However, the extreme level of cooperation or coalition may not create benefits for the port users due to the possibility that port service providers would create a monopolistic power. When considering the country level, cooperation among a few ports in the same country would be effective when competing with competitors from other countries.

2.3 Competition and Cooperation at the Intra-port Level

Since this study also analyzes the interactions among terminal operators located in the same port, the previous studies related to the intra-port competition and cooperation are discussed as follows. In terms of intra-port cooperation, the possible ways of cooperation including several partial coalitions and one grand coalition among container terminal operators in Karachi port are analyzed by Saeed and Larsen (2010) incorporating a game-theoretical approach. As per the results, owing to the higher price level of terminals under coalition than the price of external competitors, the external competitors can obtain larger market shares while acting as an orthogonal free rider to receive more benefits from the coalitions among its competing terminals. Thus, it is not advisable to have extreme cooperation or coalitional behavior at the intra-port level due to the high price sensitivity of the market. Despite this, the cooperation among terminal operators in one port has several advantages such as better utilization of terminal facilities by sharing and collaborations, relatively fewer negative externalities such as emission and congestion, and high market power over customers, among others. As the advantages of intra-port competition, De Langen and Pallis (2006) discuss several aspects such as the terminals' motivation on innovation and specialization owing to the high competition, fewer entry barriers, and fewer opportunities on rent extraction behaviors of port service providers due to the availability of several competing service providers, among others. The regional port competition considering a dual gateway port system is analyzed by Yu et al. (2016) by adopting a hotelling game model for two competing ports and two terminals operated under each port. As per the results, although the government prefers the competition among terminals, the concentration among terminals generates more profits to the terminal operators when the absence of competitive advantages related to the individual terminals.

Moreover, a theoretical framework on evaluating the competition among container terminal operators is proposed by Yap et al. (2005), which emphasizes on advantages with maintaining complementary relationships among terminal operators because it can stimulate the demand of the entire market while creating more benefit to the industry as a whole. Besides, the study reveals that the long-run competitive advantages can be reduced owing to the coalition behaviors among terminals and the promotion of entry barriers. Moreover, a study of Yuen et al. (2013) on investigating the impacts of foreign and local ownerships on the efficiency of container terminals in China highlights that both the intra-port and inter-port competition can enhance the efficiency of container terminals. Thus, in terms of intra-port interactions, previous studies discuss both the advantages and disadvantages associated with competition and cooperation among terminal operators in a single port. Therefore, to incorporate the advantages and to minimize the disadvantages associated with both the competition and cooperation at the intra-port level, we propose the coopetition to the intra-port level with different approaches with Chapter 3 and Chapter 4 of this study.

2.4 Coopetition in General

Since this study focuses on the coopetition among market players, it is significant to understand the previous studies related to the coopetition in general. As emphasized by Rai (2016), coopetition involves many industries while about half of the inter-firm collaboration occurs among the competitors in the same industry. Four genetic drivers of coopetition-based business models are discussed by Ritala et al. (2014); namely, the increasing size of the current markets, creating new markets, increasing efficiency in resource utilization, and improving the firms' competitive position. This study elaborates on the coopetition-based business model of Amazon.com related to their online store which allows customers to choose a product offered by Amazon or another seller (a competitor of Amazon) from the same website. Illustrating industrial examples, Gnyawali and Park (2011) discuss the coopetition between two dominant market competitors, Sony and Samsung on innovating LCD panels for producing flat-screen TVs. This study emphasizes that coopetition is helpful for addressing the major technological challengers while creating benefits for partnering firms. Yami and Nemeh (2014) discuss the coopetition for innovation in the wireless telecommunication sector in Europe, which suggests that the “dyadic coopetition” which exists only between two competitors is successful for incremental innovation and the “multiple coopetition” which exists among multiple competitors is successful in radical innovation. Therefore, coopetition occurs among two or more market players and has advantages especially with technological innovation.

As per Bouncken et al. (2018), the market overlap situation with coopetition can increase the possibility of value capture by firms, hence coopetition with horizontal alliances create more benefits. However, only the formation of coopetition is not sufficient, because firms should consider value creation approaches with coopetition to ensure the possibility of value capture. Gnyawali and Park (2009) discuss three main reasons for considering coopetition in high-tech industries; short product life cycle, technology convergence and high cost required for research and development. Besides, Park et al. (2014) discuss the implications of coopetition on innovations performance, where a moderate level of competition with alliance partners is proposed as beneficial for them than a very high or low level of competition. Moreover, their empirical analysis with the semiconductor industry founds a non-monotonic positive relationship of competition and cooperation intensities with the firm's innovation performance derived from coopetition. Moreover, Kafi and Ghomi (2014) emphasize the trends in employing coopetition among supply chain partners to create value and their mathematical analysis suggests that coopetition is preferred over the pure competition in terms of profitability. Moreover, Gnyawali and Park (2009) discuss the applicability of coopetition to small and medium-sized enterprises, to reduce vulnerability in the challenging business environment. Accordingly, these small and medium-sized enterprises have challenges with limited resources, limited research and development, and investment risk, among others. Therefore, the coopetition is proposed for the technological innovation of a group of enterprises with their combined cooperative approach although they are competing in the market. Therefore, the implications of coopetition are different depending on the market context because the approaches of value creation and value appropriation are different from one case to another.

Furthermore, Bengtsson and Kock (2000) argue that coopetition is the most complex but also the most advantageous relationship among competitors and the complexity of coopetition comes due to the presence of fundamentally different and contradictory logic of interactions simultaneously. This study elaborates coopetition with industry examples such as cooperation on material development while competing on product development by firms in the lining industry, and the cooperation on empty bottles handling while competing on full bottles selling in the brewery industry, among other. Therefore, previous studies have discussed the coopetition application in several industries considering examples and the advantages and complexity of coopetition interactions. The genetic drivers and significance of coopetition discussed by previous studies emphasize the motivation for applying the coopetition concept to the ports and container terminals in the liner-shipping industry as focused by our study.

2.5 Coopetition in the Liner Shipping Industry

Although the coopetition among terminal operators at the intra-port and inter-port levels are not discussed by the previous studies, several studies have discussed the coopetition among ports and shipping lines. The possible ways of coopetition among ports in Hong Kong and South China are analyzed by Song (2003) while discussing the right balance between the competition and cooperation and suggesting the need for a new form of interaction among ports to create a countervailing power. The transmission and development of ports from the direct competition to cooperation are discussed by Mclaughlin and Fearon (2013), who introduces a cooperation/competition matrix which analyzes the major types of port cooperation and major competitive dynamics associated with the maritime industry. Focusing on the Yangtze Delta region, Yan-Bo (2012) discusses the competition and cooperation between Shanghai and Ningbo-Zhoushan ports and suggests a coopetition strategy for integrating ports, which helps for distribution of port functions in a more rational way. Moreover, incorporating a game-theoretical framework, the coopetition among port clusters is analyzed by Dong (2011) and that is among the shipping service resources is analyzed by Dong (2015). According to their results, the optimal charges of service providers tend to increase when they move from perfect competition to cooperation, and an appropriate institutional arrangement is needed for maximizing the profit of the entire port cluster. Besides, the coopetition among ports in proximity is identified as an important driver on the port competitiveness by Parola et al. (2017). Accordingly, they emphasize that the coopetition among ports can create a shared brand name, which generates more advantages for all ports and also discuss the main reasons for ports' coopetition such as rationalization of port space and infrastructure, pooling of financial resources, and promotion through joint-marketing, among other.

Hwang and Chiang (2010) discuss the two types of interactions among ports, namely complementary cooperation and coopetition. Accordingly, the internal condition of ports, liner service, and the pricing strategies of ports are identified as significant for determining complementary cooperation and the internal management of the port, resource integration, pricing strategy, and liner services are identified as significant for the coopetition. Zhong et al. (2010) discuss the coopetition between Hong Kong and Shenzhen ports with the analytical hierarchy process and develop an index system about ports' coopetition abilities with the aim of maximizing the benefits of both ports. Considering the coopetition among shipping lines, Lin and Huang (2013) propose a theoretical framework, which investigates the behaviors of shipping lines with their changing business models. Besides, Lin et al. (2017) formulate a nonlinear mixed-integer problem to analyze the significance of having collaborative relationships among shipping lines, who also compete with each other to maximize their individual profits. As per the results, shipping lines tend to choose similar levels of coopetition to maximize their individual profits and the coopetition game reaches an equilibrium under the generalized condition. The possibility of competition and cooperation among the adjacent ports in Hong Kong and South China is discussed by Song (2002) while demonstrating the advantages of developing a strategic alliance among them in the form of collaborating to compete, especially considering the situation after Hong Kong became a part of China. Moreover, the possible areas of coopetition among ports are discussed by Fraunhofer CML (2016) such as port marketing, investment and planning, human resources, port traffic management, and environmental projection among others. Accordingly, the port service providers can have a cooperative approach to a common value creation, which generates a synergetic impact on improving port performance.

Therefore, previous studies have discussed the coopetition in terms of various approaches including functional allotments between ports, and arrangements between port authorities in a port cluster, among others, that can derive significant implications on the market. Moreover, these studies emphasize the significance of maintaining the right balance between pure competitive and cooperative approaches. Despite this, only a few studies have attempted to quantitatively analyze the impacts of coopetition among market players in the liner shipping industry. Regardless of the availability of several previous studies on coopetition focusing on shipping lines and port clusters, none of the previous studies discussed the coopetition among terminal operators at the intra-port or inter-port level, to the best of our knowledge, which emphasizes the significance of our study.

2.6 Selection of Ports and Container Terminals

Since the model development of this study incorporates the aspects of selecting container ports and terminals by shipping lines or shippers and consignees, it is significant to discuss the previous studies related to a similar context. Moreover, Chapter 5 considers a range of port selection criteria when estimating the transshipment cargo flows among the ports. In terms of previous studies on factors related to the container terminal selection in Europe, Saeed and Aaby (2012) utilize a factor analysis method and as per the results, loading/discharging rate, handling charges, service quality are identified as the most important factors for selecting container terminals. Moreover, factors such as personal contacts, investments by shipping lines and value-added activities are identified as the least significant factors. In terms of port selection criteria of shipping lines, terminal handling charge, berth availability, port location, transshipment volume, and feeder network, among others are identified by Chang et al. (2008) with a factor analysis method. Besides, the different perspectives between the mainline and feeder operators are identified, which indicate a higher price sensitivity on port services from mainlines than feeder operators. The study of Salem and El-Sakty (2014) on analyzing port selection criteria considering East Mediterranean ports utilizes the cost, location, depth, berth availability, equipment, infrastructure, and customs regulations, among others. Considering the significant role of a seaport as an element of the global supply chain, Wang (2011) discusses the port selection criteria from the perspective of the global supply chain. As per the results from the analytical hierarchy process, port location, feeder services, intermodal connections, size of the hinterland and port efficiency are identified as the most significant criteria.

To identify the significant criteria on selecting a transshipment hub port for both the hub and spoke and relay networks, Kavirathna et al. (2018.b) conduct a questionnaire survey with a sample set of shipping lies. As per the results, berth availability is considered as the most significant criterion for both networks and the criteria related to the feeder segment obtain higher significance in the hub and spoke case while the criteria including hub port accessibility and operational delays obtain high significance in the relay networks. Besides, the port selection in the Mediterranean Sea area is analyzed by Kurt al at (1999) with the analytical hierarchy process. Accordingly, the port location is identified as the key factor while factors such as proximity to main routes, liner shipping connectivity index, operation performance, port capacity, and investment on infrastructure development are identified as the other important factors. According to the Dyck and Wua (2015), port efficiency and performance, political stability, cargo volume, port location, port costs, and port infrastructure are identified as the significant criteria in port selection in the West African region. The port selection behavior in the Pearl River Delta region in South China is analyzed by the Wu and Peng (2013) with a multinomial logit model, which incorporates port choice and inland transport mode choice simultaneously. The port monetary cost, dwell time and intangible cost generated with intangible factors related to the port services are considered as the main factors of port choice. As per the results of Lirn et al. (2003), the proximity of the feeder ports, berthing delay and loading discharging rate, and loading discharging cost are identified as the important criteria in selecting a transshipment port by Taiwanese international container carriers. Besides, the port selection in Europe and Africa is analyzed by Ng (2006), and Gohomene et al. (2016), respectively, considering a range of criteria including costs, time efficiency, and port infrastructure.

Moreover, when selecting a gateway port by shippers and consignees, the significance of criteria is varied depending on the geographic context because the studies from different regions focus on different criteria (Aronietis et al., 2010; Grosso and Monteiro, 2008; De Langen, 2007; Ugboma et al., 2006; Wu and Peng, 2013). When considering different decision-makers, De Langen (2007) emphasizes the similar port selection aspects between shippers and forwarders, however, shippers indicate a comparatively less price-elastic demand. Thus, previous studies emphasize various port selection criteria depending on the different decision-makers and the geographical contexts, however, the majority of studies highlight the significance of port handling charges, handling time, port location, and operating efficiencies as the most significant criteria. Therefore, Chapter 3 and Chapter 4 focus on various strategies on reducing the cost of port users, enhancing time efficiencies by reducing berthing delays and waiting time, among others. Moreover, Chapter 5 of this dissertation combines various significant criteria on port selection discussed by previous studies into a port choice model, which estimates the transshipment and domestic cargo flows between Colombo and Hambantota ports in Sri Lanka. Besides, the model developments with Chapter 3 and Chapter 4 incorporate the most significant port selection criteria discussed by the majority of previous studies.

2.7 Optimizing Container Terminal Facilities

As one of the possible outcomes of coopetition, Chapter 4 focuses on optimizing container terminal facilities. Thus, it is important to distinguish the contribution of this study from the previous studies related to optimizing container terminal facilities. In terms of optimizing berth allocations at container terminals, several previous studies including Gudelj et al. (2010), Legato et al. (2014) and Moorthy (2006) attempt to minimize the operation cost at the terminals. Besides, owing to the significance of vessel handling time at ports on the port competitiveness, studies such as Chen et al. (2012), Imai et al. (2007), Wang et al. (2015) and Zhen et al. (2011) focus on minimizing total service time of vessels at ports. Considering the competition among ports in the liner shipping industry, shipping lines would expect more reliable services from port service providers with minimum delays. Therefore, several studies including Hansen et al. (2008), Kim and Moon (2003) and Zhen et al. (2011) focus on optimizing terminal facilities to minimize the tardiness cost at terminals, which is defined as the difference between actual and expected operation completion time of vessels at the port. Due to the growing environmental concern on emissions generated from container terminals, studies such as Hu et al. (2014), Du et al. (2011), and Peng et al. (2019), among other focus on minimizing the emissions and the fuel consumption at the container terminals.

Despite the availability of a number of studies on optimizing container terminal facilities, they purely focus on physical components mostly within a given terminal. However, as the main difference from previous studies, Chapter 4 of this study proposes a coopetition strategy to optimize the terminal facilities, which incorporates a collaborative approach on facility sharing among terminals in the same port in a congested circumstance. Moreover, since this study focuses on collaborative approaches among terminals with different ownership types, we formulate a model to analyze and discuss the practical implications associated with such collaborative approaches such as revenue sharing among terminals, terminal pricing, and terminal profits, among others, which are not focused by previous studies. Thus, the contributions of this study and related implications are different from those of previous studies.

2.8 Port Developments Issues

Chapter 5 of this study mainly focuses on the interactions at the inter-port level considering the involvement of a GTO and the port authority in two competing ports. Therefore, as the focused case study from Chapter 5, its first objective analyses the port competition issues resulted from port developments in Sri Lanka. To clarify the contribution of this study, the previous studies associated with port development issues are discussed here. Accordingly, Jung (2011) analyses the economic contribution given by Korean ports and highlights the failure of few port cities implying that the convenience of port cities that are readily available cannot confirm the high economic performance of those cities. To discuss the appropriate port development policies, Xiao et al. (2016) conduct a throughput estimation, which emphasizes the necessity of adding future capacities by constructing new waterways and berths, as well as other infrastructure. Besides, Yang et al. (2019) discuss the integration among ports in a multiport gateways region and the industry transformation and upgrades of ports considering their overcapacities. Moreover, they discuss the strategies for optimizing existing transportation systems in the region. Economic and financial evaluation of port development projects is discussed by Veldman and Buckmann (2003) with forecasting container traffic with their derived demand function. Thus, as discussed by previous studies, the impacts of port development are greatly decided by the practical context, especially the factors related to the countries, where the ports are located. A study from Wilmsmeier et al. (2011) on the port development in Uruguay discusses the influence of regional characteristics such as geographical, functional and operational aspects on port development. Moreover, the success or failure of development strategies on regional hub port is discussed, while considering the impacts from liner service networks to define the role of a port in the regional port system. Besides, the economics of scale in transportation, port infrastructure, and port connectivity are identified as the determinants of port development.

Although the implications of port development are discussed by previous studies, they are varied based on the geographical context. Moreover, the port ownership and management and their changes with the time would have a significant influence on the port development aspects. Besides, the port development issues can have different impacts on the shipping lines and the local shippers and consignees of the country depending on the practical context and each port would have distinct roles in the domestic import/export market as well as the transshipment market. Considering the lack of previous studies on those aspects of port developments, our study makes a significant contribution by analyzing them with a quantitative modeling approach. Chapter 5 analyzes several scenarios considering the port developments with different ownership types to provide recommendations on the current port development projects and active discussions on port development issues in Sri Lanka.

2.9 Research Positioning

After summarizing the previous related literature, next, it is important to clarify the significance of our study by considering its positioning with the current research gap. This study focuses on coopetition at both the intra-port and inter-port levels, which are not discussed by previous studies. In each chapter, we develop models on analyzing the coopetition considering the different scenarios, which are not addressed by previous studies. The positioning of the current study with respect to the previous studies is illustrated in Table 2.1. Accordingly, a number of studies focus on the coopetition in port clusters and few studies focus on coopetition among shipping lines. However, in Chapter 3, we develop a model for analyzing the coopetition among terminal operators in one port, when competing with external ports and terminals. Despite the several previous studies available on coopetition, none of them focuses on coopetition at the intra-port level and its impacts on the external competitors, neither with quantitative or qualitative approaches to the best of our knowledge. Besides, Chapter 3 discusses the coopetition with different terminal ownership types, which are not discussed in most previous studies related to the competition and cooperation analysis as well. Moreover, various objectives associated with public terminals are discussed with different extents of profit and non-profit focuses, which are not discussed by previous studies. Only a few numbers of previous studies focus on the competition and cooperation at the intra-port level, which are discussed as a part of the coopetition strategy in our study. Since we incorporate the advantages and minimize the disadvantages related to the competition and cooperation, the implications related to this study are different from those of previous studies.

Although extensive number of previous studies focus on competition and cooperation among ports, the Chapter 5 of this study analyzes port competition in terms of both the domestic and transshipment container handling, separately, to discuss the impacts from transshipment cargo flow on the local shippers and consignees in a country where the majority of container ports' throughput is represented by transshipment cargo, as the main difference from the previous studies. Besides, Chapter 5 also analyzes the interactions among market players considering both the port and terminal levels, simultaneously, which is not discussed in previous studies. By analyzing the decision-making behavior of the port authority with multiple objectives including the total user surplus maximization generated from two competing ports, and discussing the functional allotments between ports with their distinct roles, this study discusses the coopetition at the port level as well.

Table 2.1. Research Positioning with Competition, Cooperation and Coopetition Studies

Focus of studies		**Competition**	**Cooperation**	**Coopetition**
Ports		Bae et al. (2013), Chang et al. (2008), Ducruet et al. (2011), Ishii et al. (2013), Kavirathna et al. (2018a, 2018b), Koi (2006), Lam and Yap (2008), Twrdy and Batista (2014), Yap et al. (2007), Yap and Lam (2006), Song et al. (2016), **[Current Study]**	Dong et al. (2018), Hoshino (2010), Lam and Yap (2011), Li and Oh (2010), Mclaughlin and Fearon (2013), Munim and Haralambides (2018), Zhou (2015), Yang et al. (2019)	Dong (2011), Dong (2015), Hwang and Chiang (2010), Mclaughlin and Fearon (2013), Parola et al. (2016), Song (2003), Zhong et al. (2010), Yan-Bo (2012) **[Current Study]**
Terminal Operators	**Intra-Port**	De Langen and Pallis (2006), Saeed and Larsen (2012)	Munim et al. (2018), Saeed and Larsen (2012)	**[Current Study]**
	Inter-Port	**[Current Study]**	**[Current Study]**	**[Current Study]**
Shipping Lines				Lin and Huang (2013) Lin et al. (2017)

In Chapter 4, we propose a coopetition strategy among terminal operators in one port to minimize delays and congestion at container terminals as a vessel transfer arrangement among them. To clarify the positioning of this study, several previous studies associated with optimizing container terminal facilities are summarized in Table 2.2. As the main difference, although most previous studies aim to enhance the performance of a given terminal by optimizing its physical components, the coopetition strategy proposed in Chapter 4 aims to enhance the performance of the entire port while simultaneously ensuring that each terminal will be better off from the proposed strategy. Despite the availability of previous studies on optimizing container terminal facilities, they have not considered the practical implications associated with vessel transferring between different terminal operators who act as individual economic entities, which is addressed by our study. Besides, none of the previous studies consider the impacts of coopetition with an operational level strategy as discussed in this study. Chapter 4 also incorporates the aspects related to the terminal ownership types, and revenue sharing among terminals, which are not focused by previous studies related to the optimizing terminal facilities.

Table 2.2. Research Positioning with Studies on Optimizing Container Terminal Facilities

Focus and Objectives		**Literatures**
Individual terminal	Minimize operation cost	Gudelj et al. (2010), Legato et al. (2014), Moorthy (2006)
	Minimize total service time of vessels	Chen et al. (2012), Golias (2009), Imai et al. (2007), Imai et al. (2008), Wang et al. (2015), Zhen et al. (2011)
	Minimize operation delays	Hansen et al. (2008), Kim and Moon (2003), Zhen et al. (2011)
	Minimize emissions	Du et al. (2011), Hu et al. (2014), Peng et al. (2019)
Entire port	Minimize total delays	**[Current Study]**
	Maximize total profit	**[Current Study]**

Table 2.3. Research Positioning with the Market Players and Objectives Focused by Studies

Market Players		**Objectives and interests**	**Literatures**
Port Authority		Profit	Bae et al. (2013), Dong (2011), Dong et al. (2018), Do et al. (2015), Ignatius et al. (2018), Ishii et al. (2013), **[Current Study]**
		User surplus, Social surplus	Munim and Haralambides (2018), **[Current Study]**
Terminal Operator	Private	Profit	Saeed and Larsen (2010), **[Current Study]**
	Public	Profit	Saeed and Larsen (2010), Munim et al. (2018), **[Current Study]**
		User surplus, Social surplus	**[Current Study]**
	GTO	Total profit or demand of terminals under GTO	**[Current Study]**
Shipping lines		Generalized cost of ports and terminals	Bae et al. (2013), Kavirathna et al. (2018.a), Ng et al. (2019), Veldman and Buckmann (2003), **[Current Study]**
		Factors on port selection	Chang et al. (2012), Gohomene et al. (2016), Kavirathna

		et al. (2018.b)
Shippers and consignees	Generalized cost of gateway ports	Wu and Peng (2013), **[Current Study]**
	Factors on port selection	Aronietis (2010), Dyck and Ismael (2015), Gohomene et al. (2016), Grosso and Monteiro (2008), De Langen (2007)

This study proposes coopetition strategies in the form of multi-periods decision-making models in each chapter while considering various objectives and ownership types of decision-makers as summarized in Table 2.3. Since most previous studies have not focused on multiple objectives such as profit, social surplus and user surplus maximization, this study analyzes decision-making with multiple objectives associated with the port authority and terminal operators. Although none of the previous studies analyze the different ownership types such as public terminals, private terminals, and global terminal operators, among others, this study considers decision-making with those ownership types as well. When considering the shipping lines, their generalized cost in using container terminals and ports are analyzed in Chapter 3 and Chapter 5. Moreover, the generalized cost of local shippers and consignees in using gateway ports for import and export cargo handling is analyzed in Chapter 5.

2.10 Summary of Chapter 2

This chapter reviewed and discussed the related previous studies to clarify the current research gap and the positioning of this study. Accordingly, a majority of previous studies considered case study-based approaches in analyzing competition or cooperation among ports thus results depend on the particular case study under their consideration. Moreover, a very limited number of studies focused on competition and cooperation at the intra-port level. These studies discussed both the advantages and disadvantages associated with competition and cooperation among ports and container terminals, which motivate us to propose a new type of interaction such as coopetition between these two extreme approaches. Moreover, the previous studies highlighted the current research gap on coopetition among terminals at the intra-port and inter-port levels. In terms of ports and container terminal selection, previous studies considered different selection criteria depending on the focused geographical area and the decision-makers such as shipping lines, and shippers and consignees, among others. Besides, we reviewed the previous studies on optimizing container terminal facilities, which clarify the lack of studies on enhancing the performance of the entire port by collaboration among terminals in one port. Moreover, the previous studies did not discuss the ownership types and objectives of decision-makers and did not consider both the terminal and port levels, simultaneously. To this end, this study is a vital addition to the existing literature on interactions among the ports and container terminals.

CHAPTER 3: IMPACTS OF INTRA-PORT COOPETITION ON EXTERNAL COMPETITORS

3.1 Introduction

Since this study focuses on interactions among ports and terminals, this chapter introduces an approach to balance the competitive and cooperative interactions among terminals in one port, especially when competing with terminals from external competitive ports. As emphasized from the current research gap in Chapter 2, this is one of the very first studies to propose the coopetition among terminal operators in one port, which is defined as the intra-port coopetition. Therefore, this chapter focuses more on the theoretical contribution by introducing the intra-port coopetition strategy, which can effectively incorporate the advantages associated with both the competitive and cooperative interactions among terminal operators. As mentioned in Chapter 1, coopetition presents both cooperative and competitive interactions simultaneously to represent the common value creation and individual value appropriation, respectively. Therefore, it has great advantages to the intra-port level because of the common interests among terminal operators in one port on enhancing the entire port competitiveness, which can be represented as the common value creation with their cooperative interactions and the individual interests on enhancing own terminal performance, which can be represented as the individual value appropriation with their competitive interactions, in a coopetition strategy. Considering our focus on theoretical contribution, we conduct a numerical analysis with a hypothetical scenario related to a budget allocation problem to understand the implications associated with the proposed intra-port coopetition strategy. Therefore, this chapter emphasizes a strategic decision of a terminal operator in the form of a budget allocation problem, rather than solving a tactical or operational level problem.

3.1.1. Proposed Intra-port Coopetition Strategy

The intra-port coopetition strategy in this chapter assumes that terminal operators in one port cooperate with each other to enhance the entire port competitiveness while simultaneously compete to improve the individual terminals' performance. When describing value appropriation with competitive interactions among terminals, we consider three alternative approaches such as pricing adjustment, operation cost reduction, and time efficiency improvements at terminals, undertaken by the individual terminal operator to improve the performance of own terminal as illustrated in Figure 3.1. These alternative competitive approaches are analyzed as separate scenarios to understand the implications associated with each. When considering the selection of container terminals by shipping lines for their liner services, factors related to the port level such as port location, accessibility, operational performance, and the entire port reputation, among other play a significant role. Although factors such as port location cannot be changed by the port operators, factors such as entire port competitiveness and operational performance can be improved by the port operators with various strategies. The improvements in these port-related factors generate positive impacts on all terminal operators in that port. Therefore, as a part of the coopetition strategy, we assume that terminal operators cooperate with each other to enhance the competitiveness of the entire port by creating a common value with various strategies such as combined marketing effort, inter-terminal transfer system, and single window systems, among others, which increase the attractiveness of the entire port than external competing ports in the market. The proposed coopetition strategy is easy to implement among terminal operators in a port, which is located in a very competitive market because terminal operators can be effectively incentivized to enhance the entire port competitiveness, which is an advantage for all of them.

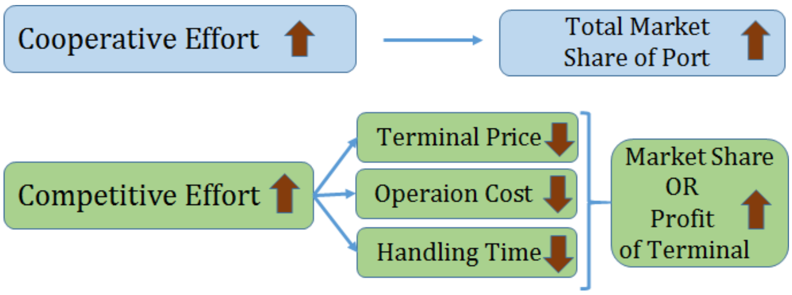

Figure 3.1. Coopetition with Competitive and Cooperative Effort Levels

Since we propose a new form of interaction for the intra-port level, it is important to discuss the implications of such interactions when considering different combinations of terminal operators in one port. In terms of terminal ownership types, we consider both the private and public terminals as introduced in Chapter 1. Therefore, the public terminals are owned and operated directly by the port authority and private terminals are operated by private terminal operating companies under a concession agreement with the port authority. As per the different combinations of terminal ownership types, this study focuses on public-public, public-private and private-private terminal combinations, which are coexisted in the same port. When considering the real-world examples of having different combinations of terminal ownership types in one port, the presence of public-public and private-private terminal combinations in one port can be observed from several countries such as Denmark, France, Germany, Spain, Sweden, Turkey, and Malaysia, among others (Brooks and Pallis, 2012). Besides, in some countries such as Sri Lanka, Pakistan, Finland, India, Germany, Greece, and Turkey, ports simultaneously have both public and private terminals in the same port. As explained by Saeed and Larsen (2010), such a situation enhances the performances of the entire port and the individual terminals owing to the competition between these public and private terminals. Since the coopetition strategy has both competitive and cooperative interactions simultaneously, the analysis with different terminal ownership types is significant owing to the different objectives and operating principles associated with individual terminals depending on their ownership types. Therefore, this study assumes that the public terminal aims to maximize the social surplus while the private terminal aims to maximize the operating profit (Brooks and Pallis, 2012; The World Bank, 2007). Since the intra-port coopetition strategy can change the ports' and terminals' profits, market share, and the generalized cost of shipping lines, it derives significant policy implications on the port authorities, terminal operators and the shipping lines that are operated in a competitive market.

Since this dissertation focuses on the decision-making of key players related to ports and terminals, it is important to specify the target market players, and affected parties from coopetition strategies discussed in each chapter. In Chapter 3, since we focus on coopetition decisions made by terminal operators, their behaviors are analyzed considering different ownership types and objectives. However, due to the coopetition strategy of terminal operators, the port users are positively affected because their cost can be reduced from the cooperative effort made by terminals on the entire port and competitive effort on price adjustment and time efficiency improvement at individual terminals. Therefore, Chapter 3 derives significant policy implications on terminal operators when executing coopetition strategy and on port users when selecting and utilizing container terminals. Besides, significant policy implications can also be derived on port authorities who are the main port administrator in terms of encouraging terminal operators on appropriate coopetition strategies, and coordinating cooperation among terminals with an effective framework on utilizing cooperative budget allocation, among others.

3.1.2 Objectives of Chapter 3

This chapter aims to achieve two main objectives as follows. Since we propose a new form of interaction among terminal operators at the intra-port level, the coopetition behavior of a single terminal operator is analyzed with the Objective [3.1] considering different market dynamics. Moreover, we discuss the differences in coopetition behaviors between the public and private terminals considering their social surplus and profit maximization objectives. After understanding the coopetition behavior of a single terminal operator with the Objective [3.1], the Objective [3.2] focuses on the intra-port coopetition strategy between two terminal operators in a given port. Thus, we analyze the coopetition strategy between the private-private, public-public and public-private terminal combinations operated in a single port, while considering various extents of profit and social surplus maximization objectives of these terminals.

Objective [3.1]. To understand the coopetition behavior of a single terminal operator with changing market dynamics

Objective [3.2]. To analyze the intra-port coopetition strategy between two terminal operators considering different mixtures of terminal ownership types

3.2 Model Development for the Intra-Port Coopetition

As discussed earlier, the coopetition strategy of this chapter assumes that terminal operators in a given port cooperate with each other to enhance the entire port competitiveness while simultaneously competing with each other to enhance the performance of their own terminal. To assess the attitudes of terminal operators toward competition and cooperation, this study considers a hypothetical scenario related to a budget allocation problem. Accordingly, terminal operators are assumed to have a maximum available budget (I^i_{max}), which is allocated on increasing the performance of own terminal and/or increasing the competitiveness of the entire port, which are represented as competitive and cooperative effort levels of the terminal operator, respectively. When interpreting with a practical scenario, we assume that terminal operators receive I^i_{max} in each financial year. Thus, they can decide the optimum allocation of I^i_{max} on coopetition strategy in a single decision-making period because we assume yearly decision-making periods as the port of calls and liner shipping services are usually planned on a yearly basis. Thus, a terminal operator decides different portions of budget allocations on competitive and cooperative efforts depending on its objective, either maximizing profit or social surplus. Since shipping lines can be considered as the direct users of container terminal facilities, the demand of terminals is analyzed in terms of the number of vessel calls made by shipping lines (Bae et al., 2013; Kavirathna et al., 2018.a). Since we analyze the competitive and cooperative interactions considering the terminal level, as followed by a similar approach of Saeed and Larsen (2010) and Munim et al. (2018), the market shares of individual terminals are estimated rather than directly estimating the market share of ports. Therefore, the total market demand, which is given as the “numbers of vessel calls” is distributed among the terminal operators that compete in the market based on the generalized cost of shipping lines related to these container terminals. For the model development, the average values are assumed for the parameters related to container vessels such as handling volumes, and turnaround time, among others, owing to the consideration of aggregate demand rather than considering each vessel call, individually.

The proposed intra-port coopetition strategy is formulated as a non-linear optimization model, which consists of two main decision variables namely the competitive effort level (x^i_t) and cooperative effort level (y^i_t). The portion of the budget (USD) allocated on increasing the performance of own terminal is defined as the competitive effort level (x^i_t) and the portion of the budget allocated on enhancing the competitiveness of the entire port is defined as the cooperative effort level (y^i_t). Since we assume a budget allocation problem for modeling the intra-port coopetition, each terminal operator is assumed to have a maximum available budget, which will be allocated to x_t^i and y_t^i. Since x_t^i can increase the performance of individual terminals, three alternative competitive approaches are considered namely, price adjustment, operation cost reduction and time efficiency improvement. In terms of price adjustment, a terminal operator decides discounts and rebates given for shipping lines depending on its competitive effort level; x_t^i. This price adjustment strategy is significant owing to the high price sensitivity of the market (Ishii et al., 2013). Since shipping lines are willing to reduce the cost at container terminals, the price discounts or rebates can help to attract more vessel calls from shipping lines towards the individual terminals (Notteboom et al., 2019). Besides, Bae et al. (2013) and Saeed and Larsen (2010) have discussed the disadvantages related to the cooperative approach among port service providers in making pricing decisions, because it leads to a monopolistic high price. Hence, the consideration of price discounts or rebates as an alternative competitive effort is significant. Therefore, due to the competitive effort level, the price (handling charges) of the individual terminal is reduced as an adjustment made to the average price level of the terminal operator in the absence of a coopetition strategy. Therefore, a high level of competitive effort results in a low price level at the terminal, which eventually increases the competitiveness of the terminal. Such an inverse relationship between the competitive effort level and the terminal price is reasonable because a high competition in the market generally results in a low-price level.

Apart from the price adjustment strategy, the competitive effort of a terminal operator can be represented as a strategy on reducing the operation cost at individual terminals, which eventually increases the profit of the terminal operator. When considering different approaches on operation cost reduction, a terminal operator can spend its budget allocated as the competitive effort level on the improvements of technology and equipment at terminal, human resource management scheme, and energy-efficient handling methods, among others, which help to reduce the operation cost when handling container vessels. Although the price adjustment strategy greatly influences on the shipping lines, who are the main users of container terminals, the cost reduction strategy influences mainly on the profit of a terminal operator. Moreover, as the third alternative strategy on the competitive effort level, the time efficiency improvement at the individual terminal is considered. As per Park et al. (2014), the intrinsic capacity of a container terminal cannot be increased without a major infrastructure development such as developments of berths, yards and terminal areas. However, by improving the time efficiency at the terminal, the operational capacity, which is defined as the maximum possible number of vessels handled at a particular terminal can be increased. The time efficiency of a terminal can be represented as the average handling time per vessel call. Therefore, the budget allocated as the competitive effort level of a terminal operator can be utilized on different strategies such as training and development of terminal labors, smart sensors, and detectors for minimizing delays, advanced IT platform, and streamlining documentation process, among others, that help to shorten the vessel handling time at terminals. The reduction of average handling time per vessel call helps to attract more vessel calls from shipping lines because the shipping lines prefer to use the terminals with high time efficiencies. Although most of the operation cost reduction strategies generate benefits for the terminal operators rather than for the shipping lines, the time efficiency improvement can generate benefits for both the terminal operators and shipping lines. Therefore, these three competitive approaches are analyzed separately as alternative scenarios on the competitive effort level of a terminal operator.

Next, as the cooperative effort level, a terminal operator allocates a portion of the budget for increasing the competitiveness of the entire port. Therefore, depending on the combined cooperative effort levels of all terminal operators in a single port, the competitiveness of that port can be increased. Hence, the budget allocated as the cooperative effort level is utilized for strategies such as improvement of inter-terminal transfer systems, combined marketing strategy, and single window system, among others, because all terminal operators and the port users can be benefited from these strategies. Therefore, with these kinds of improvements, the generalized cost of all port users can be reduced, hence the attractiveness of the entire port can be increased than the other competing ports in the same market. Owing to the higher attractiveness of the entire port, the demand for all terminal operators in that port can be increased, which is significant when competing with terminal operators from external ports. To analyze the impacts of the cooperative effort level, we defined the term “Cooperative benefit” which implies the perceived generalized cost reduction of shipping lines owing to the cooperation among terminals in a single port. Thus, the cooperative benefit of a port is calculated as a function of combined cooperative effort levels of all terminal operators in that port. Since the cooperative benefit is calculated for the entire port considering combined cooperative effort levels of all terminals, all terminal operators in this port have equal advantages from the cooperative benefit, regardless of the differences in the budget allocated as the cooperative effort level by individual terminals. Thus, this cooperative benefit is used as a component of the generalized cost function related to the container terminals as perceived by shipping lines when selecting a container terminal. Since the cooperative benefit implies the perceived generalized cost reduction of shipping lines, the competitiveness of terminals can be increased owing to the lower generalized cost, which eventually increases their market share when competing with terminal operators of external competing ports. Thus, terminal operators in external competitive ports can be negatively affected. However, the cooperative effort level of a terminal operator is different from the investments made on the long-term infrastructure development on container ports and terminals, which are usually undertaken by the port authorities. Hence, for the proposed coopetition strategy in this chapter, we assume fixed capacities of individual ports and terminals.

As per the coopetition strategy, each terminal operator decides appropriate levels of competitive and cooperative efforts from the given maximum available budget to balance its interests on increasing the performance of its own terminal and enhancing the competitiveness of the entire port. Although three approaches such as price adjustment, operation cost reduction, and time efficiency improvements are assumed as alternative scenarios on the competitive effort of a terminal operator, all these three scenarios are analyzed together with the same approach on the cooperative effort level, which is to increase the overall port competitiveness. Although the cooperative effort level generates equal benefits for all terminal operators in a single port, the competitive effort level generates benefits only for the individual terminal depending on its individual budget allocation as the competitive effort level.

3.2.1 Coopetition Decision Made by a Single Terminal Operator

Since we analyze the results of a coopetition strategy among terminal operators in a single port, first, the coopetition decision of a single terminal operator is described here considering both private and public terminals separately. Thus, a non-linear optimization model is formulated to analyze the coopetition decision of a single terminal, which is made considering the given market condition. The parameters and notations for the model formulation are given as follows;

Sets

$i \in I$	Set of terminal operators;
$h \in H$	Set of competitive ports.

Parameters

S	Total market demand from the shipping lines (total vessel calls per year);
t	Decision-making periods (t = 0 indicates the initial period);
V	Average volume (TEUs) handled per one vessel call;
K^i	The capacity of terminal $i \in I$ (available berth hours);
N^h	Navigation charges (USD) of port $h \in H$ paid by the shipping lines to the port authority;
N^h_{cost}	Cost of the port authority for providing navigation services;
m^h	Number of terminal operators in port $h \in H$;
M	Total number of terminal operators in the competitive market;
I^i_{max}	Maximum available budget (USD) for the coopetition strategy of terminal $i \in I$;
a, b	Parameters to estimate the additional generalized cost perceived by shipping lines due to the terminal congestion and delays;

γ, ρ, β Coefficients on the competitive effort level in the price, cost and time functions, respectively;

τ Benefit factor that converts the cooperative effort level into the cooperative benefits;

TF^i Terminal fee (USD/TEU) paid by the private terminal $i \in I$ to the port authority;

θ Scale parameter of the logit function;

μ The weight assigned to the profit in the *SS* function.

λ Dummy variable; equals to 1 in case of a public-private combination; 0 otherwise

Intermediate Variables

P_t^i Price for the shipping lines when using terminal $i \in I$ (USD/TEU) in t^{th} decision-making period;

C_t^i Operating cost of terminal $i \in I$ (USD/TEU) in t^{th} decision-making period;

T_t^i Average handling time per vessel at the berth (hours) for terminal $i \in I$ in t^{th} decision-making period;

$I_{spent(t)}^i$ Total budget (USD) utilized for the coopetition strategy by terminal $i \in I$ in t^{th} decision-making period;

GC_t^i Generalized cost (USD) of the shipping lines when using terminal $i \in I$ in t^{th} decision-making period;

CB_t^h Cooperative benefit, which represents the perceived generalized cost reduction (USD) of shipping lines due to the cooperation among terminal operators in port $h \in H$ in t^{th} decision-making period.

Decision Variables

x_t^i Competitive effort level (USD) of terminal $i \in I$ in t^{th} decision-making period;

y_t^i Cooperative effort level (USD) of terminal $i \in I$ in t^{th} decision-making period.

Output

Q_t^i Number of vessel calls at terminal $i \in I$ in t^{th} decision-making period;

$Share_t^i$ Market share of terminal $i \in I$ in t^{th} decision-making period;

US_t^i User surplus (USD) from terminal $i \in I$ in t^{th} decision-making period;

SS_t^i Social surplus (USD) from terminal $i \in I$ in t^{th} decision-making period;

π_t^i Profit (USD) of terminal $i \in I$ in t^{th} decision-making period.

3.2.1.1 The coopetition decision of a private terminal

Since this study considers the coopetition strategy with a different combination of terminal ownership types, the coopetition decision of a private terminal is described here. Equation (3.1) gives the profit function of a private terminal, which comprises two main components such as the direct operating profit of the terminal and the utilized budget on coopetition strategy. The direct operating profit is calculated as the multiplication of operating profit per TEU and the numbers of TEUs handled. As described in Chapter 1, the private terminal is considered as the concession terminal, which is operated under a concession agreement with the port authority. Therefore, as per the landlord port governance model, a private terminal pays a terminal fee to the port authority depending on the number of containers handled at the respective private terminal. Therefore, when calculating operating profit per TEU, operating cost and terminal fees are subtracted from the terminal handling charges collected by the terminal operator from shipping lines. As the second component of the profit function, the utilized budget for the coopetition strategy by a terminal operator is subtracted from the terminal's operating profit. The utilized budget of a terminal operator on the coopetition strategy in a particular decision-making period is calculated with Equation (3.2) by summing up its competitive and cooperative effort levels in that period. Since a private terminal operator aims to maximize its profit, Equation (3.1) is considered as the objective function of a private terminal operator.

$$Max, \pi_t^i = V * Q_t^i * \left(P_t^i - TF^i - C_t^i\right) - I_{spent\,(t)}^i, \tag{3.1}$$

$$I_{spent\,(t)}^i = x_t^i + y_t^i. \tag{3.2}$$

Considering three alternative strategies on the competitive effort level such as price adjustment, cost reduction and time efficiency improvement made by a terminal operator, Equation (3.3), (3.4) and (3.5) indicate the price function, cost function and time function of a terminal operator, respectively. As per Equation (3.3), it is assumed that the competitive effort level can reduce the handing charges of a terminal operator as an adjustment made to the initial price, which is the average price level in the absence of the coopetition strategy. Since we assume price adjustment as a strategy on competitive effort level that focuses on individual terminal competitiveness, the price is assumed to be monotonically decreased with the x_t^i. Such an inverse relationship between price and x_t^i is reasonable considering the law of demand. As per the law of demand, the price of a product and the demand have an inverse relationship (Graham, 2013). Thus, by reducing the price level, the demand can be increased. Since the demand is a representation of high competitiveness of a terminal, terminal reduces the price with x_t^i, which eventually increases its demand. Since this study considers a price adjustment strategy in terms of discounts and rebates, terminals reduce the price than the average price level rather than increasing price level because a high price level generally reduces the competitiveness of the terminal due to the high cost of port users. Although the relationship between x_t^i and terminal price is simplified with Equation (3.3), the x_t^i is decided by an optimization model with a generalized cost approach. Therefore, indirectly, the terminal price is decided from an optimization approach considering market demand. To preserve the sensitivity of parameters, the logarithm value of the competitive effort level is used. Since the price adjustment strategy of this study is assumed as the discounts or rebates given by a terminal operator to the shipping line, the actual price (handling charges) in each decision-making period is decided based on the portion of the budget allocated as the competitive effort level in that period. Thus, a high level of competitive effort can reduce the terminal price significantly, which enhances the competitiveness of the terminal than the other competing terminals in the market. Moreover, to convert the competitive effort level into rebates or discounts, a price parameter γ is used. Thus, in each period, the actual price given by a terminal operator is decided based on its competitive effort level, which reduces the terminal price in period *t* when compared to the initial period. However, price is not affected by the y_t^i because y_t^i indicates the budget allocation made to increase the competitiveness of the entire port, rather than at individual terminals.

As an alternative to the price adjustment strategy, the cost reduction strategy of a terminal operator is given by Equation (3.4) such that the operation cost of each decision-making period is decided depending on the portion of the budget allocated as the competitive effort level in that period. However, when considering strategies on operation cost reduction, the budget allocated as the competitive effort level is utilized by a terminal operator for an improvement made inside a particular terminal. Thus, the benefit received as a cost reduction with an improvement made at a particular period will be retained for the next period as well. Therefore, when making the coopetition decisions in future periods, the reduced cost from the previous period is taken as the initial operating cost in the next period. Accordingly, the competitive effort level of a terminal operator in period *t* can further reduce its operation cost than the operation cost in period *t-1*.

$$P_t^i = P_0^i - \gamma * ln(x_t^i), \quad (3.3)$$

$$C_t^i = C_{t-1}^i - \rho * ln(x_t^i), \quad (3.4)$$

$$T_t^i = T_{t-1}^i - \beta * ln(x_t^i). \quad (3.5)$$

As the third alternative strategy on competitive effort level, the time function of a terminal is expressed by Equation (3.5). Thus, depending on the competitive effort level in each decision-making period, the average vessel handing time at a terminal is decided. Since the time efficiency improvement is done as an improvement made inside the terminal similar to the explanation given with Equation (3.4), the time reduction made in a particular period can be taken for the future periods as well. Thus, the average handling time of a vessel in period *t* can be further reduced than that was in period *t – 1* depending on the competitive effort level made by a terminal operator in period *t*. Since the reduction in the average handling time of a vessel can increase the maximum number of vessels that can be handed at a particular terminal, the time efficiency improvement can enhance the terminal handling capacity, regardless of the terminal's fixed intrinsic capacity given by its infrastructure. Since the operation cost reduction and time efficiency improvement made during one decision-making period are taken for the next period as well, the coopetition decision of a terminal operator made in future periods is affected by the decisions made in the current period. Similar to the γ with the price function, the effectiveness of the competitive effort level on the operation cost reduction and the efficiency improvement at a terminal is decided by parameters ρ and β, respectively. Since we assume that cost reduction and time efficiency improvement made in one period will be taken for the next period as well due to the consideration of improvements made inside a particular terminal, the stable levels of operation cost and handling time can be achieved only if terminal operators decide not to allocate any budget on the competitive effort after several decision-making periods. Thus, at one point in time, if the benefit received by allocating all available budget on cooperative effort will be higher than the allocation of budget on both competitive and cooperative effort levels, then terminals will not further reduce operation cost and handling time. Therefore, stable levels of operation cost and handling time can be achieved in such situations. However, these three strategies; price adjustment, cost reduction, and time efficiency improvement are considered alternatives for the competitive effort level. Therefore, although we introduced three equations, Equation (3.3), (4.4), and (3.5), only one equation out of these three equations is considered at a time together with the remaining equations of the model because they are analyzed as separate scenarios.

Next, incorporating the market share of a particular terminal ($Share_t^i$), Equation (3.6) calculates the number of vessel calls at a terminal in period *t*. When estimating the terminal's market share, $Share_t^i$, a generalized cost approach is used. Therefore, Equation (3.7) expresses the logit function associated with the market share estimation, which incorporates the generalized cost of individual terminals expressed by Equation (3.8). The generalized cost function of shipping lines related to the container terminal consists of four components. The first component represents the container handling charges (price) of the terminal, because shipping lines are required to pay container handling charges to the terminal operator for loading/ unloading of containers to/ from vessels at the container terminal. Besides the container handling charges, shipping lines pay navigation charges to the port authority in each vessel arrival as given by the second component of Equation (3.8). The third component of the generalized cost function represents the congestion cost associated with container terminals. Following several previous studies (Bae et al., 2013; Saeed and Larsen, 2010), it is assumed that shipping lines experience congestion at container terminals if the level of usage of a terminal increases beyond 80% of its capacity.

Therefore, following Saeed and Larsen (2010), the congestion level is converted into the generalized cost using parameters *a* and *b*.

$$Q_t^i = Share_t^i * S, \tag{3.6}$$

$$Share_t^i = \frac{e^{-\theta GC_t^i}}{\sum_{i=1}^{i=M} e^{-\theta GC_t^i}}, \tag{3.7}$$

$$GC_t^i = (V * P_t^i) + N^h + a\left(\frac{Q_{t-1}^i * T_t^i}{0.8 * K^i}\right)^b - CB_t^h, \tag{3.8}$$

$$CB_t^h = \tau * \sum_{i=1}^{i=m^h}(y_t^i). \tag{3.9}$$

The last component of the generalized cost function represents the cooperative benefit (CB_t^h), which is resulted from the coopetition strategy. The cooperative benefit implies the perceived generalized cost reduction of shipping lines or the benefits received by shipping lines from the common value creation made by the cooperation among terminal operators in a single port. Therefore, the high value of the cooperative benefit of a port can significantly reduce the generalized cost of shipping lines related to all terminal operators in that port. When calculating the cooperative benefit, we consider the summation of cooperative effort levels given by all terminals operators in a given port as per the Equation (3.9). Although terminal operators allocate a portion of the budget as the cooperative effort level, which is an expenditure for them in creating value for all port users, the cooperative benefit perceived by individual shipping lines during a vessel call may not be equal to the actual level of expenditure made by terminal operators. As an example, if the combined cooperative effort levels of terminal operators; USD 15000 is utilized for a single-window system of the entire port, which eventually enhances the convenience of all shipping lines in transactions, the generalized cost reduction perceived by shipping lines due to this new single-window system can be valuated as USD 50, which is known as the cooperative benefit for them. Therefore, in order to convert this cooperative effort level (expenditure) into the cooperative benefit (generalized cost reduction), we incorporate the benefit factor (τ) as given in Equation (3.9). Therefore, the benefit factor implies the effectiveness of combined cooperative effort levels in reducing the generalized cost of shipping lines. This conversion is important due to the difference between actual expenditure and the benefit perceived by users.

Considering examples from other sectors, when some improvements are made to the public transport system or airports by the operators, the cost of the users can be reduced due to high convenience, comfort, etc. However, this cost reduction perceived by users is not equal to the total expenditure made by operators for those improvements. When estimating this cooperative benefit or benefit factor in a practical scenario, we can analyze similar improvements (ex: single window system) made in other ports and compare the differences in demand before and after the improvements. Moreover, we can conduct a questionnaire survey with port users to understand potential benefits for them by having such improvements and compare different alternative ways of such improvements to deliver the highest benefits for them. Apart from its interpretation in economic aspects, it is significant to have the benefit factor for the model formulation to maintain the sensitivity of all components in the generalized cost function. This is important because if we use the combined cooperative effort levels directly in the generalized cost function without converting into the cooperate benefit using a benefit factor, it will generate minus the generalized cost for shipping lines due to the high value of combined cooperative effort levels when comparing to the other components of the generalized cost function.

Constraints related to the proposed non-linear optimization model are given by the remaining equations (3.10) to (3.14). Since each terminal has a capacity constraint, the capacity of a terminal is calculated by Equation (3.10), which is given in terms of maximum available berth hours. Therefore, as per Equation (3.11), the number of vessel calls handled at a terminal should be less than or equal to the terminal's capacity. Besides, the summation of vessel calls at all terminals in the market should be equal to the total market demand as given by Equation (3.12) because the total market demand is distributed among its competing terminals. As per the Equation (3.13), a terminal operator's utilized budget on the coopetition strategy cannot exceed the maximum available budget limit. Finally, Equation (3.14) implies the non-negativity constraints associated with the terminal price, cost, time and competitive and cooperative effort levels. Thus, the set of equations, from (3.1) to (3.14), collectively expresses the coopetition decision of a private terminal operator in the form of a non-linear optimization problem.

To solve the proposed non-linear optimization problem of a single terminal operator, we utilize the analytical solver platform 2016-C version incorporating its generalized reduced gradient method. The generalized reduced gradient method has been extensively used by previous studies (Alrabadi, 2016; Elci, 2017; Lee et al., 2004; Rudd et al., 2013; Sharma and Glemmestad, 2013) as a reputed global optimization tool, which is also considered as an extension of the simplex method. As its one of the important principles, the non-linear objectives and constraints are linearized at a local solution using Taylor expansion (Lee et al., 2004). Besides, the generalized reduced gradient method divides all variables as the basic and non-basic variables. As per the Alrabadi (2016), the transformation of inequality constraints into equality constraints is done with the slack variables. Since the main contribution of this chapter is on introducing the coopetition concept to the intra-port level with a hypothetical budget allocation problem, the usage of a reputed global optimization tool such as generalized reduced gradient method is reasonable since we analyze all scenarios with the same calculation method and software. Therefore, when discussing the model results, we only consider the patterns of variations associated with significant results by comparing among multiple cases that were treated in an equal manner, rather than interpreting their exact numerical values. However, a verification of the optimization solver and software used in this study is explained in Appendix A.

$$K^i = no\ of\ berths^i * 24 * 365, \tag{3.10}$$

$$T_t^i * Q_t^i \leq K^i, \tag{3.11}$$

$$\sum_{i=1}^{i=M} Q_t^i = S, \tag{3.12}$$

$$I_{spent\ (t)}^i \leq I_{max}^i, \tag{3.13}$$

$$P_t^i, C_t^i, T_t^i, x_t^i, y_t^i \geq 0. \tag{3.14}$$

3.2.1.2 The coopetition decision of a public terminal

Owing to the differences in ownership type, the coopetition behavior of a public terminal could be different from that of a private terminal. Therefore, the coopetition decision of a public terminal is explained in this section. As explained earlier, following several previous studies (Brooks and Pallis, 2012; Munim et al., 2018; Saeed and Larsen, 2010), this study assumes that both the public terminal and the port authority are represented by the same economic entity considering the direct involvement of the port authority in the public terminal. Moreover, the objective of a public terminal is assumed as the maximization of social surplus generated from the public terminal. Thus, Equation (3.15) expresses the objective function of a public terminal, which has two main components such as profit and user surplus generated from the public terminal. As the main difference between the profit of a private terminal and a public terminal, in addition to the direct operating profit received from handling container vessels, a public terminal also receives navigation revenue from all vessels that call to the entire port with the presence of a public-private terminal combination in that port. This happens because of the assumption that the public terminal and the port authority are represented by the same economic entity. Besides, when considering the public-private terminal combination in a single port, the public terminal also receives the terminal fees paid by the private terminal in the same port as per the concession agreement (Saeed and Larsen, 2010). Therefore, i' in Equation (3.15) represents the private terminal in a public-private terminal combination in a single port.

As the different combinations of terminal ownership types, this study considers private-private, public-private and public-public combinations. Thus, the assumption regarding the similar economic entity with the public terminal and the port authority is only applicable for the public-private terminal combination. Hence, we introduce a dummy variable λ, such that $\lambda=1$ in case of a public-private combination in one port and $\lambda=0$ otherwise. However, with the presence of a public-public combination in a single port, we release the assumption related to the similar economic entity, therefore, we can allow the port authority to evaluate the performances of its multiple public terminals operated within the same port because public terminals can compete with each other to enhance their individual performance. Since the public enterprises are considered as less efficient due to the lack of competition and the support from the government (Brooks and Pallis, 2012), evaluating the operational performance of public terminals independently from the port authority can be effective. Besides, as explained by the De Langen and Pallis (2006), the lack of intra-port competition leads to the monopolistic rent-seeking behaviors of the port service providers, thus the individual public terminal's performance can be evaluated separately from the port authority to reduce such monopolistic behaviors since it allows competition among public terminals to enhance their own performances. Therefore, when considering the public-public terminal combination, none of the public terminals receives revenue from navigation services.

As the last component of the social surplus function, the user surplus generated from the public terminal is considered. Thus, following an approach similar to Saeed and Larsen (2010), the user surplus related to the public terminal is calculated with Equation (3.16). Accordingly, following the "rule of a half", the estimation of change in user surplus is done by estimating the change in generalized cost and multiplying that by the average demand before and after the decision- making. However, the user surplus function given with Equation (3.16) is considered as a simplified form of user surplus calculation. Considering a fundamental property of the logit model, the changes in user surplus can be conceptually given by the changes in logsum as expressed in Equation (3.17) based on Munim et al (2018), where U_i implies the utility of port users when using terminal i and b is the parameter of their user cost function. However, the logsum approach in previous studies is used to calculate user surplus for all users rather than a group of users related to one competing service provider. For instance, Munim et al. (2018) consider the logsum approach in user surplus calculation because they calculate total user surplus generated after transformation of port governance model and formation of coalition among terminals considering several alternative hypothetical scenarios. However, in this study, this user surplus is incorporated only as a part of the objective function of the public terminal to indicate its non-monetary focus. Thus, in the case of the private terminal's decision-making, we do not consider the user surplus generated from the private terminal. Thus, we consider the user surplus generation with only a group of port users related to the public terminal rather than calculating user surplus for all port users. Therefore, in our study, we calculate user surplus with Equation (3.16) instead of Equation (3.17) because we could not find an appropriate reference on using a logsum approach to calculate user surplus generated by only one competing service provider. Considering the dilemma on the public sector enterprises whether to focus on the profit or non-profit objectives, we introduce a parameter μ, which implies the weight given to the profit in the social surplus function by the public terminal and a detailed description on μ is given in a later section of this chapter.

$$Max, SS_t^i = \mu \left[V\left(Q_t^i * \left(P_t^i - C_t^i\right) + \lambda(Q_t^{i'} * TF^{i'})\right) + \lambda(N^h - N_{cost}^h)\left(\sum_{i=1}^{i=m^h} Q_t^i\right) \text{-} I_{spent(t)}^i \right] + (1-\mu)US_t^i, \tag{3.15}$$

$$US_t^i = 0.5\,(GC_{t-1}^i - GC_t^i)\left(Q_{t-1}^i + Q_t^i\right), \tag{3.16}$$

$$US_t^i = 0.5\ (Q_{t-1} + Q_t).\frac{1}{b}(LS_{t-1} - LS_t),\ \ LS_t = ln(\textstyle\sum_i e^{U_i}) \tag{3.17}$$

Thus, the objective of a public terminal is considered as the maximization of social surplus, although the social surplus function of a public terminal has different weights to the profit and user surplus components. Therefore, apart from the objective function, the remaining equations discussed with Section 3.2.1.1, from Equation (3.2) to Equation (3.14) are similarly applicable for the coopetition decision of a public terminal as well. Thus, following the same explanations, the utilized budget on the coopetition strategy by a public terminal is calculated with Equation (3.2). Moreover, the price, cost and time functions associated with three alternative approaches on the competitive effort level of a public terminal are given with Equations (3.3), (3.4) and (3.5), respectively. The number of vessel calls at the public terminal is calculated with Equation (3.6), which incorporates the terminal's market share estimated with Equation (3.7). To estimate the terminal's market share, the generalized cost function related to the container terminal is given with Equation (3.8). The Equation (3.9) calculates the cooperative benefit of the port and the terminal's capacity and capacity constraints are expressed by Equation (3.10) and (3.11), respectively. Besides, the Equations (3.12) to (3.14), which express the constraints to the non-linear optimization model are similarly applicable when considering the coopetition decision of a public terminal as well. Therefore, the coopetition decision of a public terminal also formulates as a non-linear optimization problem given by equations (3.2) to (3.16). Following an approach similar to the private terminal case, the generalized reduced gradient method is used to solve this optimization problem, which decides the optimal competitive and cooperative effort levels of a public terminal.

3.2.2 Problem Description on Coopetition Strategy with Two Terminal Operators

Up to now, we discuss the coopetition decision made by a single terminal operator with a given market condition. In terms of decision-making, we assume a profit maximization problem of a market player in the case of private terminals. However, since we do not consider the fixed cost of the terminal, we can consider this as a short-run profit maximization because the capacity and other fixed inputs are assumed to remain unchanged. Following previous studies related to container terminals (Munim et al., 2018; Saeed and Larsen, 2010), in an oligopoly market such as the port industry with only few players competing in a market, market shares, and prices may be treated as the outcome of a game where each player tries to maximize payoff with due consideration of the expected reaction of the competitors. Assuming that container terminals in the same market offer somewhat homogeneous services, terminal users will use the terminal that offers services at a lower total cost including handling charges and other user costs. Therefore, outcomes of such market situation can be modeled as a Bertrand game. However, in our study, we focus on coopetition instead of competition or cooperation (coalition) and consider repetitive decision-making by market players. Besides, we assume that the terminal chooses discount level due to the consideration of price adjustment as a competitive effort (inverse relationship), thus, the decision-variable is related to the discount level instead of directing choosing the price level in case of price adjustment scenario. Following an approach with the repeated game, it is reasonable to assume that the decision-maker optimizes its payoff for the current period because it cannot determine the payoff from future periods or cannot change the payoff received in past periods. Thus, in each period, a terminal operator maximizes its payoff depending on the given updated market condition.

Since the coopetition strategy requires at least two terminal operators in a given port to understand their simultaneous competitive and cooperative interactions, we consider decision-making with two terminal operators in a given port. Thus, we assume a hypothetical scenario as illustrated in Figure 3.2. According, two ports; h_1 and h_2 are competing in the market and each port consists of two competing terminal operators. Thus, four terminal operators are in the market as given by TO1, TO2, TO3, and TO4, which represent terminal i = 1, 2, 3, 4, respectively. Thus, the port h_1 has terminal operators; i =1 (TO1) and i = 2 (TO2) and the port h_2 has terminal operators, i = 3 (TO3) and i = 4 (TO4). Since we analyze the impacts of intra-port coopetition on the external competing terminals and ports, we assume that the coopetition strategy is executed only between two terminal operators in port h_1 (TO1 and TO2) for the simplicity, while considering terminal operators in port h_2 (TO3 and TO4) as the external competitors. Thus, the price, operating cost and handling time of these external competitors (TO3 and TO4) remain unchanged because they do not execute any coopetition strategy.

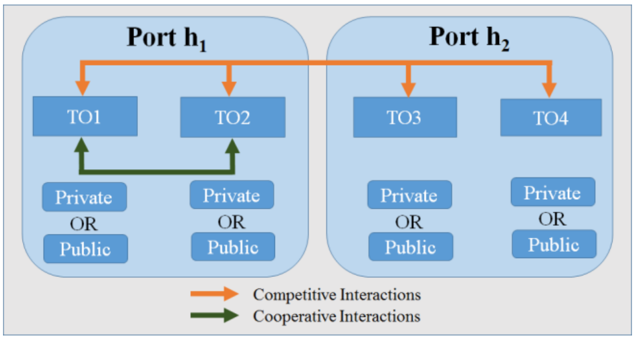

Figure 3.2. Hypothetical Market Scenario

To understand the decision-making behaviors considering the reactions on each other's coopetition decision, we assume a unilateral decision-making approach on coopetition by terminal operators where only one terminal makes the coopetition decision in one period and the second terminal makes the coopetition decision in the following period. A similar approach is used by Ishii et al. (2013) to understand the decision-making behaviors on pricing and capacity expansion by two competing ports made in response to each other's decisions. As an example, if we assume the duration of coopetition strategy as four decision-making periods $t = 0 < 1 < 2 < 3 < 4$, which is started from $t = 0$ as the initial stage, the first terminal makes the coopetition decisions in periods 1 and 3 and the second terminal makes the decisions in periods 2 and 4 (Ishii et al., 2013). As per previous studies, (Brandenburger and Nalebuff, 1996; Ritala and Tidström, 2014; Song, 2003), the fundamental characteristic of coopetition can be considered as the simultaneous presence of competition and cooperation. However, it does not necessarily mean that market players decide cooperation simultaneously because they still act as individual economic entities with different objectives. This situation can be expressed as a nonzero-sum game when describing from game theoretical perspectives because the sum of the payoffs of the market players need not be zero or any fixed value (one player's win does not necessarily make the loss for another one) due to the external competitors. As per Hiller and Lieberman (1986), many competitive situations include non-competitive aspects that contribute to the mutual advantage of the players. Due to the possibility of mutual gain, nonzero-sum games are further classified into a non-cooperative game where there is no pre-agreed communication between players and a cooperative game where initial discussion and agreement are permitted. Due to these characteristics, terminal operators are assumed to make coopetition decisions unilaterally focusing on their individual objectives, implying a non-cooperative approach in decision-making. However, as the results of their decision-making, they present both competition and cooperation simultaneously which demonstrate a coopetition behavior. Since we focus on the behavior of terminals at the intra-port level made in response to each other's decision-making, it is reasonable to assume this unilateral decision-making approach. Since only the terminal operators in port h_1 execute the coopetition strategy, we assume that TO1 makes the coopetition decision at first and then TO2 makes the coopetition decision. Thus, the TO1 is considered as the first mover and TO2 is considered as the follower of this coopetition strategy. Since the port of calls and liner shipping services are usually planned on a yearly basis, we assume yearly decision-making periods for the coopetition strategy. Moreover, fixed total market demand is assumed for each period in the initial analysis to precisely understand the impacts of coopetition strategy with multiple decision-making periods.

A detailed illustration of the calculation process related to the coopetition strategy between TO1 and TO2 is given with Figure 3.3. Accordingly, following a unilateral decision-making process, each terminal makes the coopetition decision in its respective decision-making periods considering an updated market condition. The initial market condition for the numerical analysis is given as for the Period *n* ($t = n = 0$). Then, TO1 (i = 1), which is the first mover of the coopetition strategy starts the coopetition strategy in period *n + 1* and decides its optimal competitive and cooperative effort levels (x_{n+1}^1 and y_{n+1}^1) considering the given initial market condition. When making a coopetition decision, a terminal operator maximizes its profit or social surplus depending on its terminal ownership type whether private or public terminal, respectively. As the results of the coopetition decision made by TO1, its market price, operation cost or handling time can be changed depending on one of the competitive approaches selected out of three alternative approaches. Moreover, the coopetition decision of TO1 changes the profit and market share of all four terminal operators in the competitive market. Therefore, depending on the results of the coopetition decision made by TO1 in period *n + 1*, we update the market condition exogenously for the next decision-making period. Since the initial market condition was changed by the coopetition decision of TO1, next, in period *n + 2*, TO2 decides its optimal competitive and cooperative effort levels (x_{n+2}^2 and y_{n+2}^2), depending on its objective. The same process is repeated between TO1 and TO2, therefore the TO2's coopetition decision made in period *n + 2* changes its price, operating cost or time efficiency and also influences on marker shares and profits of all four terminal operators. Therefore, after updating the market condition based on TO2's coopetition decision, next, TO1 modifies its previous decision and decides new optimal competitive and cooperative effort levels in period *n + 3* (x_{n+3}^1 and y_{n+3}^1).

Following the same decision-making process, both TO1 and TO2 modify their previous strategies unilaterally in the respective decision-making periods, while incorporating the market changes that occurred due to the coopetition decision of the other terminal made in the previous period. In other words, the coopetition strategy continues in such a way that one terminal makes a coopetition decision in period *t* considering the updated market condition given by the next terminal in period *t – 1*. We continue this calculation process for several decision-making periods and only for the purpose of this study, we stop the calculation when both terminals cannot further improve their objective functions by unilaterally changing their competitive and cooperative effort levels. Therefore, the coopetition strategy is considered as stable if the changes of competitive and cooperative effort levels between two consecutive decision-making periods of each terminal operator, $\left|\frac{(x_{n+2}^{i} - x_{n}^{i})}{x_{n}^{i}}\right|$ and $\left|\frac{(y_{n+2}^{i} - y_{n}^{i})}{y_{n}^{i}}\right|$, are less than or equal to 0.001% (Lin et al., 2017). Such a condition can be considered as the market stable situation because the market shares of individual terminals will not be changed afterward. This happens because a terminal operator is not required to modify its previous coopetition decision due to the constant levels of competitive and cooperative efforts maintained by the other terminal. However, it does not mean that terminals stop their coopetition strategy after achieving this condition. It only means that terminals will not change the coopetition decisions after achieving this condition because they continuously choose the same competitive and cooperative effort levels. Thus, we aim to understand the behaviors of both terminal operators with multiple periods until they reached stable coopetition decisions although it is not necessary to achieve such stable condition of the coopetition strategy in the practical scenario due to the changes in the external market environment. After reaching this condition, stable x_{t}^{i} and y_{t}^{i} of terminals mean that terminals try to retain the benefit received from the coopetition (ex: higher market share, lower price, etc) with the individual terminals/entire port continuously because the external market factors are assumed to be fixed in this study. As per Mclaughlin and Fearon (2013), the same coopetition relationship is difficult to maintain over the long term because market players interact with two fundamentally conflicting interactions, namely competition and cooperation, hence their interactions would be changed with the time. Therefore, the optimization of long-run benefit/return from coopetition is not considered in this study.

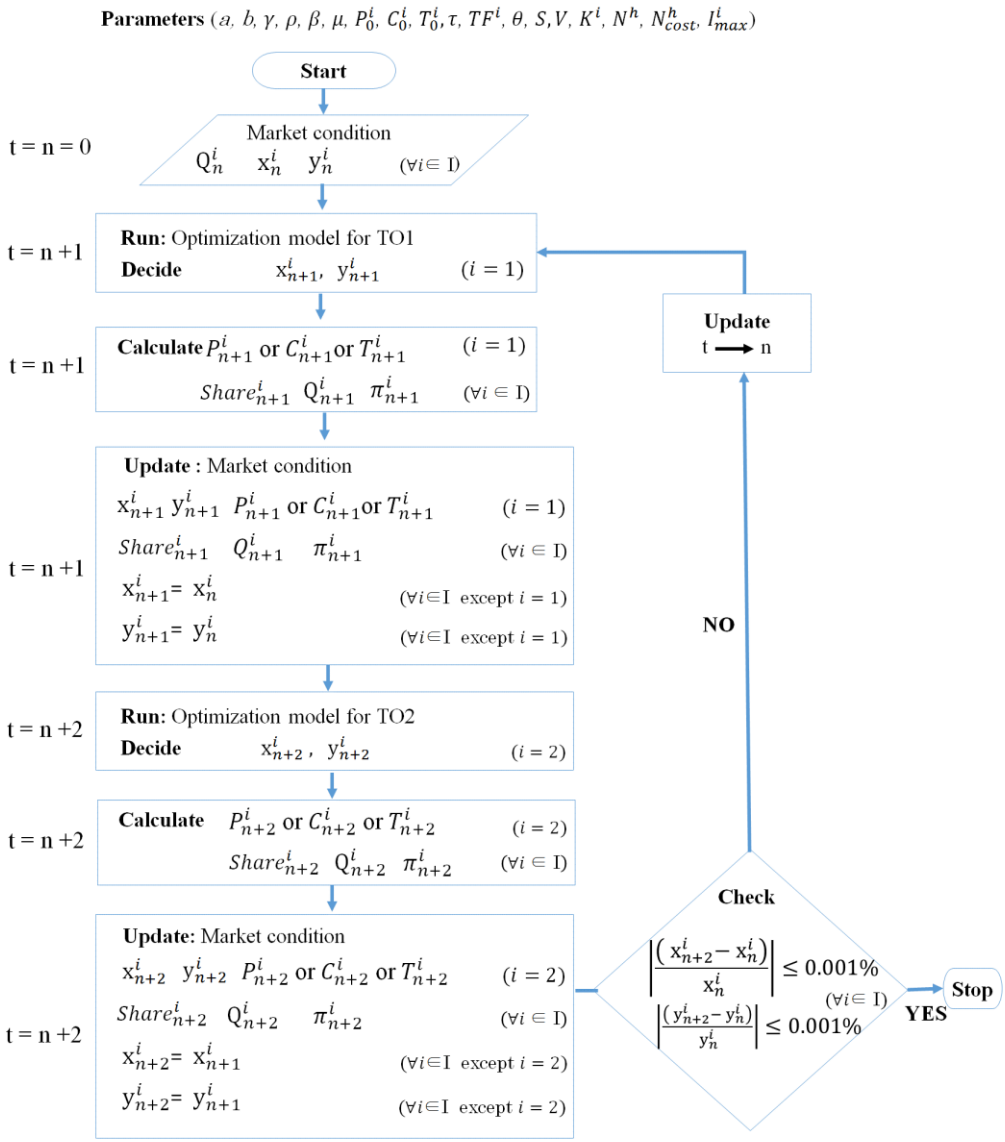

Figure 3.3. Calculation Process for the Coopetition Strategy with Multiple Periods

When introducing the coopetition concept in general, Chapter 1 incorporates a payoff matrix with strategy options for two market players in Figure 1.5. Thus, the proposed coopetition strategy in Chapter 3 between two terminal operators can be expressed more clearly using a similar payoff matrix as given in Figure 3.4 considering strategy options of two players in their unilateral decision-making process. Accordingly, the strategy options of TO1 and TO2 are represented in columns and rows of the strategy matrix. When considering strategy options, the very first row ($x_{n+1}^1 = 0,\ y_{n+1}^1 = I_{max}^1$) and very first column ($x_n^2 = 0,\ y_n^2 = I_{max}^2$) represent the extreme levels of cooperative efforts because terminal operators allocate all available budget on y_n^i. In contrary, last row ($x_{n+1}^1 = I_{max}^i,\ y_{n+1}^1 = 0$) and last column ($x_n^2 = I_{max}^i,\ y_n^2 = 0$) represent the extreme levels of competitive efforts because terminal operators allocate all available budget on x_n^i. Thus, when making coopetition decisions, terminal operators choose different combinations of y_n^i and x_n^i depending on their objective function and the updated market condition. Since only one terminal makes the decision at a given time, each terminal can decide its optimal coopetition strategy as a combination of y_n^i and x_n^i within a given column or row in its respective decision-making period. As an example, when TO1 makes the coopetition decision, it can decide an optimal strategy given within a particular column, which is decided by the coopetition decision of TO2 made in the previous period. Consequently, when TO2 makes the coopetition decision in the following period, its strategy options are limited to a particular row, which is decided by the coopetition decision of TO1 made in the previous period. This process continuous between two terminals in one port for multiple decision-making periods to understand the effectiveness of the coopetition strategy with the time.

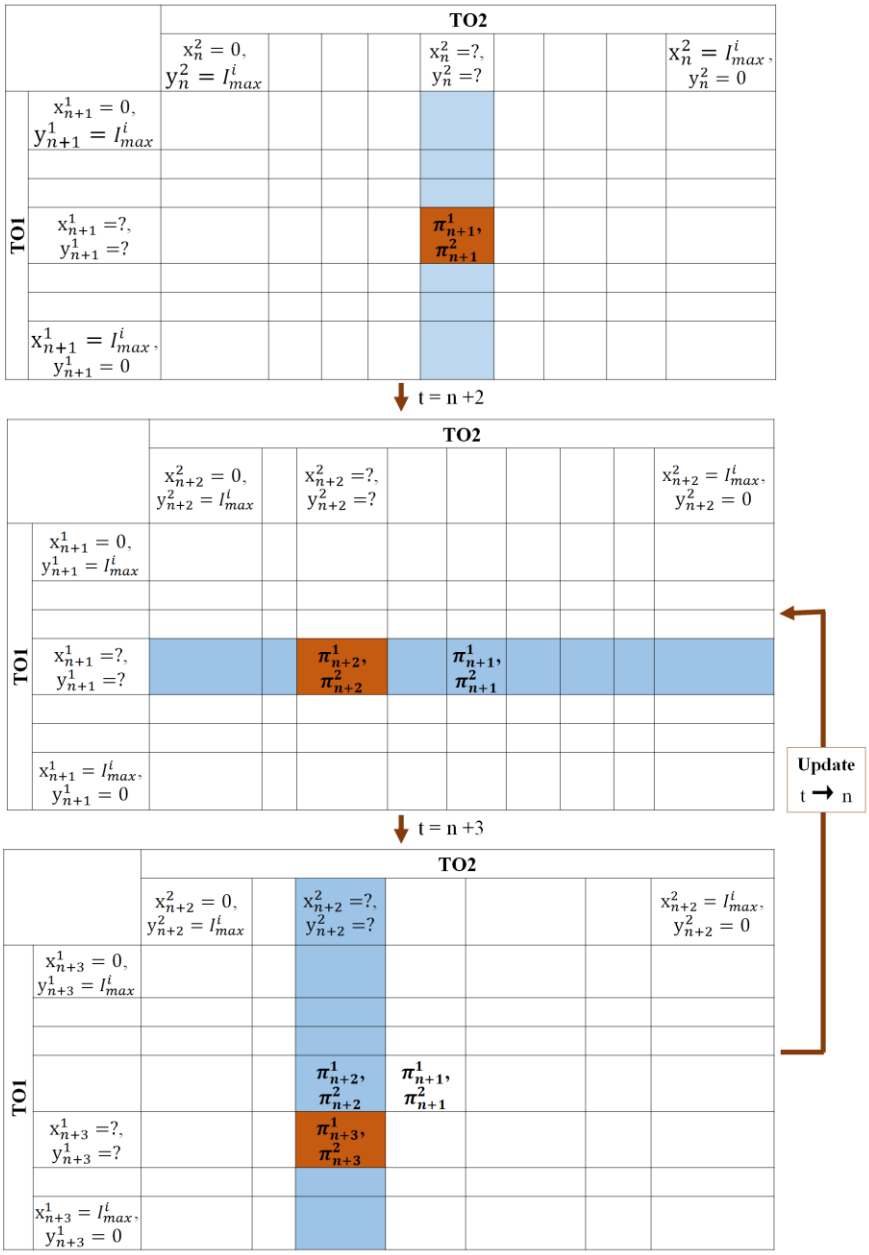

Figure 3.4. Unilateral Decision-Making for the Coopetition Strategy

The model formulation can be discussed as a dynamic system with multiple stages in decision-making due to the consideration of the updated market condition given from the previous period. Since the demand of terminal operators are decided based on the logit function, the coopetition decision of a single terminal operator can be transformed into a functional form expressed by Equation (3.19) considering profit objective; π_t^1 as a function of x_t^1, y_t^1, x_{t-1}^2 and y_{t-1}^2. The remaining Equations; from (3.20) to (3.24) give different components of the objective function for easy representation. Finally, Equation (3.25) and (3.26) give the maximum available budget level and non-negativity constraints. Thus, as per the system of equations, it is observed that the objective function of TO1 (i =1) is affected by the coopetition decision of TO1 in period t (x_t^1, y_t^1) and also the coopetition decision made by TO2 (i =2) in the period $t-1$ ($x_{t-1}^2,\ y_{t-1}^2$). Besides, the objective function of TO1 is affected by the updated condition of the market received from the previous period as given in demands at all four terminals. Accordingly, we can observe that the output of the optimization problem in one period is affected by the inputs from the previous period as well, implying a behavior of a dynamic system. Similarly, when we consider the coopetition decision of the TO2 made in the period $t-1$, the same set of equations is applied after transforming i =1 and i =2 in equations. Therefore, following the same explanation, the objective function of TO2 in period $t-1$; $\pi_{t-1}^2 = f(x_{t-1}^2, y_{t-1}^2, x_{t-2}^1, y_{t-2}^1)$ is affected by not only the coopetition decision of TO2 made in period $t-1$ ($x_{t-1}^2,\ y_{t-1}^2$) but also the coopetition decision made by TO1 in the earlier period $t-2$ (x_{t-2}^1, y_{t-2}^1) and the updated market condition received from period $t-2$ as expressed by Equation (3.27). This implies the relationship between periods and dynamics in their decision-making behaviors.

$$\pi_t^1 = f(x_t^1, y_t^1, x_{t-1}^2, y_{t-1}^2) \tag{3.18}$$

$$\pi_t^1 = \frac{V \times S \times [W^1 - \gamma \times ln(x_t^1)] \times [e^{-\theta(N_1 - V\times\gamma\times ln(x_t^1) - \tau(y_t^1 + y_{t-1}^2)}]}{\left[e^{-\theta\left(N_1 - V\times\gamma\times ln(x_t^1) - \tau(y_t^1 + y_{t-1}^2)\right)}\right] + \left[e^{-\theta\left(N_2 - V\times\gamma\times ln(x_{t-1}^2) - \tau(y_t^1 + y_{t-1}^2)\right)}\right] + L_t^3 + M_t^4} - (x_t^1 + y_t^1) \tag{3.19}$$

$$W^1 = P_{avg}^1 - TF^1 - C^1 \tag{3.20}$$

$$N_1 = V \times P_{avg}^1 + N^{h1} + a\left(\frac{Q_{t-1}^1 \times \beta^1}{0.8 \times K^1}\right)^b \tag{3.21}$$

$$N_2 = V \times P_{avg}^2 + N^{h1} + a\left(\frac{Q_{t-1}^2 \times \beta^2}{0.8 \times K^2}\right)^b \tag{3.22}$$

$$L_t^3 = e^{-\theta\times(V\times P_{avg}^3 + N^{h2} + a\left(\frac{Q_{t-1}^3 \times \beta^3}{0.8\times K^3}\right)^b} \tag{3.23}$$

$$M_t^4 = e^{-\theta\times(V\times P_{avg}^4 + N^{h2} + a\left(\frac{Q_{t-1}^4 \times \beta^4}{0.8\times K^4}\right)^b} \tag{3.24}$$

$$x_t^1 + y_t^1 \le I_{max}^i \tag{3.25}$$

$$0 \le x_t^1, y_t^1 \tag{3.26}$$

$$\pi_{t-1}^2 = \frac{V \times S \times [W^2 - \gamma \times ln(x_{t-1}^2)] \times [e^{-\theta(N_2 - V\times\gamma\times ln(x_{t-1}^2) - \tau(y_{t-1}^2 + y_{t-2}^1)}]}{\left[e^{-\theta\left(N_1 - V\times\gamma\times ln(x_{t-2}^1) - \tau(y_{t-1}^2 + y_{t-2}^1)\right)}\right] + \left[e^{-\theta\left(N_2 - V\times\gamma\times ln(x_{t-1}^2) - \tau(y_{t-1}^2 + y_{t-2}^1)\right)}\right] + L_{t-1}^3 + M_{t-1}^4} - (x_{t-1}^2 + y_{t-1}^2) \tag{3.27}$$

Since we consider repeated decision-making between two terminal operators with multiple periods, the coopetition strategies of them may become stable after a few decision-making periods depending on the market condition. Although we discussed the relationship between decision-making periods, when making decisions by one terminal, the decisions of the other player is assumed to be fixed. Thus, considering the nature of objective function as a maximization problem, the condition for satisfying the concavity property is obtained as in Appendix B. However, since we consider a dynamic system with the changes in payoff of both terminals until reaching to the stable market condition, it is difficult to conclude that the coopetition strategy reaches to a stable condition in all cases. However, if we assume that the coopetition strategy becomes stable for both terminals after a few decision-making periods, then we can generate the condition for maintaining this stable strategy continuously as follows. After achieving a stable strategy, the profit of terminals will not be changed. Therefore, the relationship between profits received from the remaining periods can be written as; $\pi_t^1 = \pi_{t+1}^1 = \pi_{t+2}^1 = \pi_{t+3}^1 = \pi_n^1$. If we assume a discount factor δ when considering payoff in future periods after achieving this stable condition, the total payoff with n periods can be written as Equation (3.28). However, because the payoff is equal in all periods, the combined profit can be written as the righthand side of the Equation (3.28) considering a discount factor.

$$\pi_t^1 + \delta\, \pi_{t+1}^1 + \delta^2\, \pi_{t+2}^1 + \delta^3 \pi_{t+3}^1 + \delta^n\, \pi_n^1 = \frac{\pi_t^1 f(x_t^1, y_t^1, x_{t-1}^2, y_{t-1}^2)}{(1-\delta)} \tag{3.28}$$

Since we consider a coopetition situation rather than competition or cooperation, it is hard to directly follow the concepts associated with game theory in explaining the market situation and decision-making behavior. However, assuming that TO1 maintains some positive values of x_t^1 and y_t^1 as the stable coopetition strategy, one possible way of deviating from this stable strategy is the allocation of the available budget only on the individual x_t^1 to receive benefit from y_{t-1}^2 decided by TO2 in the previous period while behaving as a free-rider. Assuming that at one point of time, TO1 deviates from this stable strategy by choosing a zero level of cooperative effort level ($y_t^1 = 0$), then it may earn a high payoff for this period as a free-rider. However, since we consider private-private combination here, after observing zero y_t^1 made by TO1 in period t, TO2 may also discourage to allocate budget on y_{t+1}^2 in period $t+1$. Hence, TO2 may also decide to allocate zero budget on y_{t+1}^2 in period $t+1$. Thus, in such a situation, the combined payoff of TO1 in the remaining decision-making periods after deviating from the stable strategy can be given as Equation (3.29). Here, we assume that, at any point of time, if TO1 decides not to allocate budget on cooperative effort to enhance the overall port competitiveness, TO2 also decides not to allocate any budget on cooperative effort level in the next and remaining periods, following the concepts related to the individual rationality, and grim-trigger in game theory. However, here we assume cooperation as the allocation of budget on y_t^i and whenever one terminal deviates from stable strategy by allocating zero budget on y_t^i, we consider that cooperation between two terminals fails at this point and they continuously allocate budget only on own competitive effort (x_t^i).

$$\pi_t^1 + \delta\,\pi_{t+1}^1 + \delta^2\,\pi_{t+2}^1 + \delta^3\pi_{t+3}^1 + \delta^n\,\pi_n^1 = \pi_t^1 f\big(x_t^1 = I_{spent\,(t)}^1, y_t^1 = 0,\ x_{t-1}^2, y_{t-1}^2\big) + \frac{\delta\big[\pi_{t+1}^1 f\big(x_t^1 = I_{spent\,(t)}^1, y_t^1 = 0,\ x_{t+1}^2 = I_{spent\,(t+1)}^2, y_{t+1}^2 = 0\big)\big]}{(1-\delta)} \quad (3.29)$$

Therefore, in order to continue with a stable coopetition strategy by both terminal operators, the combined payoff generated from Equation (3.28) should be greater than or equal to the payoff generated from Equation (3.29) for both terminals as given in Equation (3.30). Thus, we can consider this as the condition for continuing stable coopetition strategy by terminal operators and a similar condition is applicable when considering deviating from stable coopetition strategy by TO2 as well. However, this condition is applicable only when considering the possible deviation of terminal operators as the allocation of zero budget on cooperative effort level (y_t^i=0) only. As expressed with the strategy matrix in Figure 3.4, there are many alternative strategies that the terminal operator can choose when making a coopetition decision. Therefore, to continue with a stable strategy, both terminals should not be able to find any profitable deviation with any alternative strategies than the stable strategy.

$$\frac{\pi_t^1 f(x_t^1, y_t^1,\ x_{t-1}^2, y_{t-1}^2)}{(1-\delta)} \geq \pi_t^1 f\big(x_t^1 = I_{spent\,(t)}^1, y_t^1 = 0,\ x_{t-1}^2, y_{t-1}^2\big) + \frac{\delta\big[\pi_{t+1}^1 f\big(x_t^1 = I_{spent\,(t)}^1, y_t^1 = 0,\ x_{t+1}^2 = I_{spent\,(t+1)}^2, y_{t+1}^2 = 0\big)\big]}{(1-\delta)} \quad (3.30)$$

Since we update the market condition in each period to analyze the coopetition strategy with multiple decision-making periods, the results of the current coopetition decision made by a terminal operator will influence its future coopetition decisions as well. However, the consideration of multiple decision-making periods is significant for understanding the impacts of the coopetition strategy on the competitive market until it reaches a stable condition. Although we assume that the external terminal operators have fixed price, operation cost and handling time as they do not execute the coopetition strategy due to our main focus on analyzing the impacts on external competitors, in a practical situation, such external competitors would react to this market situation with various strategies to secure their market shares. Therefore, in such circumstances, the effectiveness and implications associated with the coopetition strategy are influenced by the related market condition given by the external competitors.

Since the model consists of multiple parameters, it is important to understand their effective range by considering the expected influence from the target parameter to the objective function. Therefore, a comparative statistics analysis is performed for price parameter (γ), benefit factor (τ), and the number of TEUs handled during a vessel call (V) as given in Appendix C. However since this study conducts a numerical analysis by assuming a hypothetical budget allocation scenario to clarify the simultaneous competitive and cooperative behaviors among terminal operators in a single port, we will discuss the implications and conclusions only by considering the pattern of variations of significant variables without interpreting their actual numerical values in detail.

3.2.3 Numerical Analysis for the Coopetition Strategy with Two Terminal Operators

Owing to the lack of previous studies on intra-port coopetition, this study conducts a numerical analysis to understand the implications associated with the proposed coopetition strategy. A similar approach is used by Lin et al. (2017) when introducing the coopetition strategy among shipping lines. To perform the numerical analysis, it is important to decide appropriate values for the market-specific parameters of the model. Therefore, Table 3.1 summarizes the values of several parameters, which are decided based on the industry average values and also from the previous studies. Since it is significant to understand the model dynamics associated with the proposed intra-port coopetition strategy, we assume equal terminal capacities (K^i), terminal fee (TF^i), initial terminal prices (P_0^i), operating costs (C_0^i), average handling times of a vessel (T_0^i), and initial demands (Q_0^i) with all four terminals. Such an assumption helps us to understand the results of the coopetition strategy more clearly by comparing the performances of container terminals before and after the implementation of the coopetition strategy. Therefore, assuming four container berths with each container terminal, the terminal capacity is assumed as 35,040 (4 × 24 × 365) available berth hours per year. Since we assume a competitive market scenario, the initial market demand at each terminal is assumed as 800 vessel calls per year, which implies nearly 50% of terminal capacity utilization at the beginning. Consequently, due to the four competitive terminals in the market, the total market demand is considered as 3,200 (800 × 4) vessel calls per year. As per the industrial context, it is reasonable to assume 3,200 vessel calls as the total demand for a market with four container terminals. Besides, the average handling time of a vessel at the initial period (T_0^i) is assumed as 20 hours as per the industry average.

Table 3.1. Market-Related Parameters of the Numerical Analysis

Parameter	K^i	Q_0^i	S	P_0^i	C_0^i	T_0^i	TF^i	N^h	N_{cost}^h	V	I_{max}^i
Value	35,040 berth hours	800 vessel calls	3,200 vessel calls	USD 40 per TEU	USD 20 per TEU	20 hours	USD 5 per TEU	USD 800 per vessel call	USD 780 per vessel call	1,200 TEUs	USD 10,000

Since a container vessel should have at least 1000 TEUs to be handled when making a port of call as per the economical industry practices, the average number of TEUs handled during a vessel call is assumed as 1,200. However, it is important to note that, although we assume 1,200 TEUs as an average value due to the consideration of aggregate demand rather than considering each individual vessel call, some container vessels such as feeder vessels and short-sea vessels can make a port of call even with less than 1,200 TEUs to be handled, which can be considered as a limitation of this study. However, considering the advantages of coopetition strategy for highly competitive markets, which are mainly represented by mainline vessels, it is reasonable to assume 1,200 TEUs for this study, especially targeting those mainline vessels. Moreover, shipping lines are assumed to pay USD 800 per vessel call as the navigation charges (N^h) although these navigation charges are usually dependent on the tariff structures of individual ports. As the cost of providing navigation services (N_{cost}^h), USD 780 is assumed, thus the port authorities can yield a small profit from the provision of navigation services. Since the coopetition strategy is analyzed as a budget allocation problem, the maximum available budget (I_{max}^i) is assumed as the USD 10,000, although we conduct a sensitivity analysis to understand the impacts of I_{max}^i to the model. Besides, following the industry average values, USD 5 per TEU is assumed as the terminal fee, which is paid by the private terminals to the port authority, although this value is varied in individual ports depending on their concession agreements.

Table 3.2 summarizes several model-specific parameters related to the numerical analysis. Following Saeed and Larsen (2010), the values of a and b are assumed as 0.5 and 4, respectively. Besides, to conduct the numerical analysis, the magnitude of γ and τ are taken as 0.01 and 0.002, respectively. However, to understand their impacts on the model, a sensitivity analysis is carried out as explained in Section 3.3.1. After conducting sensitivity analysis, the values of ρ and β are taken as 0.02 and 0.1, respectively. Moreover, we assume a small value for θ to avoid errors from a very large exponential function, because it is difficult to estimate an exact value of θ with a numerical analysis which is based on a hypothetical market scenario.

Table 3.2. Model-Specific Parameters of the Numerical Analysis

Parameters	a	b	γ	ρ	β	θ	τ
Value	0.5	4	0.01	0.02	0.1	0.01	0.002

As mentioned earlier, apart from proposing the intra-port coopetition model, this study also considers the different combinations of terminal ownership types operated within a given port. Thus, assuming the different degrees of profit and social surplus maximization of terminal operators, we consider 11 different cases for the analysis as given in Table 3.3, that are derived from three different terminal combinations; private-private, public-private and public-public operated within a given port. As per the Brooks and Pallis (2012) and the World Bank (2007), the public sector organizations usually provide services at a reasonable price while focusing on maximizing social surplus rather than maximizing only operational profit. Thus, we assume a social surplus function, which consists of different weights given for the profit and user surplus components. Therefore, the parameter μ given in Equation (3.15) is assumed with five different values, which represent different weights given to the profit in the social surplus function. Thus, when considering the public-private and public-public terminal combinations, five sub-cases are assumed, which are varied depending on the weight given to the profit in the social surplus function of the public terminal. According to the Brooks and Pallis (2012), despite the availability of a port governance model, which identifies the profit or non-profit objectives and operating principles of the ports and terminals, these aspects can vary significantly from country to country. Therefore, analyzing the social surplus function with different extents of profit and user surplus components is significant owing to the dilemma on profit or non-profit objectives associated with public sector organizations. Moreover, since this study considers purely maximization of profit and purely maximization of user surplus as well as per Table 3.3, the results can derive significant policy implications considering these two extreme conditions as well.

When we analyze the coopetition strategy related to the private-private and public-private terminal combinations in port h_1, the terminal operators in external competitive port h_2 (TO3 and TO4) are also assumed as private terminals. Further, when we analyze the coopetition strategy related to the public-public terminal combination in port h_1, the TO3 and TO4 are also assumed as public terminals, hence the results of all four terminals will not be affected by the terminals fees related to the private terminal and we also separate the navigation revenue from all four public terminals owing to the assumption that the operating performance of public terminals are evaluated independently from the port authority when considering the public-public terminal combination. Besides, in case of analyzing the coopetition strategy with public-private terminal combination, the first decision-maker TO1 is assumed as the public terminal because it is being operated by the port authority, thus has high potential to initiate this kind of coopetition strategy to enhance the overall port competitiveness.

Table 3.3. Cases for the Numerical Analysis

Cases	μ	**The objective of Public Terminal**
private-private	N/A	Both are private terminals with profit maximization objective
public-private (μ_0)	0.00	*SS* function of public terminal focuses on only user surplus
public-private ($\mu_{0.25}$)	0.25	*SS* function of public terminal focuses on user surplus than profit
public-private ($\mu_{0.5}$)	0.50	*SS* function of public terminal equally focuses on profit and user surplus
public-private ($\mu_{0.75}$)	0.75	*SS* function of public terminal focuses on profit than user surplus
public-private (μ_1)	1.00	*SS* function of public terminal focuses on only profit
public-public (μ_0)	0.00	Both are public terminals with *SS* function focusing on only user surplus
public-public ($\mu_{0.25}$)	0.25	Both are public terminals with *SS* function focusing on user surplus than profit
public-public ($\mu_{0.5}$)	0.50	Both are public terminals with *SS* function equally focusing on profit and user surplus
public-public ($\mu_{0.75}$)	0.75	Both are public terminals with *SS* function focusing on profit than user surplus
public-public (μ_1)	1.00	Both are public terminals with *SS* function focusing on only profit

3.3 Results and Discussion

The main findings related to the coopetition strategy with numerical analysis are described in this section. To understand the model dynamics and the coopetition behavior of a single terminal operator with Objective [3.1], a sensitivity analysis is carried out with several significant parameters. Then, the results of a coopetition strategy between two terminal operators and related implications are discussed with Objective [3.2].

3.3.1 Results and Discussion for the Objective [3.1]

Since the Objective [3.1] analyses the coopetition behavior of a terminal operator, we discuss the dynamics of the proposed model based on significant parameters. Since we consider both the private and public terminals, a sensitivity analysis is carried out separately for them. Although several forms of social surplus function with different μ values are considered as the objective function of a public terminal, the sensitivity analysis related to the public terminal is carried out considering only the user surplus maximization objective (when $\mu = 0$). Thus, we can understand the differences in coopetition decisions between a private terminal that focuses on profit maximization and a public terminal that focuses on user surplus maximization. Although we consider three alternative approaches such as price adjustment, operation cost reduction and time efficiency improvement as the competitive effort level made by individual terminals to enhance their own terminal's performance, the sensitivity analysis is carried out only considering the price adjustment strategy to maintain the brevity. Since the main decision variables of the model are cooperative effort level (y_t^i), the portion of the budget allocated for enhancing the overall port competitiveness and the competitive effort level (x_t^i), the portion of the budget allocated for increasing the performance of individual terminals, we use y and x to simply represent y_t^i and x_t^i in all figures hereafter for convenience.

First, the impact of benefit factor (τ) to the model is discussed because it is an important parameter, which converts the combined cooperative effort levels into the cooperative benefits, implying the effectiveness of cooperation among terminals in one port for reducing the generalized cost of shipping lines. Therefore, τ must be a positive value usually within the range of $0 < \tau < 1$ because the perceived generalized cost reduction of shipping lines cannot exceed the expenditure made by terminals in the form of combined cooperative effort levels. Figure 3.5 illustrates the variations of the coopetition decisions of both the private and public terminals when changing the magnitude of τ. Accordingly, a significant difference is indicated at relatively high values of τ because the public terminal spends all its available budget on the coopetition strategy, although the private terminal does not spend all budget on the coopetition at high value of τ. This happens because the private terminal can receive a significantly high return even with a small budget allocation on y_t^i due to the high value of τ, which discourages private terminal from allocating it's all available budget on coopetition. Since one of the motivations of this study is to analyze the simultaneous competitive and cooperative behavior of terminal operators, it is important to decide an appropriate value for τ, which enables us to analyze the tradeoff relationship between y_t^i and x_t^i. A high value of τ is not appropriate as it generates a very high return even from a small y_t^i while reducing the sensitivity of other components of the model. However, in a practical situation, the value of τ can be decided depending on the level of effectiveness in using the cooperative budget allocation to reduce the generalized cost of shipping lines. As an example, if the cooperative budget allocated by terminal operators are utilized for functional improvements such as single-window system or inter-terminal transfer system, etc, the value of τ can be decided by considering the significance of having such systems to reduce the generalized cost of shipping lines. Therefore, the policy implications can be derived in a practical circumstance depending on the various strategies on utilizing the budget allocated as the cooperative effort level.

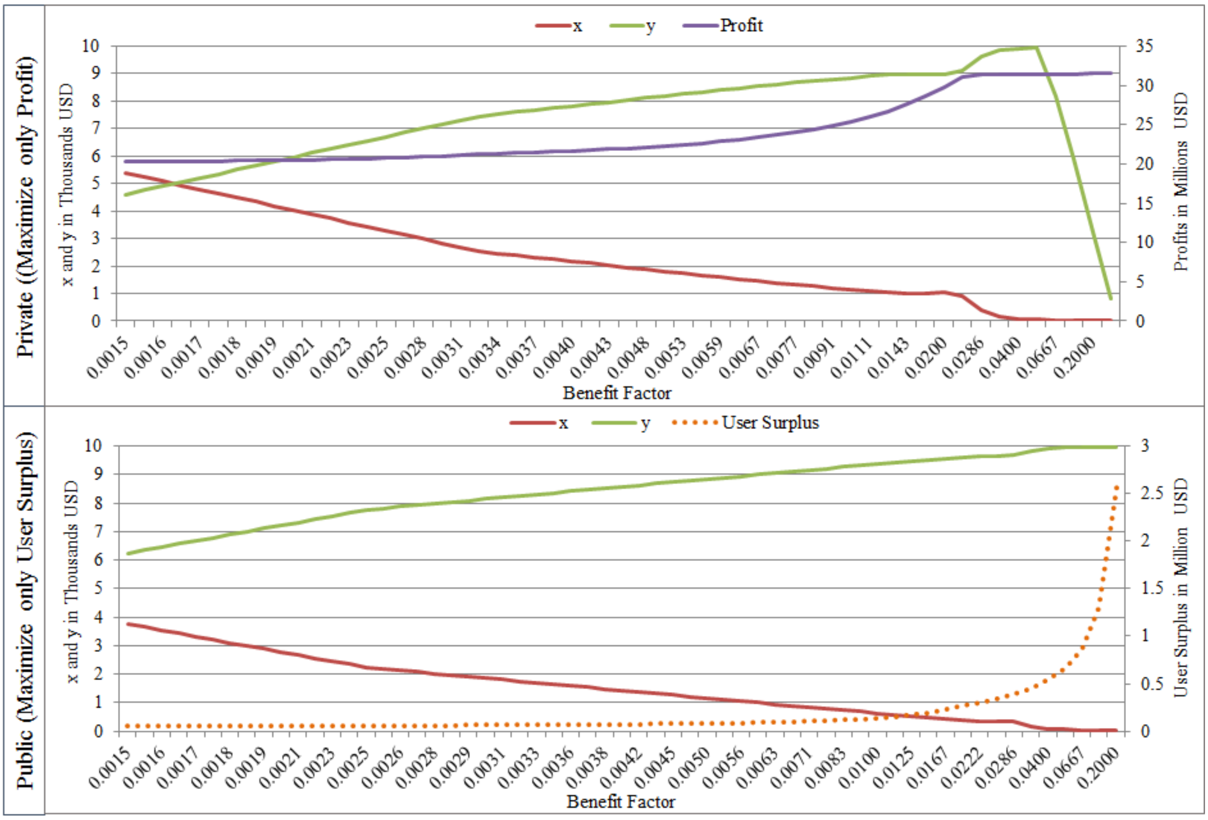

Figure 3.5. Sensitivity Analysis of the Benefit Factor (τ)

Since we analyze the coopetition strategy as a budget allocation problem, the maximum available budget I_{max}^{i} has a significant impact on the model. Therefore, the changes in the coopetition decisions depending on the various level of I_{max}^{i} are analyzed here to assess the terminal operators' relative efforts on competition and cooperation depending on their budget constraints. As per the results in Figure 3.6, both private and public terminal operators spend a larger portion of I_{max}^{i} on y_t^i than x_t^i when increasing the level of I_{max}^{i}. However, at very high levels of I_{max}^{i}, the utilized budget on the coopetition strategy by a private terminal is reduced than the available I_{max}^{i} because the private terminal is not motivated to invest all available I_{max}^{i} on the coopetition owing to its profit maximization objective. Despite, the public terminal always spends its entire I_{max}^{i} on the coopetition strategy regardless of the very high level of I_{max}^{i} could be due to its user surplus maximization objective.

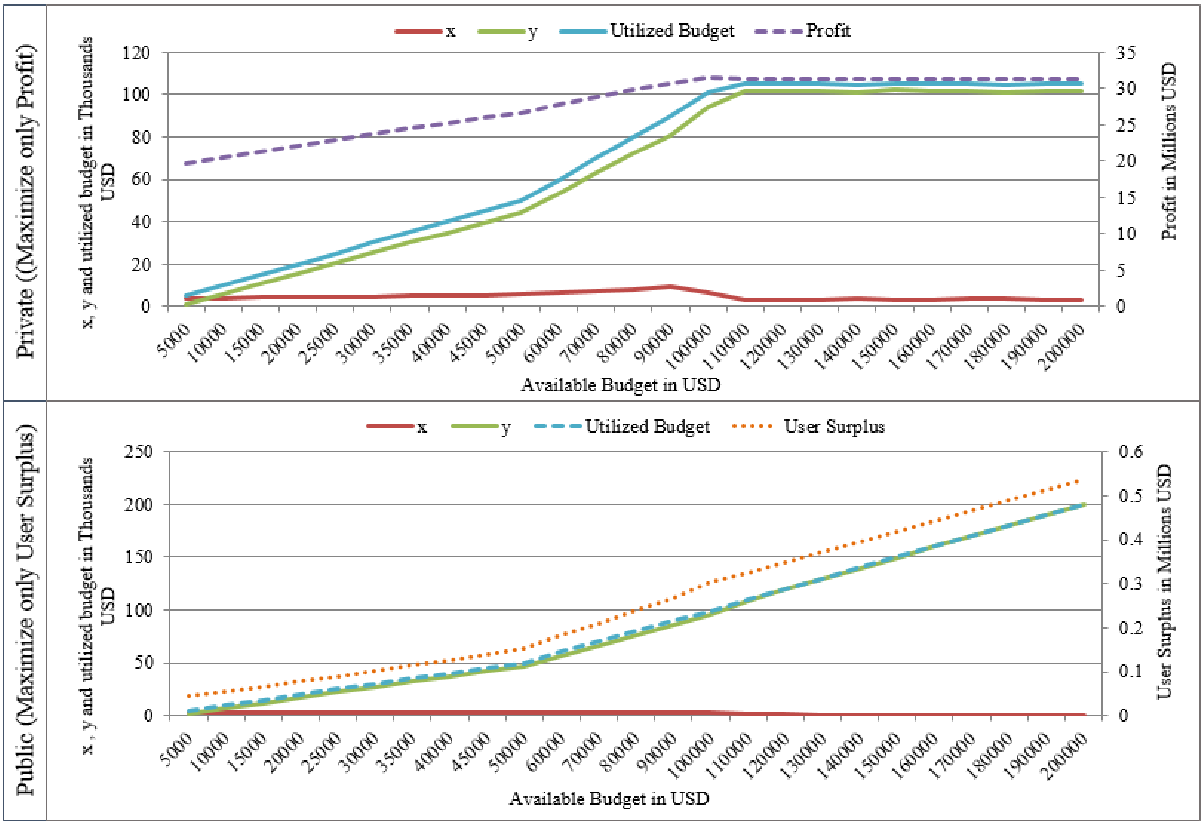

Figure 3.6. Sensitivity Analysis of the Maximum Available Budget (I^{i}_{max})

Since we conduct the sensitivity analysis considering the competitive effort level in terms of price adjustment strategy, it is important to understand the sensitivity of the coefficient on x_t^i in the price function (γ), which as an important parameter for deciding the terminal price level. As per the results, both the private and public terminals indicate a similar variation of coopetition decisions when changing the value of γ, thus results are graphically illustrated in Figure 3.7 only for the private terminal case to maintain the brevity. Accordingly, when increasing the value of γ, both the private and public terminals tend to reduce their prices down to a certain minimum level by increasing their budget allocation on x_t^i because they can obtain high market shares with lower handling charges. However, since it is not economical for them to reduce the price to a very low level, terminals tend to maintain a constant price level while reducing the level of x_t^i at the high values of γ. When considering the variation of the terminal's profit, the reduction of price helps to increase the terminal's profit to a certain level and then it maintains a stable profit owing to the constant price level. In terms of policy implications related to the coopetition strategy, the policy instruments such as price ceilings or minimum price level can be imposed by the port authority for minimizing the negative impacts from the extreme price competition among terminals in the same port while simultaneously encouraging price rebates and discounts as well, to maintain a more competitive average price level for the entire port than the external competing ports in the same market.

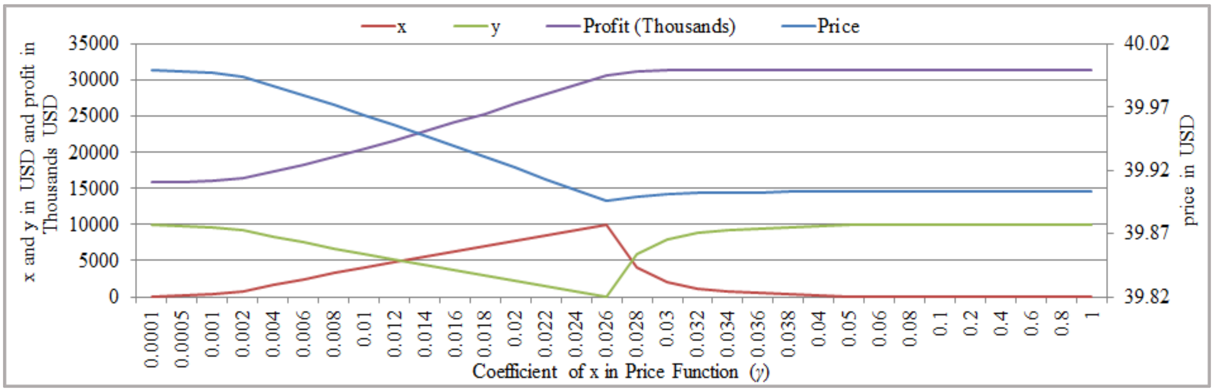

Figure 3.7. Sensitivity Analysis of the Coefficient on x_t^i in the Price Function (γ)

Apart from the parameters related to the model, the market-related conditions such as total market demand (S) can significantly influence the coopetition strategy. Since terminal operators can decide various competitive and cooperative effort levels depending on the different market sizes, the sensitivity of the total market size given in terms of the total number of vessel calls is analyzed as illustrated in Figure 3.8. Since both the private and public terminals indicate a similar variation in the coopetition decisions depending on the different market sizes, the graphical illustration is given only for the private terminal case. Accordingly, the terminal operators maintain constant y_t^i and x_t^i levels when increasing the market size up to a certain level, which generates constant market share for the terminal and for the entire port. However, the market share of the terminal and the entire port are decreased at a large market size regardless of the high cooperative effort made by the terminal operator to secure its market share. Subsequently, when the market size becomes very large, the terminal operator loses its motivation on allocating the budget on the coopetition strategy because the terminal cannot handle a very large number of vessel calls due to the limitation with its available capacity despite the large market size. Thus, both y_t^i and x_t^i are reduced at a very large market size because a terminal can obtain a sufficient number of vessel calls that is compatible with the terminal's capacity even without spending any budget on the coopetition strategy. Accordingly, when considering a large market size, terminals are not motivated to reduce their handling charges or enhance the entire port competitiveness, thus the coopetition strategy is meaningful only when the demand of a terminal is lower than its capacity, which can be observed from most highly competitive markets.

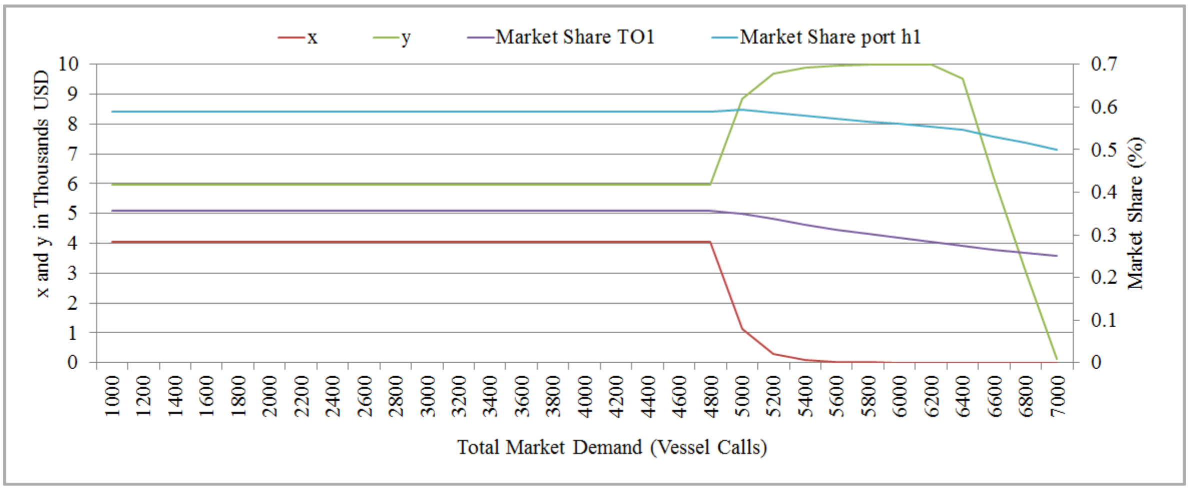

Figure 3.8. Sensitivity Analysis of the Total Market Demand (*S*)

Since we derive these implications based on numerical analysis, the findings could be varied in a different market setting depending on the various factors such as numbers of competitive port and terminals, their ownership types, and alternative approaches on competitive and cooperative effort levels, among others. Moreover, owing to the consideration of numerical analysis, we mainly discuss the significant differences derived among cases, which were treated in an equal manner with a similar calculation process.

3.3.2 Results and Discussion for the Objective [3.2]

After analyzing the coopetition behavior of a terminal operator with changing market conditions with the first objective, the second objective analyzes the coopetition strategy between two terminal operators considering a different mixture of terminal ownership types in a given port, as summarized in this section. As discussed previously, the model assumes a unilateral decision-making approach, thus one terminal makes the coopetition decision in its respective decision-making period by considering the updated market condition given by the coopetition decision of the other terminal made in the previous period. Although we analyzed 11 different cases derived from public-public, public-private and private-private terminal combinations, to maintain the brevity, discussions with graphical illustrations are made only for the cases with significant differences in terms of all three alternative approaches on competitive effort level.

3.3.2.1 Resulting competitive and cooperative effort levels of terminals

As illustrated in Figure 3.9, the decision-making periods of terminal operators are given with the horizontal axis, which starts from period *0* to represent the initial market condition. The decision-making periods of TO1 and TO2 are represented by odd and even numbers, respectively. Considering each alternative approach on competitive effort level, the variations of the resulted competitive and cooperative effort levels are graphically illustrated for three selected cases with significant differences. First, we consider the results of the coopetition strategy when terminal operators' competitive efforts are devoted to the price adjustment at individual terminals together with their cooperative efforts on enhancing the port competitiveness. Accordingly, due to the significant differences arise among private-private, public-private (μ_0), and public-public (μ_0) cases, the results related to these three cases are illustrated in panel (a) of Figure 3.9. When considering the private-private case, which means when both TO1 and TO2 are private terminals with profit maximization objective, they decide higher y_t^i than x_t^i at the beginning to enhance the overall port competitiveness could be due to the possibility of the increasing market share of the entire port by eroding some vessel calls from the external competitors. This is reasonable because the external competitors also have a reasonably high market share at the beginning since we assume an equal number of vessel calls with all four terminals as the initial market condition. However, when it reaches a stable condition, terminals maintain a slightly higher x_t^i than y_t^i, which is reasonable because terminals compete with each other while maintaining a lower price level at individual terminals to obtain a large portion of the entire port market which was expended during initial periods. Therefore, at the later decision-making periods, the competition is mainly occurred between TO1 and TO2 rather than with terminal operators in external competitive port (h_2) owing to the less market share associated with those external competitors.

Next, when considering the results with the public-private case (μ_0) case, the public terminal (TO1) tends to spend relatively a higher portion of the budget on the y_t^i than x_t^i could be due to its user surplus maximization objective when μ=0 case. Despite, the private terminal (TO2) tends to spend comparatively a higher portion of the budget on x_t^i than y_t^i at the stable condition. Thus, when the public terminal in a public-private combination in a given port focuses on maximizing the user surplus, the private terminal in the same port tends to behave as a free rider. This happens due to the possibility that the private terminal also can receive the benefits from the high amount of budget allocation as the cooperative effort level made by the public terminal to increase the entire port competitiveness because all terminals in a given port are equally benefitted from the combined cooperative effort levels regardless of their individual contribution given as y_t^i. Therefore, the market share of the private terminal can be increased even without a significant budget allocation on y_t^i. Thus, when considering a public-private terminal combination, the public terminal may not receive a high benefit from the coopetition when it focuses only on maximizing user surplus. However, considering the long-term positive externalities, it is significant to implement this kind of coopetition strategy with a public-private terminal combination when a port has a market-leading public terminal, with a willingness to support the private terminals in the same port. As per the results of coopetition strategy related to the public-public (μ_0) case, which implies that both public terminals focus on maximizing user surplus, they tend to allocate a relatively higher portion of the budget on y_t^i than x_t^i. Thus, if a port has two public terminals with user surplus maximization objective, the port authority of this port can receive high incentives from these public terminals to enhance the overall port competitiveness, which can facilitate effective port development policies.

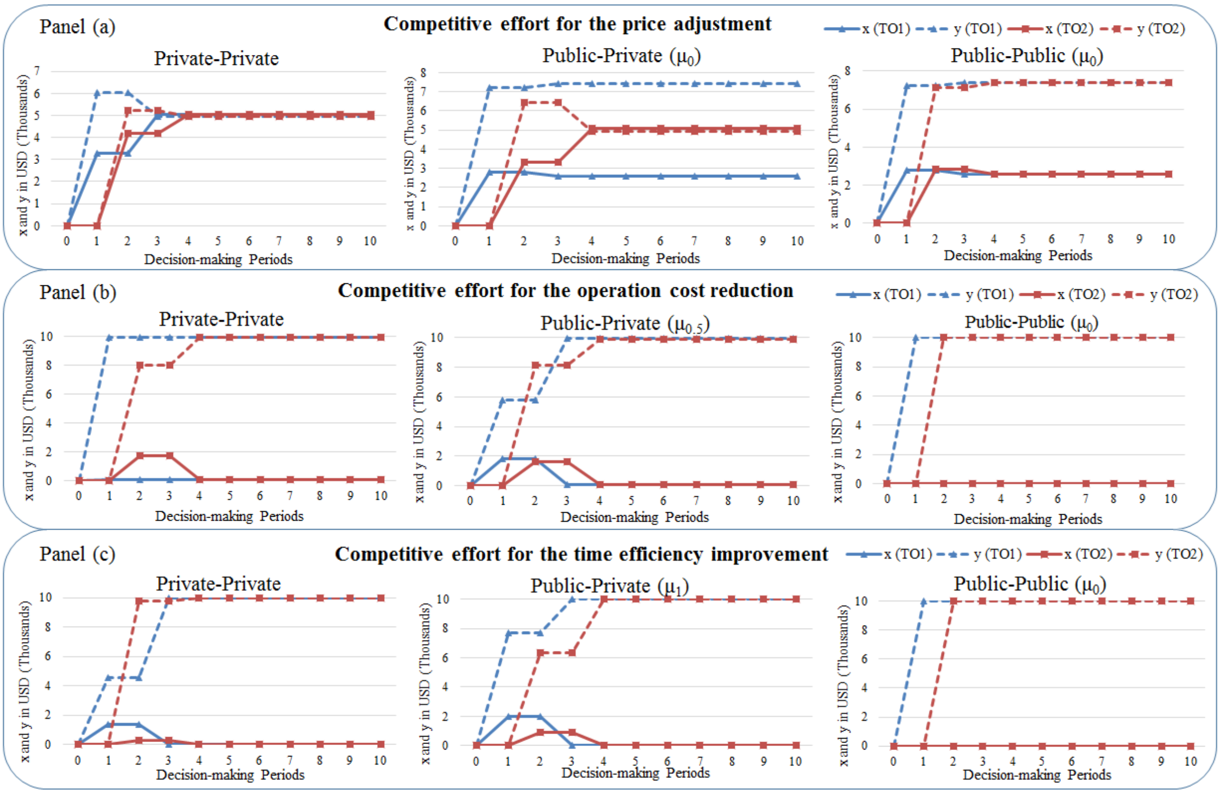

Figure 3.9. Variation of Competitive and Cooperative Effort Levels

Next, when discussing the results of the coopetition strategy with the operation cost reduction scenario, the private-private, public-private ($\mu_{0.5}$), and public-public (μ_0) cases indicate significant differences. Accordingly, higher y_t^i than x_t^i can be observed with the cost reduction scenario. These results are reasonable because the reduction of operation cost does not create direct impacts on the market share of individual terminals regardless of its impacts on the terminals' profit. Therefore, the additional profit gain by a terminal operator by increasing its demand would be higher than the profit gain by reducing its operational cost. Thus, spending a higher portion of the budget on y_t^i than x_t^i would be advantageous. With respect to the results from the time efficiency improvement scenario, due to the changes in the terminal's objective from maximizing profit to maximizing user surplus, TO1 tends to increase its cooperative effort level when it moves from the private-private case to the public-

public (μ_0) case. However, the improvement in time efficiency influences not only on the generalized cost of shipping lines but also on the profit of a terminal operator by increasing its market share and the operational capacity, represented by the maximum possible vessel calls that can be handled at the terminal. In the cases of cost reduction and time efficiency improvement scenarios, a stable market condition can be achieved only because of nearly zero levels of competitive efforts maintained by TO1 and TO2 after several decision-making periods. This happens because the additional benefits received from the cooperative effort are higher than those received from reducing operation cost and handling time at later decision-making periods. Even we made these discussions considering only the patterns of variation of significant results obtained from the numerical analysis, these results can be varied when considering a coopetition strategy with a case study depending on its implementation setting.

When considering all three alternative scenarios on competitive effort level, in the majority of cases except the public-public (μ_0) case, if TO1 initiates the coopetition with a high y_t^i values, the next terminal, TO2 tries to have a smaller y_t^i than that of TO1 while enjoying the benefits from high y_t^i made by TO1. However, a small y_t^i of TO1 made at the initial period encourages TO2 to have a comparatively high y_t^i. When considering the results with public-public (μ_0) cases, despite the three different scenarios on competitive effort level, both public terminals maintain higher y_t^i values than x_t^i. Due to the significance of terminal price in the generalized cost function of shipping lines and the competitive nature of the market, comparatively higher x_t^i values can be observed from the price adjustment scenario than the other two alternative scenarios related to the competitive effort level.

Since the competitive effort level, x_t^i has a direct influence on the terminal price, operating cost or the time efficiency at individual terminals depending on the three alternative scenarios, it is important to discuss the cases associated with the least and highest terminal price, operation cost and the handling time at the stable market condition. In terms of all three alternative scenarios, both TO1 and TO2 obtain their highest terminal price, operating cost and the longest handling time per vessel call from the public-public (μ_0) case, possibly due to their extreme focus on maximizing user surplus, which generates small x_t^i values in the stable condition. However, TO1 and TO2 obtain the least terminal prices with the price adjustment scenario from the public-public (μ_1) case and public-private (μ_0) case, respectively. Owing to the profit maximization objective of TO1 with the public-public (μ_1) case, the least price of TO1 is generated from this case because it focuses more on the competitive effort level. Moreover, due to a public terminal, TO1 does not pay a terminal fee to the port authority in the public-public (μ_1) case, thus its price can be reduced significantly with this case than the other cases. The public-private (μ_0) case generates the least price of the TO2 because the behavior of TO2 as a free rider, that mainly focuses on its competitive effort level. When considering the scenario related to the operation cost reduction, TO1 and TO2 obtain their least operation costs from the public-public ($\mu_{0.5}$) and private-private cases, respectively. The shortest handling time per vessel call, which represents the highest improvement in time efficiency of TO1 is obtained from the public-public ($\mu_{0.25}$) case and that of TO2 is obtained from the public-private ($\mu_{0.5}$) case when considering the time efficiency improvement scenario.

As discussed earlier, the stable market condition may be achieved after a few decision-making periods because we assumed a stable market size (fixed total market demand). Thus, terminals maintain the same competitive and cooperative effort levels after achieving this stable condition. However, it is not always possible to achieve stability in coopetition strategy especially when the total market size is growing or shrinking. Therefore, we did additional analysis while changing the total market demand to understand whether the stability in coopetition strategy can be achieved in those market situations as illustrated in Figure 3.10 considering the private-private case only. Since the purpose of this analysis is just to understand the possibility of achieving a stable condition after few decision-making periods, we compare the resulting competitive and cooperative effort levels in several market situations between period 6 - period 10 because the stable condition is achieved after period 6 when having fixed total market demand.

Accordingly, assuming the competitive effort in terms of price adjustment at individual terminals, we analyze six market situations such as market size is shrinking slightly (by 50 vessel calls per year), shrinking moderately (by 100 vessel calls per year), fixed market size (fixed total demand per year), growing slightly (by 50 vessel calls per year), growing moderately (by 100 vessel calls per year), and growing highly (by 200 vessel calls per year). As per the results in Figure 3.10, it is observed that the coopetition strategy becomes fairly stable after a few decision-making periods with highly shirking and fixed market sizes. This is possibly happened due to the less opportunity for terminal operators to erode demand from external competitors in shrinking and fixed total market sizes after few decision-making periods. Therefore, terminal operators are not motivated to change their previous coopetition strategy because the external competitors would not have high demand after a few decision-making periods. However, in growing market situations, it is not possible to obtain a stable coopetition strategy even in the 10th decision-making period because terminal operators slightly modify their coopetition strategies in each period. The changes in competitive and cooperative effort levels are more obvious especially in highly and moderately growing market situations as given in the bottom two graphs in Figure 3.10 possibly due to the high opportunity to erode demand from external competitors even in later decision-making periods due to the growing total market size. Although the constant levels of growth and shrinking demand (vessel calls) conditions are assumed for the numerical analysis to simplify the calculation, the total market demand can have different other variations and dynamics in a practical situation.

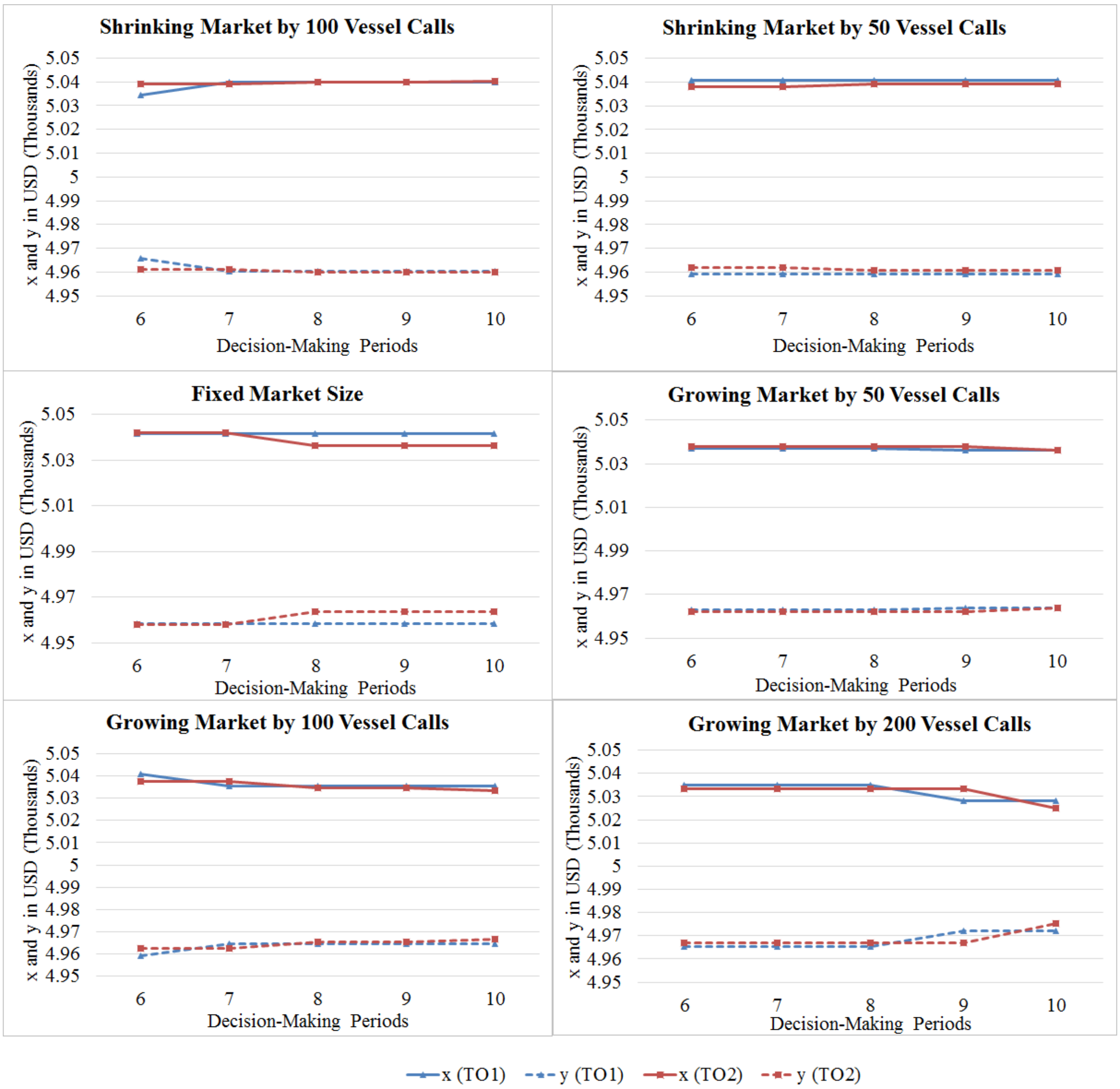

Figure 3.10. Coopetition Strategy when Changing Total Market Size

3.3.2.2 Resulting market shares of terminals

Owing to the competitive nature, the market shares of terminal operators can be affected by the coopetition strategy. Thus, the variations in the resulted market shares at the stable market condition are illustrated in Figure 3.11 considering all 11 cases under consideration, where panels (a), (b) and (c) respectively represent the results related to the price adjustment, cost reduction, and the time efficiency improvement scenarios. Since it is important to understand the overall impacts on the external competitors, the total market share of port h_2, which is calculated as the summation of market shares related to TO3 and TO4 are considered. As per the results, the market shares of both TO1 and TO2 have increased with the coopetition because we assumed an equal 25% market share with all four terminals as the initial condition. It is reasonable that both TO1 and TO2 receive comparatively high market shares with the price adjustment scenario than the other two scenarios owing to the high significance of terminal price (handling charges) in the generalized cost function of shipping lines. However, equal market shares are obtained by both TO1 and TO2 with the cost reduction scenario, since it does not influence the market share of terminals on an individual basis, despite its influence on the terminals' profit. Owing to the behavior of a private terminal (TO2) as a free rider, which focuses more on the competitive effort of own terminal while taking the advantages of high cooperative effort made by a public terminal, a relatively higher market share is obtained by TO2 than TO1 in all public-private combinations, with the price adjustment and time efficiency improvement scenarios. The lowest market share of port h_2 is generated with the public-public (μ_0) case with the price adjustment scenario, despite the highest market share of h_2 is generated from the same case with the time efficiency improvement scenario. Although this analysis with multiple periods is done with the assumption of stable market size to eliminate the impacts from changes in the external market environment, the coopetition strategy in growing and shrinking market conditions are analyzed only considering the private-private case with the price adjustment scenario as an example to understand the implications related to those market condition. However, to maintain the brevity, a summary of results is presented in Appendix D. Accordingly, we analyzed four market situations such as growing slightly (by 50 vessel calls per year), growing moderately (by 100 vessel calls per year), shrinking slightly (by 50 vessel calls per year), and shrinking moderately (by 100 vessel calls per year).

In terms of policy implications with a practical scenario, the resulting market shares from the coopetition strategy are affected by the significance of implemented competitive and cooperative approaches on the competitive market. For instance, if the terminal operators' budget allocation as the cooperative effort levels are utilized for improving a single-window system, while their budget allocation as the competitive effort levels are utilized for one of the three alternative competitive approaches, the resulting market shares from coopetition would be affected by the relative significance those single window system or alternative competitive approaches on reducing the generalized cost of shipping lines. Thus, the impacts of coopetition can be analyzed quantitatively with a case study-based approach while utilizing the industrial data. Considering the main contribution of this study is to propose the coopetition concept to the intra-port level, we discuss the implications of the proposed coopetition strategy by comparing among 11cases under consideration by having the same parameters and assumptions during the entire calculation process.

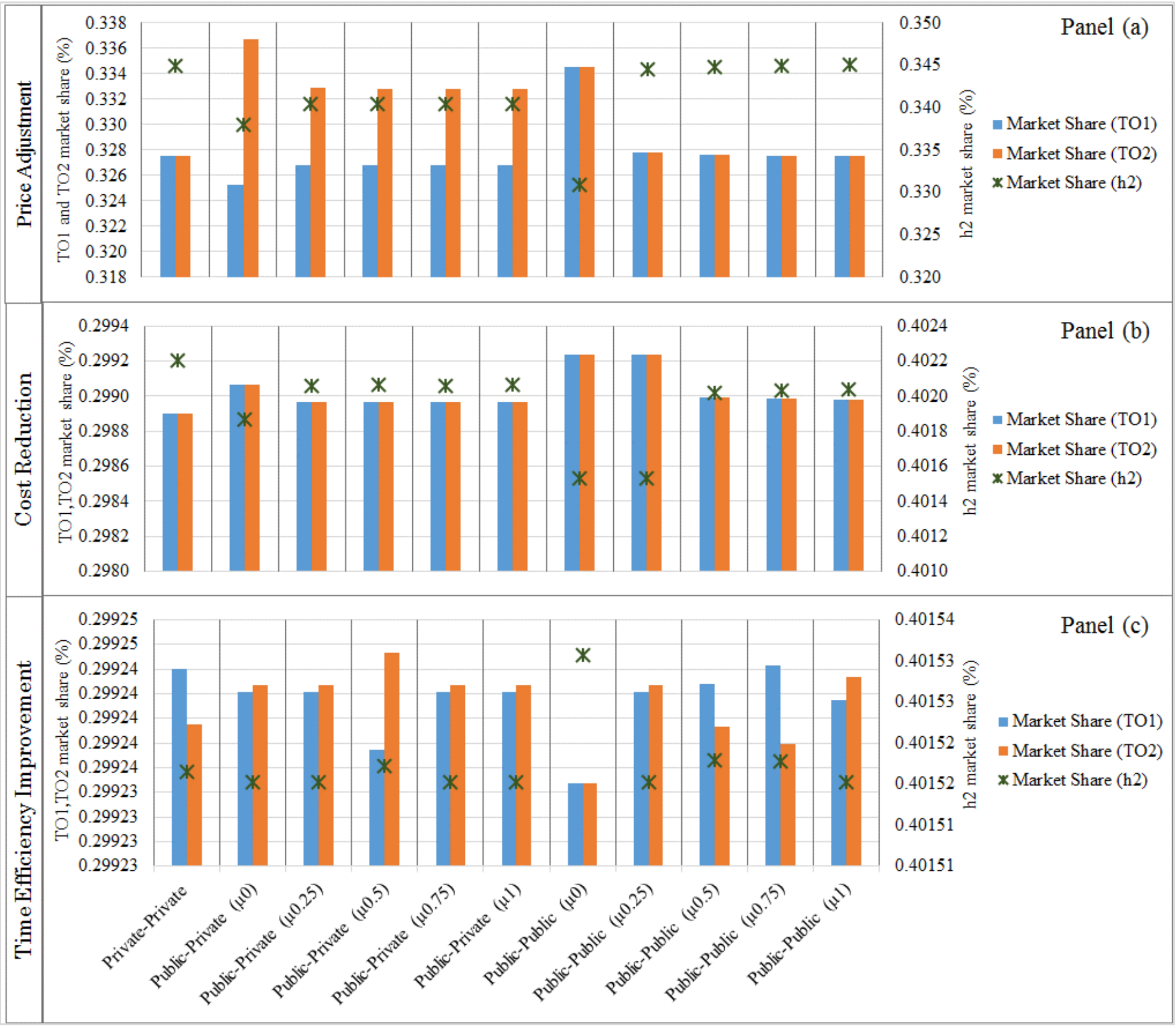

Figure 3.11. Variations in Resulting Market Share

Moreover, the cases related to the least and highest market shares of TO1, TO2, and the port h_1 at the stable market condition are summarized in Table 3.4 in terms of all three alternative scenarios. Accordingly, TO1 and TO2 derive their least market shares from the public-private (μ_0) and the public-public (μ_1) cases, respectively in case of price adjustment scenario. Owing to the behavior of TO2 as a free rider, it receives the highest market share from the public-private (μ_0) case while creating the least market share for TO1 from the same case. Moreover, TO1 and the entire port h_1 obtain the highest market shares from the public-public (μ_0) case could be due to the high cooperation among both public terminals on enhancing the entire port competitiveness. Similarly, the public-public (μ_1) case generates the least market share for port h_1 owing to the less cooperation among its public terminals as they focus on maximizing their own profit. When considering the results from the cost reduction scenario, the public-public ($\mu_{0.25}$) case generates the highest market shares for the TO1, TO2, and port h_1 and the private-private case generates the least market shares for all of them. In the time efficiency improvement scenario, the public-public (μ_0) case generates the least market shares for the TO1, TO2, and the entire port h_1, possibly because of the focus of both public terminals on y_t^i than x_t^i, which results in the least reduction of handling time at container terminals. Thus, it is important to have the best mixture of both competitive and cooperative efforts to receive a high return from the coopetition strategy. In the case of public-public (μ_1), the port h_1 obtains its highest market share since its terminals reduce the handling time than the initial condition during the early decision-making periods and also maintain high y_t^i levels after reaching a stable market condition. The least market shares of port h_1 under the cost reduction and time efficiency improvement scenarios are derived from the private-private and public-public (μ_0) cases, respectively.

Table 3.4. Summary of Resulting Market Shares

		Market Share		
		TO1	**TO2**	**h_1**
Price Adjustment	Lowest	public-private (μ_0)	public-public (μ_1)	public-public (μ_1)
	Highest	public-public (μ_0)	public-private (μ_0)	public-public (μ_0)
Cost Reduction	Lowest	private-private	private-private	private-private
	Highest	public-public ($\mu_{0.25}$)	public-public ($\mu_{0.25}$)	public-public ($\mu_{0.25}$)
Time Efficiency Improvement	Lowest	public-public (μ_0)	public-public (μ_0)	public-public (μ_0)
	Highest	public-public ($\mu_{0.75}$)	public-private ($\mu_{0.5}$)	public-public (μ_1)

3.3.2.3 Resulting profits of terminals

Since the coopetition strategy influences the profit of terminal operators, this section summarizes the variation of resulting profits from the coopetition. Therefore, the cases related to the lowest and highest profits of TO1, TO2, port h_1, and port h_2 are summarized in Table 3.5 by considering each alternative competitive approach. Accordingly, in terms of all three alternative competitive approaches, the highest profit of TO1 is generated from the cases related to the public-private terminal combinations. This is reasonable because the public terminal, TO1 receives the additional revenue such as the terminal fee paid by the private terminal and the navigation charges from all vessels called at port h_1 with the public-private cases, owing to the assumption that both the port authority and the public terminal are represented by the same economic entity. Besides, TO1, TO2, and the entire port h_1 obtain the lowest profit mainly from the private-private case since both private terminals have to pay terminal fees to the port authority and the navigation revenue is not included in the profit of any private terminal. With respect to the public-public terminal combination, since we assume that the terminal operators in the external competitive port are also as public terminals, it is reasonable to receive the highest profit of h_2 from the public-public (μ_1) case in both the price adjustment and cost reduction scenarios.

Table 3.5. Summary of Resulting Profit

		Profit			
		TO1	TO2	h_1	h_2
Price Adjustment	Lowest	private-private	private-private	private-private	public-private (μ_0)
	Highest	public-private ($\mu_{0.75}$)	public-public (μ_0)	public-public (μ_0)	public-public (μ_1)
Cost Reduction	Lowest	private-private	public-private (μ_1)	private-private	public-private (μ_0)
	Highest	public-private ($\mu_{0.25}$)	public-public ($\mu_{0.5}$)	public- private ($\mu_{0.5}$)	public-public (μ_1)
Time Efficiency Improvement	Lowest	private-private	private-private	private-private	public-private (μ_0)
	Highest	public-private ($\mu_{0.5}$)	public-public (μ_1)	public-private ($\mu_{0.5}$)	public-public (μ_0)

In the case of time efficiency improvement scenario, the highest profit of h_2 is received from the public-public (μ_0) case could be due to the least improvement in time efficiencies at TO1 and TO2 and the lowest market share of h_1 in this case. Due to the focus on both the cooperative and competitive efforts by the public and private terminals respectively, in port h_1, and their interests on both the user surplus and profit maximization objectives with the public-private (μ_0) case, the port h_2 receives its lowest profit from the public-private (μ_0) case under all three alternative scenarios on competitive effort level. When considering the scenarios related to the operation cost reduction and time efficiency improvement, the highest profit of port h_1 derives with the public-private ($\mu_{0.5}$) case, which gives equal weights for the profit and user surplus components in the social surplus function of the public terminal. Since the public-public (μ_0) case generates the highest market share for the port h_1 and both public terminals are not required to pay a terminal fee to the port authority, the highest profit of port h_1 is obtained from the public-public (μ_0) case in the price adjustment scenario.

3.4 Conclusions and Policy Implications from Chapter 3

This chapter proposes a coopetition strategy among terminal operators in a single port to overcome challengers when competing with external competitors in the market. Terminal operators cooperate with different strategies to enhance the entire port competitiveness while simultaneously maintaining their competitive interactions to increase the individual terminals' performance. The benefits received from high port competitiveness with the common value creation by terminals in one port generate a win-win solution, which enables them to over-perform the external competitors. The coopetition strategy is proposed as a non-linear optimization problem, which allows terminal operators to choose appropriate levels of competitive and cooperative efforts as the main decision variables. Three alternative scenarios are assumed in terms of value appropriation with competitive effort level, namely price adjustment, operation cost reduction and time efficiency improvement at individual terminals. As per the different combinations of terminal ownership types, this chapter analyzed 11 different cases with the profit maximization objective of private terminals and the multiple forms of social surplus function, which consider different extents of profit and user surplus combinations as the objective of public terminals.

The main findings from Chapter 3 can be summarized as follows. Owing to the profit maximization objective of the private terminal, it does not utilize the entire available budget on the coopetition strategy in all situations, although the public terminal with user surplus maximization objective spends the entire budget on the coopetition. Therefore, the port authority should have an effective framework for utilizing the budget allocated as the cooperative effort level for receiving continuous support from the private terminals on the coopetition strategy. Both the private and public terminals tend to reduce their prices down to a certain minimum level while increasing their competitive effort levels, and then, maintain a constant price level by increasing their cooperative effort levels. Thus, the policy instruments such as minimum price level or price ceilings can be imposed by the port authority to prevent extreme price competition among terminals while simultaneously encouraging strategies such as price discounts and rebates, which are significant in maintaining a competitive average price for the entire port.

Both public and private terminals maintain relatively stable cooperative and competitive efforts when the total market size increases and they reduce both the cooperative and competitive efforts at a large market size because they do not have incentives on coopetition strategy due to the terminals' capacity constraints, which prevent them from handling a high number of vessel calls given from a large market. Hence, a coopetition strategy is meaningful for ports located in highly competitive markets, where all terminals have lower demand than their capacities. When considering a coopetition strategy between two private terminals in one port and their competitive efforts are devoted to the price adjustment, both terminals start with high cooperative effort levels focusing on value creation to enhance the entire port market share, but subsequently focus on their individual competitive efforts that confirm the value appropriation on individual terminals to obtain a larger share from the expended port market. When considering the public-private combination and the public terminal focuses only on user surplus maximization, the private terminal tends to behave as a free rider and concentrates on its own competitive effort, while receiving benefits from the high cooperative budget allocation made by the public terminal. Thus, when a port has a market-leading public terminal, a coopetition strategy supports the growth of the private terminals in the same port considering the long-term positive externalities. When both public terminals focus on only user surplus maximization, the port authority can receive high incentives from these terminals to increase the entire port competitiveness, which facilitates effective port development policies. When comparing the results from 11 cases, the highest price, highest operation cost and the highest handling time of both terminals that implement the coopetition strategy are derived when they are public terminals with only the user surplus maximization objective, because of their focus on cooperative efforts. The highest market share for the port that implements the coopetition strategy under the price adjustment scenario is derived when it's both public terminals focus on only user surplus maximization and that of time reduction scenario is derived when it's both public terminals focus only on the profit maximization objective. Although we discuss some significant results derived after achieving the stability in the coopetition strategy due to the assumption of fixed total market demand with multiple periods, the stability in the coopetition strategy is not achieved in some cases such as growing or shrinking market situations.

3.5 Limitations of Chapter 3

As the limitations of this chapter, the implications related to the proposed coopetition strategy are discussed with a numerical analysis based on a hypothetical budget allocation scenario, which does not fully represent the industrial practices in the current context. However, as one of the very first studies to discuss the simultaneous competitive and cooperative interactions at the intra-port level, the significant implications could be derived while comparing among different cases that were treated in an equal manner. Thus, further studies may consider the case study-based approaches as well, which enable interpreting the numerical values in detail. Although we assume a price discount approach in this study due to the consideration of competitive effort level in terms of individual terminal prices, the price can be increased when considering other pricing strategies. Moreover, we assume a competitive market in a simplified manner, which consists of four container terminals that are operated in two competing ports. Moreover, equal demands and other parameters are assumed with all four terminals to clearly understand the difference between before and after implementing the coopetition strategy. Therefore, a complex market setting can be considered in further studies.

Moreover, since we consider the coopetition strategy with a competitive market, the influences from dedicated terminals, liner-own terminals, and the other inter-organizational relationships between terminal operators and shipping lines are not considered because of the analysis of such influences are beyond the scope of this study. Despite considering multiple decision-making periods by holding the assumption that the external competitors do not change their decisions over the analysis period, the external competitors would react in securing their market shares in a practical situation and further studies may consider the reactions of these external competitors as well. Therefore, further developments can be made to the model to analyze the simultaneous decision-making of terminals, because the current study considers a unilateral decision-making approach. Besides, according to the model structure, a stochastic user equilibrium situation can be obtained in the cargo flow allocation due to the consideration of the flow-dependent model assuming a bi-level optimization problem with operator level (upper) and shipping lines (lower). Since the contribution of this study is mainly to introduce the coopetition to the intra-port level, there can be many possible aspects for making such enhancements in the model development and analysis, which will be considered in future studies.

Note: Related Journal Publications from Chapter 3

- ✓ Kavirathna, C.A., Kawasaki, T. and Hanaoka, S. (2019) Intra-port coopetition with different combinations of terminal ownership, Transportation Research Part E: Logistics and Transportation Review, 128: 132-148. https://doi.org/10.1016/j.tre.2019.06.001

CHAPTER 4: INTRA-PORT COOPETITION STRATEGY WITH A VESSEL TRANSFER POLICY AMONG CONTAINER TERMINAL OPERATORS IN A SINGLE PORT

4.1 Introduction

The coopetition can be implemented on different levels such as strategic, tactical and operational levels. Since the previous chapter discusses an intra-port coopetition strategy in the form of a budget allocation problem, which is mostly a strategic decision of a terminal operator, this chapter focuses on the application of intra-port coopetition considering an operational decision of a terminal operator in the form of a berth allocation. As per the Lavie (2006), the resource-based argumentation can be considered as a possible way of value capturing through coopetition because the usage of supplementary and complementary resources in an integrated approach can generate more benefits than using them separately. The budget allocation problem discussed with the previous chapter focuses on intra-port coopetition when competing with terminals from external competing ports, which addresses the implications of intra-port coopetition to a port competition problem. However, this chapter discusses the implications of intra-port coopetition mainly on the port competitiveness by limiting the discussion only to a single port without quantitatively analyzing the impacts on external competing ports and terminals.

Competitiveness of a port is influenced by various internal and external factors and some of these factors can be controlled by different strategies made within the port. Congestion and delays at container terminals and longer vessel waiting times are significant operational issues that can reduce the competitiveness of a port because shipping lines attempt to reduce the time in port especially the waiting time at the anchorage area. Therefore, major seaports come up with various strategies such as window berthing, dedicated terminals, and just-in-time sailing, among others, to reduce the waiting time and congestion at container ports, which enhance the utility of shipping lines. Although it is difficult to eliminate these congestion and delay issues completely, a proper arrangement and collaboration among terminal operators can help to reduce these issues significantly. Therefore, this chapter focuses on an intra-port coopetition strategy, which effectively balances the competition and cooperation among terminal operators in a single port, to reduce congestion and delays at container terminals, which eventually increases the competitiveness of the entire port.

4.1.1 Coopetition Strategy with the Vessel Transfer Policy

This chapter proposes a coopetition strategy to minimize delays and congestion in vessel operations at container terminals. Container berths and handling equipment are significant resources at container terminals to carry out vessel handling functions. However, in some instances, a terminal operator faces challenges due to the limitation of these resources available within its own terminal, which leads to delays and congestion. Besides, the practical issues such as the variation of vessel arrival patterns, mismatching berthing windows, accidents, and technical breakdowns, among others can cause delays and congestion at container terminals, which generate an excessive number of vessel calls beyond the terminal's available capacity at a given time. The coopetition among container terminals can be one possible solution to minimize these adverse impacts related to the operational issues because of the similarities in resources and handling practices at most container terminals.

The coopetition strategy in this chapter comprises two different stages namely, contract and operation stages. The contract stage represents the stage where terminal operators make initial negotiations with shipping lines on terms and conditions, and decide the vessel calls at individual terminals. The operation stage is the stage where vessels are physically arriving at ports for container loading/ unloading functions. Generally, due to the differences in terminal ownerships, the terminal operators have only competitive interactions with each other during both the contract and operation stages and they handle only their desired vessel calls received from the negotiations made with shipping lines in the contract stage. Thus, terminals compete with each other to obtain a greater number of vessel calls towards own individual terminal. Here onwards, the term 'contracted terminal' refers to the terminal selected by shipping lines during the contract stage. However, due to such extreme competitive interactions, a terminal operator could experience congestion and excess vessel calls at own terminal due to the limited container berths and resources at own terminal, although at the same time, another terminal in the same port has idle container berths and resources. Therefore, vessels have to wait at anchorage even when some idle container berths are available inside the port because those idle container berths are owned by another terminal operator. However, such instances create a negative impression about the entire port as a congested port with long waiting times, which reduces the competitiveness of the entire port. Less competitiveness of the entire port can have negative impacts on all terminal operators in that port because the port-related factors have a significant influence on the terminals' demand when attracting a higher number of vessel calls than the external competing ports in the same market.

The coopetition strategy is proposed which simultaneous presence both competitive and cooperative interactions among terminal operators in one port. Accordingly, although terminals compete with each other during the contract stage to attract a higher number of vessel calls towards the own terminals, they cooperate with a vessel transfer policy during the operation stage, where the actual vessel operations are carried out, as illustrated in Figure 4.1. This vessel transfer policy enables vessel transfers between two terminals if one terminal experiences congestion and excess vessel calls when another terminal in the same port has idle container berths and resources. Thus, we refer to the term 'operation terminal' for the terminal who actually carried out the vessel operation after executing a vessel transfer. As discussed in Chapter 1, the coopetition consists of two main components such as value creation and value appropriation, derived from cooperation and competition among market players, respectively. Therefore, when describing the coopetition strategy in Chapter 4, the value creation is defined in terms of terminal operators' cooperation in enhancing the overall port competitiveness by reducing average waiting time, berthing delays and congestion with the vessel transfer policy in the operation stage. Moreover, the individual value appropriation can be discussed with their competition during the contract stage to attract more vessel calls toward the own terminal.

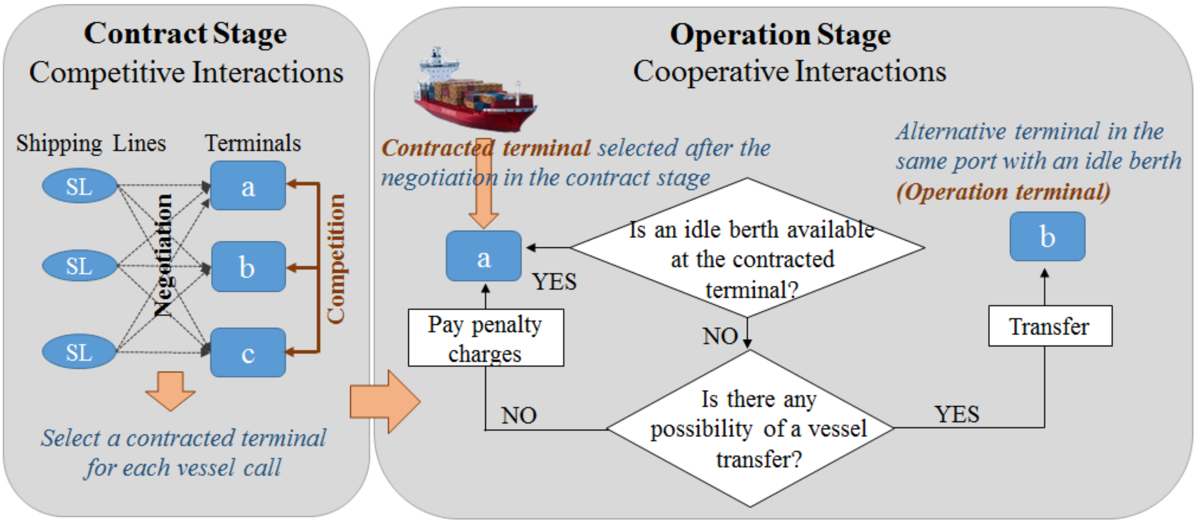

Figure 4.1. Proposed Intra-port Coopetition Strategy

The effectiveness of the proposed coopetition strategy is evaluated in comparison to the extreme competition strategy where terminals have only competitive interactions in both the contract and operation stages, which is considered as the status quo. Therefore, competition and coopetition strategies are described in Table 4.1. With the coopetition strategy, terminals can enhance the competitiveness of the entire port by reducing congestion and delays at individual terminals, which may result in positive externalities for all terminals in that port. Since coopetition can incorporate the advantages of both competition and cooperation simultaneously, its implications are different from the extreme competitive or cooperative scenarios, discussed in previous studies. For instance, the cooperation with the vessel transfer policy in this study is different from extreme cooperation or coalition among terminal operators in one port, which leads to the higher prices and lower market shares of members in the coalition as discussed by Saeed and Larsen (2010). In our proposed strategy, although terminals cooperate with the vessel transfer policy during the operation stage, they still act as individual economic entities who compete with each other during the contract stage. Moreover, the coopetition strategy enables an effective competition among terminal operators during the contract stage while reducing the risks of terminal congestion and delays even if the demand exceeds the capacity of individual terminals. This is possible because each terminal can employ an extended capacity by cooperating with other terminals in the same port during the operation stage. Preserving such competitive interactions in the contract stage is significant to enhance the port competitiveness because it helps to maintain a competitive average price for the entire port when compared to the price of external ports and terminals in the market. Besides, the competitive interactions among terminals are significant for distributing the total port demand among its terminal operators more effectively owing to their different terminal ownership types.

Table 4.1. Competition and Coopetition Strategies

Strategy	**Description**
Competition	This is the status quo, where all terminal operators compete with each other during both contract and operation stages
Coopetition	Terminal operators have competitive interactions during the contract stage to attract a greater number of vessel calls toward their own terminals but they have cooperative interactions during the operation stage with the vessel transfer policy.

Since the coopetition strategy in Chapter 4 also focuses on decision-making on the proposed coopetition strategy, it is important to discuss the target decision-makers and affected parties from the proposed coopetition strategy. Since Chapter 4 focuses on both private and public terminals, the policy implications can be derived focusing on their ownership types as well. Owing to the consideration of vessel transfer policy, shipping lines are greatly affected by the proposed coopetition strategy in multiple ways. First, the proposed vessel transfer policy can reduce the waiting time of vessels and enhance the utility of shipping lines. However, due to the transfer of vessels between terminals with different ownership types, shipping lines may be affected by operational issues and compatibility between terminals. Moreover, coopetition strategy can influence on contract stage when selecting a contracted terminal for individual vessel calls because shipping lines would utilize their past vessel transfer experiences when making the future contracts with shipping lines. Besides, the port authority and private terminals are affected by the terminal fee collection policies related to the transfer vessels. Apart from that, policy implications can be derived for other logistic companies such as inter-terminal container transportation companies, and stevedores among others because they are required to have integrated logistics functions to support the proposed vessel transfer policy.

4.1.2 Objectives of Chapter 4

Therefore, this chapter aims to achieve two main objectives as follows;

Objective [4.1]. To analyze the effectiveness of intra-port coopetition strategy to reduce berthing delays and idle berths at container terminals considering different mixtures of terminal ownership types

Objective [4.2]. To understand the coopetition behavior among terminal operators in one port with the objective of minimizing total berthing delays or maximizing total profit of the port considering policy scenarios

Accordingly, the first objective evaluates the effectiveness of the proposed intra-port coopetition strategy by measuring the possible reduction of berthing delays and idle berths at container terminals. Moreover, this objective analyzes the results of coopetition considering all possible combinations of terminal operators in a single port, such that the vessel transfer policy between the private-private and public-private terminal combinations are considered depending on the case study under consideration. Since we utilize a simplified analysis method for Objective [4.1] just to understand the effectiveness of intra-port competition strategy, in Objective [4.2], we analyze the coopetition behavior among terminal operators in a port for minimizing total berthing delays and maximizing the combined profits of terminal operators in one port, which are discussed as separate scenarios. Although the Objective [4.1] is analyzed with all possible combinations of terminal ownership types separately, the Objective [4.2] is analyzed by considering all terminal operators in the focused port simultaneously. As discussed in Chapter 2, despite the availability of several previous studies on optimizing terminal facilities with various objectives such as minimizing operation cost (Gudelj et al., 2010; Legato et al., 2014; and Moorthy, 2006), minimizing total service time of vessels (Imai et al., 2007; Wang et al., 2015), and minimizing total tardiness cost (Hansen et al., 2008; Kim and Moon, 2003; Zhen et al., 2011), among others, they focus on purely the optimization of physical components such as berths, yard space, equipment, etc within a given terminal without considering practical implications associated with vessel transfers and facility sharing between different terminals such as pricing, revenue sharing, terminal profit, and terminal ownership types, among other factors. Therefore, the contribution of this study confirms with introducing an intra-port coopetition strategy incorporating those practical implications with a mathematical modeling approach.

4.1.3 Focused Study Area

Since we propose a coopetition strategy to overcome challenges associated with berthing delays and congestion at container terminals, which are related to the operational aspects of container terminals, it will be easy to understand the implications related to the proposed strategy by applying and testing it with an appropriate case study. Therefore, we choose the Port of Colombo as the case study for testing the proposed strategy considering its high applicability for the intra-port coopetition due to the following main reasons.

a) Competition among container terminals in Colombo and different ownership types

The Port of Colombo is a main transshipment hub in the South Asian region due to its strategic location with main sea routes. This study focuses on three main container terminals in Colombo namely, Jaya Container Terminal (JCT), South Asia Gateway Terminal (SAGT) and Colombo International Container Terminal (CICT), owing to the intense competition among them as indicated in Figure 4.2 with their container handling statistics. As a public terminal, JCT is directly operated by the Sri Lankan Port Authority (SLPA) and SAGT and CICT are concession (private) terminals operated under BOT agreements for 30 years to 35 years, respectively. As per Figure 4.2, CICT started its operation in 2013 and indicated a speedy growth in container handling, also giving competition to the other two terminals. The competition among terminals is one of the significant factors for implementing the proposed intra-port coopetition strategy because it helps to maintain a competitive average price for the entire Colombo port during the contract stage, which enhances the port competitiveness over competing ports in the same market.

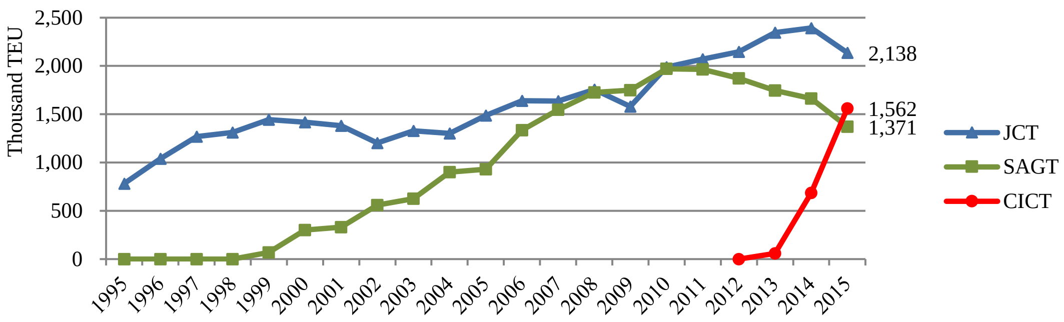

Figure 4.2. Throughputs of Container Terminals

b) Joint initiative on increasing overall port competitiveness by minimizing berthing delays

Regardless of the competitive situation among terminals in Colombo, these three terminal operators came up with a joint initiative in 2018 to enhance the overall competitiveness of Colombo by minimizing the average vessel waiting time while reducing berthing delays and congestion at individual container terminals (Mudugamuwa, 2018; Nanayakkare, 2018). As per the interviews conducted with the SLPA and the terminal operators by authors, there are instances that vessels have to wait at anchorage due to the unavailability of idle berths and facilities at their desired contracted terminals although some idle facilities are available at another terminal in Colombo at the same time. However, it creates a negative impression on the overall efficiency of Colombo as a congested port with a long waiting time. With this joint initiative, terminals agreed to handle excess vessels of their competitive terminals if they have idle berths and facilities at their own terminals, thereby aim to enhance the overall competitiveness of the Colombo port. Apart from enhancing the port competitiveness, terminals can improve their berth utilization by handling excess vessels of their competitors, which is more beneficial for them than maintaining idle berths and facilities. Even with this joint initiative, terminals still compete with each other during the contract stage to attract more vessel calls towards own terminals because they act as individual economic entities.

c) Consent from shipping lines on vessel transfers

As another important factor in successfully implementing the proposed coopetition strategy, it is important to have consents from shipping lines on this kind of vessel transfer arrangement. As per our interviews with the SLPA and the preliminary data analysis, over 70% of shipping lines called at Colombo are simultaneously being customers of at least two different terminals. Thus, there is a high possibility to obtain shipping lines' consent on this vessel transfer arrangements if no additional cost will be transferred to them. Besides, shipping lines generally have a high willingness to reduce the time in port especially waiting time at anchorage area because their revenue is mainly generated by the sailing of vessels, and terminals/ ports are considered as the cost centers for shipping lines rather than profit centers.

d) Possibility to have integrated supporting services (inter-terminal transfer systems, common information platform, among other)

Besides the above factors, it is important to have better integration among terminal operators on supporting logistics functions such as inter-terminal transfer of containers, shared information platform, etc for successfully implementing the proposed intra-port coopetition strategy. When considering the Port of Colombo, its three terminal operators have already outsourced their inter-terminal transfer functions to the same logistic provider, which is a great advantage on this vessel transfer policy due to the possible inter-terminal transfers of containers. Moreover, they agreed on this joint initiative for sharing required information through a common platform and already use a common system for some documentation and monitoring functions as well.

4.2 Analysis for Objective [4.1]

4.2.1 Methodology for Objective [4.1]

Since the Objective [4.1] evaluates the effectiveness of the intra-port coopetition strategy with a vessel transfer policy among different combinations of terminal operators, we utilize a simplified approach to understand the applicability of the proposed strategy in the context of the Port of Colombo. It is important to conduct such a preliminary analysis with the first objective before formulating a detailed model with the second objective. As mentioned previously, we consider three main terminal operators in Colombo for the analysis. Therefore, for the first objective, we utilize the actual vessel handling data at the Colombo port from 1st April 2017 to 31st March 2018 due to data availability during this period. The consideration of the vessel handling data for a duration of one year enables us to incorporate the seasonal variations of the vessel arrival patterns at each terminal with the proposed coopetition strategy.

4.2.1.1 Cases related to the different combinations of terminal ownership types

Due to the presence of both the public and private terminals in the same port, the profit of a terminal varies based on the different combinations of terminal ownership types participated in the coopetition strategy. Therefore, we consider all possible combinations made out of three terminals in Colombo as given by Case A, B, C, D, and E, in Table 4.2 with their strategies. Case A implies the status quo, where all three terminal operators maintain their initial competition strategy without any vessel transfers with other terminals. Case B, C, and D are associated with the coopetition strategy between only two terminals at once while the remaining terminal maintains its initial competition strategy. As an example, in case B, only JCT and CICT execute the coopetition strategy while SAGT maintains its initial competition strategy. Case E indicates the situation where all three terminal operators execute the coopetition strategy collectively. The consideration of different combinations of terminal operators as different cases enables us to discuss significant policy implications related to the coopetition strategy because of their different ownership types.

Table 4.2. Cases Related to the Competition and Coopetition Strategies

Case	Description
A	All three terminals maintain the competition strategy
B	JCT and CICT execute the coopetition strategy, SAGT maintains its competition strategy
C	JCT and SAGT execute the coopetition strategy, CICT maintains its competition strategy
D	CICT and SAGT execute the coopetition strategy, JCT maintains its competition strategy
E	All three terminals execute the coopetition strategy collectively

4.2.1.2 Status for vessel transfer decisions and model assumptions

Since a vessel can be transferred only if one terminal experiences idle container berths and facilities and another terminal in the same port experiences excess vessel calls and congestion, simultaneously, the probabilities of such occurrences are calculated considering the actual vessel arrival data at the Port of Colombo within a year. As for the simplification with the Objective [4.1], we sorted the vessel arrival data of the whole year on a daily basis, which gives the number of vessel arrivals at each terminal within a given day. Therefore, to understand the possibility of vessel transfers, the occurrence of the following six status are analyzed as illustrated in Figure 4.3. The horizontal and vertical axis of Figure 4.3 implies the information related to Terminal-*1* and terminal-*2*, respectively. Therefore, K_1 and K_2 imply the capacities of terminal *1* and *2*, respectively, in terms of numbers of berths and Q_1 and Q_2 imply the numbers of vessel arrivals at terminals *1* and *2*, respectively, within a given day. Accordingly, the possibility of occurrences of each status is significant in understanding the applicability of the proposed coopetition strategy in the Port of Colombo.

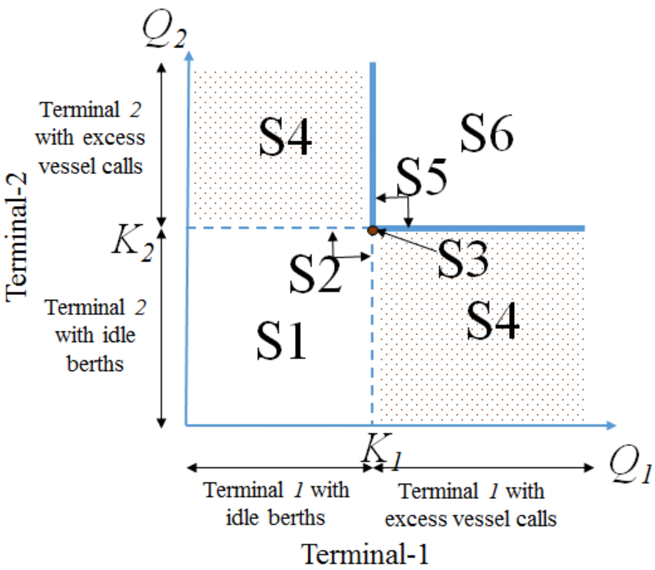

Figure 4.3. Status Related to the Vessel Transfer Policy

- ✓ Status 1: the area represented by S1 in Figure 4.3, where both terminals have idle berths. Since both terminals have idle container berths on the same day, it is not required to execute any vessel transfers between terminals, thus the vessel transfer policy is not applicable when a port has a high probability for the occurrence of Status 1
- ✓ Status 2: the dotted line segments, where one terminal has idle berths whereas the other terminal is exactly fully occupied. Since both terminals have no excess vessel calls in this status, it is not required to execute any vessel transfers regardless of the availability of idle berths at one terminal.
- ✓ Status 3: the cross-segment of dotted lines and solid-bolded lines, where both terminals are fully occupied. Since both terminals are fully occupied, it is not necessary to execute any vessel transfers between terminals in this status. Moreover, no terminal experiences idle container berths or excess vessel calls in this status.
- ✓ Status 4: two segments of area S4, where one terminal has excess vessel calls when the other has idle container berths. The vessel transfers can be executed only in this status because the excess

vessels of one terminal can be transferred to the idle berths of the other. Therefore, it can reduce berthing delays at one terminal and idle berths at another terminal occurred within the same day.

- ✓ Status 5: the solid-bolded line segments, where one terminal has excess vessel calls when the other is exactly fully occupied, which indicates the congestion and berthing delays at the port. Although one terminal experiences excess vessel calls, it is not possible to execute any vessel transfers due to the unavailability of idle berths at another terminal.
- ✓ Status 6: the area S6, where both terminals have excess vessel calls. Since both terminals experience excess vessel calls on the same day, it is not possible to execute vessel transfers in this status. A high probability for the occurrence of this status implies a very congested port condition, which should be solved with either restricting vessel arrival patterns while negotiating with shipping lines or by capacity enhancement of terminals and port.

As per the explanation, the vessel transfers can be executed with only Status 4. When considering Status 4, the number of vessels that can be transferred from terminal *1* to terminal *2* (T_{12}) is decided by the lowest of the two magnitudes; the number of excess vessel calls at terminal *1* (Q_1- K_1) in a given day and the number of idle berths at terminal *2* (K_2-Q_2) within the same day as given by Equation (4.1). Following a similar approach, the number of vessel transfers from terminal *2* to terminal *1* (T_{21}) can be decided. The non-negativity property of the numbers of idle berths and the excess vessel calls are confirmed with Equations (4.2) and (4.3), respectively.

$$T_{12} = min[(Q_1 - K_1)^+, (K_2 - Q_2)^+] = \begin{cases} Q_1 - K_1 & K_2 - Q_2 \geq Q_1 - K_1 \geq 0 \\ K_2 - Q_2 & Q_1 - K_1 \geq K_2 - Q_2 \geq 0 \\ 0 & otherwise \end{cases} \quad (4.1)$$

$$(K_i - Q_i)^+ = max\{0, (K_i - Q_i)\} \qquad \forall i \in I \quad (4.2)$$

$$(Q_i - K_i)^+ = max\{0, (Q_i - K_i)\} \qquad \forall i \in I \quad (4.3)$$

To come up with the vessel transfer policy in this study, several assumptions are made with the model development as follows. Since this study discusses the effectiveness of the coopetition strategy to minimize disadvantages associated with the current competition strategy rather than solving a pure berth allocation problem, an effort is taken to develop a relationship between significant policy-related variables. Therefore, the berth allocation process follows a practical decision-making approach such that each vessel is transferred to a competitor's berth if the contracted terminal has no idle berths available within the vessel's arrival day. Therefore, two competitive terminals cooperate with a vessel transfer policy. A penalty charge is assumed to be paid by a terminal operator to the shipping lines if the vessel operation could not be commenced within the arrival day of the vessel. This penalty charge can be associated with the loss of goodwill of a particular terminal due to longer waiting times. In the practical scenario, the payment of penalty charge can be considered as a discount from the container handling charges (terminal price) given by terminals to the shipping lines in case of berthing delays. Thus, an amount equals to the penalty charge is discounted when shipping lines pay the container handling charge to the terminal operators, which is reasonable because both the container handling charge and the penalty charge are calculated corresponding to the number of TEUs handled from a vessel. Besides a terminal operator incurs a minor cost for maintaining idle container berths, which can be considered as an opportunity cost of an idle berth, because such idle berths cannot generate revenue during its idle stage. Terminal operators are incentivized to accept transfer vessels from its partner terminal rather than maintaining berths at the idle stage because they receive a transfer price from the partner terminal when handing its excess vessels. Moreover, the number of TEUs handled during a vessel call is taken as an average value for the simplicity with the Objective [4.1] only. When deciding berth allocations, considering the average vessel turnaround time at Colombo, which is about 20 hours, it is assumed that one berth is occupied by only one vessel within a given day.

4.2.1.3 The game-theoretical approach in decision-making

Game theory describes a rational decision-making approach, which is extensively used in previous studies for analyzing competitive and cooperative interactions among market players. Therefore, this study incorporates a game-theoretical approach for evaluating the effectiveness of coopetition strategy among terminal operators in one port compared to their initial competition strategy.

Following a game-theoretical approach, a rational decision-maker selects the best strategy among all alternatives to maximize the individual payoff. Therefore, the minimum satisfying condition for executing the coopetition strategy is derived in the context of individual rationality with the characteristic function. A characteristic function of a cooperative game with transferable utilities on a set of players confirms the “super-additivity” (Saeed and Larsen, 2010). The super-additivity property indicates that the payoff which two players achieve by cooperating with each other should be greater than or equal to the summation of payoffs they can achieve by working individually. Here, the cooperation implies the vessel transfer policy among terminals in the operation stage as a part of the coopetition strategy. As given in Equation (4.4), the individual rationality implies that the individual agent will participate in the cooperation only if he can achieve a payoff at least as much as he can achieve on his own. Since this study focuses on coopetition rather than pure cooperation, the collection of terminal operators who partnered with the coopetition strategy is not a single economic entity because they simultaneously maintain competitive interactions as well. Therefore, the decision-making approach of this study focuses on individual rationality rather than group rationality. In each case, we derive a common condition that simultaneously satisfies the individual rationality of each terminal who participates in the coopetition strategy. Therefore, such a common condition eventually satisfies the group rationality and the super-additivity property. The payoff function of a terminal operator is associated with its profit. Thus, as the minimum satisfying condition for executing the coopetition strategy, this study derives a relationship between significant policy-related variables such as penalty charges, and the cost of maintaining an idle berth, among others to discuss their implications. The nomenclature of the model development is given as follows, which consists of two main outputs representing the profits related to the competition and coopetition strategies.

$$\pi_{i,coopetition} \geq \pi_{i,competition} \qquad \forall i \in I \tag{4.4}$$

Nomenclature

Parameters

S	set of terminals $s = a, b, c$ ($s \in S$)
Q_s	number of vessels desired service at terminal s ($s \in S$) within a given day
K_s	number of berths at terminal s ($s \in S$)
C_s	operation cost (USD/TEU) of terminal $s \in S$
C^u	cost of maintaining an idle berth at a terminal (USD/berth/day)
F_s	terminal fee (USD/TEU) paid by private terminal $s \in S$ to the port authority
V	the average number of containers handled during a vessel call
P_s	terminal price (handling charges) of terminal s ($s \in S$) paid by shipping lines (USD/TEU)

Decision variables

W_s	transfer price (USD/TEU), paid by the contracted terminal to the operation terminal for handling transfer vessels
g	penalty charge (USD/TEU), paid by terminal s ($s \in S$) to the shipping lines if the vessel operation cannot be commenced within the arrival day of the vessel
T_{ab}	number of vessels initially desired service at terminal *a* but transferred to terminal b within a given day

Outputs

$\pi_{s,competition}$	profit of terminal s ($s \in S$) when executing the competition strategy
$\pi_{s,coopetition}$	profit of terminal s ($s \in S$) when executing the coopetition strategy

4.2.1.4 Competition strategy with the status quo (Case A)

As the competition strategy, the terminal operators have only competitive interactions during both the contract and operation stages. Thus, Case A in Table 4.2 represents that all three terminal operators maintain their initial competition strategy. Therefore, Case A does not generate any vessel transfers between terminals and each terminal handles only its desired vessel calls during the operation stage. The desired vessel calls at each terminal within a given day (Q_s) are decided by the negotiations with shipping lines in the contract stage. The terminal price, P_s (USD/TEU) is paid by the shipping lines to the terminal operator as the basic container handling charges depending on the number of containers handled. Since this study considers both the private and public terminals, the profit functions of private and public terminals related to Case A are given with Equations (4.5) and (4.6), respectively. Accordingly, the profit function of a private terminal consists of three components, direct operating profit, penalty charge and the cost of maintaining idle berths. Direct operating profit is calculated by subtracting the terminal fee and the operating cost from the container handling charge they received from shipping lines. The terminal fee is paid by the private terminal to the port authority depending on the number of containers handled. Penalty cost is calculated depending on the number of containers handled from a vessel with berthing delay because it is assumed that terminal operators pay a penalty charge to the shipping lines if they cannot commence the vessel's operation within the arrival day of the vessel. Moreover, the cost of maintaining idle container berths is given by the last component of the profit function.

When considering the profit of a public terminal given by Equation (4.6), in contrast to a private terminal case, the public terminal does not pay a terminal fee to the port authority because the port authority and the public terminal are represented by the same economic entity as discussed in Chapter 3. However, the public terminal collects a terminal fee from the private terminals in the same port as given by the second component of Equation (4.6) (Saeed and Larsen, 2010) and s' represents such private terminal in the same port. Besides the terminal fee, the remaining components of the Equation (4.6) are similar to that of Equation (4.5) because a public terminal also requires to pay penalty charges for berthing delays and incurs a cost for maintaining idle berths. In terms of competition and coopetition strategies, the aggregate profit of the year is calculated by summing up the profits from daily vessel operations because the berth allocations are done based on the vessel arrival data within a given day.

$$\pi_{s,competition,private} = V\left[\left[\sum Q_s * (P_s - F_s - C_s)\right] - g\left[\sum (Q_s - K_s)^+\right]\right] - C^u\left[\sum (K_i - Q_i)^+ - \sum (Q_i - K_i)^+\right] \tag{4.5}$$

$$\pi_{s,competition,public} = V\left[\left[\sum Q_s * (P_s - C_s)\right] + \left[F_{s'} * \sum Q_{s'}\right] - g\left[\sum (Q_s - K_s)^+\right]\right] - C^u\left[\sum (K_i - Q_i)^+ - \sum (Q_i - K_i)^+\right] \tag{4.6}$$

4.2.1.5 *Coopetition strategy between public and private terminals (Case B and C)*

Since the profit of a terminal operator varies depending on the different terminal combinations that participated in the coopetition strategy, the profit functions of terminals related to the Cases B and C, are described here. In these cases, the coopetition strategy is executed between one public terminal and one private terminal because such situations can be observed in Colombo. Here we assume a as the public terminal and b as the partner private terminal of the coopetition strategy, could be either CICT or SAGT. The profit functions of the public and private terminals related to the coopetition strategy are given with Equation (4.7) and (4.8), respectively. The first component of the profit function of terminals a (public terminal) is the direct operating revenue received as the container handling charges from shipping lines for all desired vessel calls at the terminal a because shipping lines pay handling charges directly to the contracted terminal even in case of vessel transfers. Then, the second component indicates the transfer prices paid by terminals a to the terminal b for handling excess vessels of terminals a, where T_{ab} indicates the number of vessels transferred from terminal a to terminal b and w_b indicates the transfer price charged by terminal b from terminal a. The third component indicates the transfer price received by terminal a from terminal b because of handling excess vessels of terminal b, where T_{ba} indicates the number of vessels transferred from terminal b to a. The fourth component of Equation (4.7) indicates the operating cost of terminal a for handling vessels at own container berths. Since the terminal a represents the public terminal, the fifth and sixth components indicate the terminal fees collected by the terminal a from terminals b and c (private terminals) because the public terminal and the port authority are assumed to be represented by the same economic entity. The penalty costs paid by terminal a to the shipping lines in case of berthing delays are given by the seventh component of Equation (4.7). Moreover, the cost of maintaining idle berths is given by the last component of the profit function.

However, when considering the profit function of a private terminal (terminals *b*), instead of receiving terminal fee, the private terminal pays a terminal fee to the port authority as given in Equation (4.8). Besides from terminal fee, the remaining components of the profit function of a private terminal are similar to that of a public terminal as previously explained with Equations (4.7). Besides from terminals *a* and *b*, who participated in the coopetition strategy, the profit function of the private terminal, who did not participate in the coopetition strategy (terminals *c*) is similar to the Equation (4.5), which is explained previously under the profit function of a private terminal with the competition strategy, since terminals *c* maintains its initial competition strategy and does not execute any vessel transfers with other terminals.

$$\begin{aligned}\pi_{a,coopetition} = \; & V\Big[P_a \sum Q_a \; - w_b \sum T_{ab} + w_a \sum T_{ba} - C_a \Big[\sum Q_a - \sum T_{ab} + \sum T_{ba}\Big] \\ & + \Big[F_b * \sum Q_b\Big] + \Big[F_c * \sum Q_c\Big] - g\Big[\sum((Q_a - K_a)^+ - T_{ab})\Big]\Big] \\ & - C^u \Big[\sum (K_a - Q_a)^+ - \sum[(Q_a - K_a)^+ - T_{ab}] - \sum T_{ba}\Big]\end{aligned} \tag{4.7}$$

$$\begin{aligned}\pi_{b,coopetition} = \; & V\begin{bmatrix} P_b \sum Q_b \; - w_a \sum T_{ba} + w_b \sum T_{ab} \\ -C_b\Big[\sum Q_b - \sum T_{ba} + \sum T_{ab}\Big] \\ -\Big[F_b * \sum Q_b\Big] - g\Big[\sum((Q_b - K_b)^+ - T_{ba})\Big] \end{bmatrix} \\ & - C^u \Big[\sum (K_b - Q_b)^+ - \sum[(Q_b - K_b)^+ - T_{ba}] - \sum T_{ab}\Big]\end{aligned} \tag{4.8}$$

4.2.1.6 Coopetition strategy between two private terminals (Case D)

Since Equations (4.7) and (4.8) calculate the profits of terminals who engaged in the coopetition strategy with case B or C, where the coopetition strategy takes place between one public and one private terminal, the Equations (4.9) and (4.10) calculate the profits of terminals in case D, where the coopetition strategy takes place between only two private terminals (terminal *b* and terminal *c*) and the public terminal (terminal a) maintains its competition strategy. Since the public terminal does not execute any vessel transfers, its profit function is similar to the Equation (4.6), which expresses the profit of a public terminal with the competition strategy. The components of the profit functions of terminal *b* and terminal *c* are similar to that of Equation (4.8) besides the fact that vessel transfers are taken placed between terminals terminal *b* and *c* instead of terminals a and *b*. Therefore, T_{bc} and T_{cb} in Equations (4.9) and (4.10) indicate the number of vessels transferred from terminal *b* to terminal *c* and the number of vessels transferred from terminal *c* to terminal *b*, respectively. Besides, the other components of profit functions described with Equation (4.8) such as operating cost of handling vessels at own terminal, terminal fee paid to the port authority, the penalty cost paid to the shipping lines in case of berthing delays and the cost of maintaining idle container berths are similarly applicable for Equations (4.9) and (4.10) as well.

$$\begin{aligned}\pi_{b,coopetition} = V\Big[&\left(P_b \sum Q_b\right) - w_c \sum T_{bc} + w_b \sum T_{cb} \\ &- C_b\left[\sum Q_b - \sum T_{bc} + \sum T_{cb}\right] - \left[F_b * \sum Q_b\right] \\ &- g\left[\sum ((Q_b - K_b)^+ - T_{bc})\right]\Big] \\ &- C^u\left[\sum (K_b - Q_b)^+ - \sum [(Q_b - K_b)^+ - T_{bc}] - \sum T_{cb}\right]\end{aligned} \tag{4.9}$$

$$\begin{aligned}\pi_{c,coopetition} = V\Big[&\left(P_c \sum Q_c\right) - w_b \sum T_{cb} + w_c \sum T_{bc} - C_c\left[\sum Q_c - \sum T_{cb} + \sum T_{bc}\right] \\ &- \left[F_c * \sum Q_c\right] - g\left[\sum ((Q_c - K_c)^+ - T_{cb})\right]\Big] \\ &- C^u\left[\sum (K_c - Q_c)^+ - \sum [(Q_c - K_c)^+ - T_{cb}] - \sum T_{bc}\right]\end{aligned} \tag{4.10}$$

4.2.1.7 Coopetition strategy among all three terminals (Case E)

Besides the analyzing coopetition strategy between only two terminals at once, we also analyze the coopetition strategy among all three terminals at once, which is represented by case E. Therefore, the profit function of the public terminal is given by Equation (4.11) and that of two private terminals are given by Equations (4.12) and (4.13). As the main difference between the profit functions of case E compared to the previously discussed cases, here the profit of one terminal is calculated considering the vessel transfers with both remaining terminals, simultaneously. For instance, since terminal a has vessel transfer arrangement with both terminals b and c, terminal a's profit depends on all T_{ab}, T_{ac}, T_{ba} and T_{ca}. Besides that, the remaining components of the profit function are similar to that of Equation (4.7). Accordingly, the profit function consists with direct operating revenue received from shipping lines' desired vessel calls, transfer price paid to other two terminals for handling own excess vessels, transfer price received from other two terminals for handling their excess vessels, operating cost of handling vessels at own container berths, terminal fees collected from two private terminals, the penalty cost paid to the shipping lines in case of berthing delays and the cost of maintaining idle container berths. Since the number of vessel transfers is decided based on the occurrence of Status 4 in Figure 4.3 considering two terminals at a time, a priority rule is considered when deciding vessel transfers in case E due to the involvement of all three terminals. Accordingly, when deciding vessel transfers in each day, a higher priority is given for the vessel transfers between two private terminals than the vessel transfers between the public and private terminals to reduce the possible inter-terminal transfer cost because these two private terminals are located close proximity to each other. Besides, the non-negativity constraints of the variables are given in Equation (4.14).

$$\begin{aligned}\pi_{a,coopetiton} = V\Bigg[&\left(P_a \sum Q_a\right) - w_b \sum T_{ab} - w_c \sum T_{ac} + w_a \sum T_{ba} + w_a \sum T_{ca} \\ &- C_a \left[\sum Q_a - \sum T_{ab} - \sum T_{ac} + \sum T_{ba} + \sum T_{ca}\right] + \left[F_b * \sum Q_b\right] \\ &+ \left[F_c * \sum Q_c\right] - g\left[\sum ((Q_a - K_a)^+ - T_{ab} - T_{ac})\right]\Bigg] \\ &- C^u \left[\sum (K_a - Q_a)^+ - \sum [(Q_a - K_a)^+ - T_{ab} - T_{ac}] - \sum T_{ba} - \sum T_{ca}\right]\end{aligned} \tag{4.11}$$

$$\begin{aligned}\pi_{b,coopetiton} = V\Bigg[&P_b \sum Q_b - w_a \sum T_{ba} - w_c \sum T_{bc} + w_b \sum T_{ab} + w_b \sum T_{cb} \\ &- C_b \left[\sum Q_b - \sum T_{ba} - \sum T_{bc} + \sum T_{ab} + \sum T_{cb}\right] - \left[F_b * \sum Q_b\right] \\ &- g\left[\sum ((Q_b - K_b)^+ - T_{ba} - T_{bc})\right]\Bigg] \\ &- C^u \left[\sum (K_b - Q_b)^+ - \sum [(Q_b - K_b)^+ - T_{ba} - T_{bc}] - \sum T_{ab} - \sum T_{cb}\right]\end{aligned} \tag{4.12}$$

$$\begin{aligned}\pi_{c,coopetiton} = V\Bigg[\Bigg[&\left(P_c \sum Q_c\right) - w_a \sum T_{ca} - w_b \sum T_{cb} + w_c \sum T_{ac} + w_c \sum T_{bc} \\ &- C_c \left[\sum Q_c - \sum T_{ca} - \sum T_{cb} + \sum T_{ac} + \sum T_{bc}\right] - \left[F_c * \sum Q_c\right] \\ &- g\left[\sum ((Q_c - K_c)^+ - T_{ca} - T_{cb})\right]\Bigg]\Bigg] \\ &- C^u \left[\sum (K_c - Q_c)^+ - \sum [(Q_c - K_c)^+ - T_{ca} - T_{cb}] - \sum T_{ac} - \sum T_{bc}\right]\end{aligned} \tag{4.13}$$

$$\mathrm{P}_s, w_s, T_{ss'} \geq 0 \qquad \forall i, \forall i' \in I \tag{4.14}$$

After deriving profit functions of terminals related to the competition strategy (case A) and the coopetition strategy with all four cases (case B, C, D, and E), the condition for simultaneously satisfying the individual rationality of all terminal operators is derived with Equation (4.4) for case B, C, D, and E, separately. Therefore, the derived condition from Equation (4.4) in each case implies that all terminal operators who participated in the coopetition strategy are better off with the coopetition strategy than their initial competition strategy. Since the relationship between significant policy-related variables is derived as the condition for simultaneously satisfying the individual rationality of all terminal operators, the port authority may decide appropriate policies to encourage the terminal operators on executing all possible vessel transfers between them.

4.2.2 Results and Discussion for the Objective [4.1]

Since this study proposes an intra-port coopetition strategy, it is important to understand the applicability of such a strategy in the context of the Port of Colombo by analyzing the actual vessel arrival data. The vessel transfers related to the coopetition strategy can be executed only in Status 4 in Figure 4.3, where one terminal has idle container berths when its partner terminal experiences excess vessel calls. Therefore, the probabilities of occurrence of all six status in Figure 4.3 are calculated with the actual vessel arrival data of the Port of Colombo from 1st April 2017 to 31st March 2018. The probabilities are calculated considering each possible terminal pair separately for understanding the applicability of the vessel transfer policy among terminal operators in the Port of Colombo as given in Figure 4.4. Since the vessel transfers are decided considering the number of vessel arrivals at each terminal within a given day, these calculated probabilities indicate the number of days of occurrences of each status out of 365 days in a year (1st April 2017 to 31st March 2018). Therefore, when calculating the probabilities, the vessel arrival data at all three terminals are shorted on a daily basis. As an example, on a number of days equals to 20.55% of one year (75 days), both JCT and CICT simultaneously have idle container berths on the same day (Status 1). Accordingly, the highest probabilities in JCT-CICT and JCT-SAGT, are received for the occurrence of Status 4 and that of CICT-SAGT is received for Status 5 although a considerable high probability is also received for the occurrence of Status 4. Moreover, comparatively lower probabilities are obtained for the occurrence of Status 3, which represents the simultaneous fully occupied conditions at both focused terminals. Therefore, the vessel transfer policy is applicable among the container terminals in the Port of Colombo.

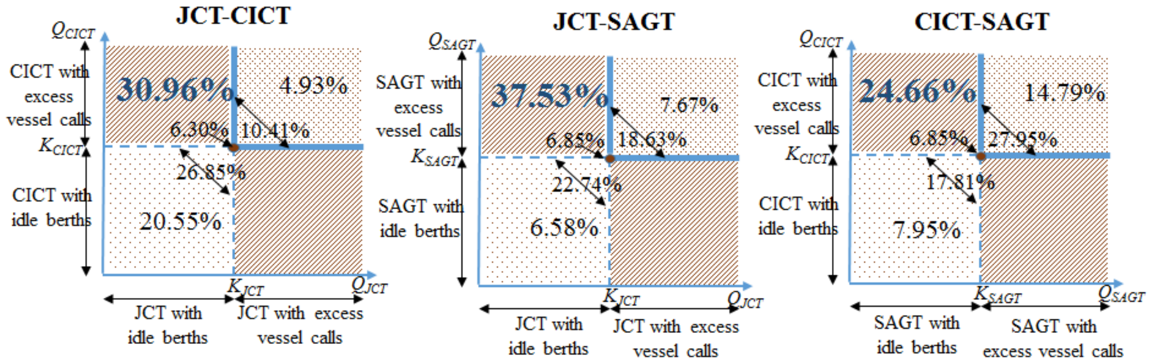

Figure 4.4. Probabilities of Occurrence of Status Related to the Vessel Transfers Policy

Since the initial competition strategy generates berthing delays and idle container berths, the effectiveness of the vessel transfer policy can be evaluated considering the possible reductions of the occurrences of berthing delays and the idle container berths. Therefore, after confirming the high probability associated with Status 4, next, we estimate the possible vessel transfers between terminals with all four cases as illustrated in Figure 4.5 during the period of one year as mentioned before. The direction of the arrow with the number indicates the number of vessel transfers to a particular terminal from another connected terminal for a specific case mentioned on the arrow (e.g. in case B, 41 vessels can be transferred from JCT to CICT). Since all three terminals collectively execute the coopetition strategy in case E, there are six possible ways of vessel transfers between terminals. When considering the coopetition strategy between only two terminals (case B, C, and D), JCT receives the highest number of vessel transfers from both CICT and SAGT, and CICT receives a considerable high number of vessel transfers from SAGT, although SAGT receives the least number of vessel transfers from both JCT and CICT. The number of vessel transfers between CICT and SAGT in case E is equal to that of case D because of the high priority given for the vessel transfers between these two terminals in case E to reduce possible inter-terminal transfer cost.

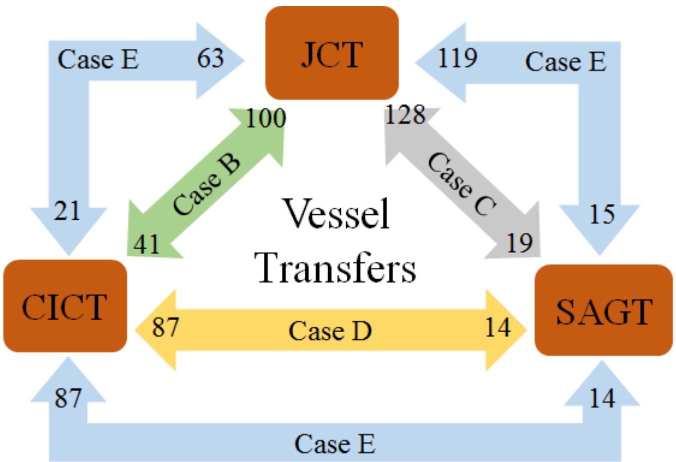

Figure 4.5. Vessel Transfers between Terminals in Each Case

To evaluate the effectiveness of the coopetition strategy, the number of vessel calls handled without penalty charges, the number of vessel calls handled with penalty charges and the number of idle container berths (summation of the numbers of idle berths within a day across the whole year) are calculated for each case. Hereafter, we refer to the term "penalty calls" to identify the vessel calls handled with penalty charges related to berthing delays. As indicated in Table 4.3, the numbers of idle berths and penalty calls related to case A are higher than those related to other cases. Therefore, the coopetition strategy helps terminal operators to reduce both the idle berths and penalty calls than the initial competition strategy while increasing the number of vessels handled without penalty charges.

When comparing among cases, all three terminals receive maximum benefit from case E, where they collectively execute the coopetition strategy. When coopetition strategy takes place between only two terminals, JCT receives a higher number of vessel calls handled without penalty charges and a lower number of idle berths by having partnered with SAGT than CICT although this case generates a higher number of penalty calls for JCT than case B. Moreover, CICT receives a higher number of vessel calls handled without penalty charges and a lower number of idle berths by having partnered with SAGT than JCT. In the case of SAGT, it receives a higher number of vessel calls handled without penalty charges, a lower number of idle berths and a lower number of penalty calls by having partnered with JCT than CICT. Therefore, SAGT is benefitted by having cooperation strategy with JCT than CICT regardless of the relative monetary values associated with the penalty charges and the cost of idle berths. However, when executing the coopetition strategy between only two terminals, the most benefitted partner of JCT and CICT are depended on the relative monetary values associated with the penalty charges and the cost of idle berths.

Table 4.3. Benefits of Vessel Transfers between Terminals in Each Case

Case	**JCT**			**CICT**			**SAGT**		
	Number of vessel calls handled without penalty	**Number of idle berth days**	**Number of vessel calls handled with penalty**	**Number of vessel calls handled without penalty**	**Number of idle berth days**	**Number of vessel calls handled with penalty**	**Number of vessel calls handled without penalty**	**Number of idle berth days**	**Number of vessel calls handled with penalty**
A	1400	425	110	1237	223	166	1024	71	306
B	1500	325	69	1278	182	66	1024	71	306
C	1528	297	91	1237	223	166	1043	52	178
D	1400	425	110	1324	136	152	1038	57	219
E	1582	243	74	1345	115	89	1053	42	100

Since the monetary values associated with the penalty charges and the cost of idle berths are significant for the coopetition strategy, the relationship between them is derived as the satisfying condition for implementing the coopetition strategy. As per the input values for the case study, the numbers of berths available at JCT, CICT and SAGT are taken as 5, 3 and 3 according to the data collected from the SLPA and the operation cost per TEU are assumed to be USD 25, 18 and 20, respectively because JCT incurs comparatively high operating cost due to its large labor force according to the interview with the port authority. The terminal handling charge of JCT is taken as 42 USD/TEU and that of CICT and SAGT is taken as 40 USD/TEU each. The price difference exists because the public terminal maintains relatively high prices as it adheres to the published traffic as per interviews with the SLPA. Terminal fees are taken as 5 USD/TEU and 4 USD/TEU for CICT and SAGT, respectively, although these values are escalated on yearly basis depending on the handling volume as per data collected during the interviews with the SLPA. Considering the container handling statistics of Colombo (Performance Review-2007 to 2016) and the industry average values, it is assumed that 1200 TEUs are handled during a vessel call on average.

As per the game-theoretical decision-making approach, we derive a common condition, which simultaneously satisfies the individual rationality of all terminal operators, who execute the coopetition strategy in each case in comparison to the case A. The derived common condition implies that all terminal operators who implement the coopetition strategy in a particular case receive higher payoff than the case A. Table 4.4 summarizes the minimum satisfying conditions for implementing the coopetition strategy in all cases when compared to the case A. Accordingly, the minimum value of penalty charge decreases when the cost of idle berth increases because both variables encourage terminal operators to implement the coopetition strategy. If we assume zero cost for maintaining idle berths ($C^u = 0$), then the minimum value of penalty charge is about USD 3.53 per TEU in case B. In case C, as the condition for implementing the coopetition strategy, the summation of penalty charge per vessel call and the cost of an idle berth should be greater than or equal to the USD 5148. Similar to case B, if we assume that $C^u = 0$, the penalty charge should be at least USD 4.29 per TEU for successfully executing all possible vessel transfers between JCT and SAGT. Therefore, the port authority requires to impose a higher penalty charge for implementing the coopetition between JCT and SAGT than the penalty charge required for implementing the coopetition between JCT and CICT.

When considering case D, where the coopetition strategy takes place between CICT and SAGT, a common condition, which simultaneously satisfies the individual rationality of both terminals could not be derived. Therefore, the coopetition strategy between CICT and SAGT does not hold with any positive values of penalty charge or cost of idle berths. The coopetition between these two private terminals is unstable and cannot simultaneously generate higher payoff for both terminals than their payoff related to the initial competition strategy. In case E, where all three terminals collectively execute the coopetition strategy, the summation of penalty charge per vessel call and the cost of idle container berth should be greater than or equal to the USD 2508 for executing the all possible vessel transfers. Therefore, in comparison to cases B, C, and D, the coopetition strategy in case E can be executed at a lower value of penalty charge or cost of idle berths. This is reasonable because terminal operators have more benefit from the coopetition strategy in case E than the other cases as given in Table 4.3.

Table 4.4. Conditions for Implementing the Coopetition Strategy

Case	Condition
B	$1200g + C^u \geq 4236$
C	$1200g + C^u \geq 5148$
D	Cannot hold
E	$1200g + C^u \geq 2508$

Since both the penalty charge and the cost of idle container berths encourage terminal operators on executing vessel transfers, the coopetition strategy can be implemented even at a low penalty charge, when the port authority has a higher valuation on the opportunity cost of idle berths. Therefore, the policies related to the penalty charges and the cost of idle berths must be carefully decided to encourage terminal operators on implementing the coopetition strategy. Since the penalty charge may indicate the loss of goodwill of a terminal due to the long waiting time, the enforcement of such policies would help to enhance the overall port competitiveness. Besides, such policies are significant in enhancing the utility of shipping lines.

4.3 Analysis for Objective [4.2]

After understanding the applicability and effectiveness of the proposed coopetition strategy in the context of the Port of Colombo with the first objective of this chapter, the second objective understands the coopetition behavior of terminal operators in one port for minimizing total berthing delays at the port or maximizing combined profits of terminal operators, with different policy scenarios. Although the Objective [4.1] is analyzed with four different cases associated with the coopetition strategy, the Objective [4.2] considers only the case E, which represents the coopetition strategy among all terminal operators, simultaneously, because of the higher advantages related to case E than the other cases. Although the Objective [4.1] follows a simplified approach by assuming that all possible vessel transfers are executed between terminal operators to understand the maximum possible benefits from coopetition, the terminal operators can decide whether or not to transfer the vessel to another terminal in the practical circumstances, depending on their willingness. Moreover, we assumed the parameters related to the container vessels such as the number of containers handled per vessel call, and handling time of a vessel, among other as the average values, although these parameters can be varied in each vessel call depending on the size and characteristics of the container vessel, thus, could have a significant influence on the vessel transfer decision of a terminal operator. For instance, if a vessel has a relatively high number of TEUs to be handled, a terminal operator may decide to handle the vessel at its own terminal even with the penalty charge while considering its operational profit, rather than transferring to another terminal. Thus, to incorporate the variations in vessel-related aspects to the model, the analysis with Objective [4.2] considers the actual vessel handling data including handing TEUs, and handling time, among others, collected from the Port of Colombo and the Japan Maritime Center. Although a vessel's berth allocation with Objective [4.1] is done based on the arrival day of the vessel rather than the actual arrival time, the Objective [4.2] considers the actual arrival time of the vessel. Besides, the coopetition strategy with Objective [4.2] is analyzed considering four different policy scenarios that are related to the collection of terminal fees from the private terminals by the port authority in case of vessel transfers. Although the Objective [4.1] assumes that the operation terminal receives the same transfer price from both remaining terminals throughout the whole year, the Objective [4.2] considers the variations in transfer prices between each terminal pair in multiple periods.

Therefore, the Objective [4.2] analyzes the vessel transfer decisions of terminal operators with a mixed-integer programming optimization (MIPO) model. Owing to the consideration of actual vessel arrival time, Objective [4.2] also focuses on the total duration of the delay time of vessels at the port in addition to the occurrence of berthing delays. Thus, to achieve Objective [4.2], our sub-objectives are, to measure and compare the numbers of occurrences of berthing delays and total delay hours under the competition strategy and the coopetition strategy when terminals aim to minimize the total penalty cost or maximize their combined profit and to analyze several policy scenarios under the coopetition strategy considering their effectiveness on increasing vessel transfers and terminal profits while minimizing berthing delays.

4.3.1 Methodology for Objective [4.2]

To understand the coopetition behavior of terminal operators, a mixed-integer programming optimization (MIPO) model is formulated. Although the coopetition strategy with a vessel transfer policy is proposed to minimize berthing delays at individual terminals, this strategy could have a significant influence on terminals' profits as well. Thus, to understand the differences in vessel transfer decisions depending on the objectives of terminal operators, two separate objective functions of the MIPO model are considered namely, minimizing total penalty costs related to berthing delays (Min.PC) and maximizing total profit (Max.TP) of terminals. The analysis with both objectives is significant owing to the differences in terminals' ownership types. Similar to the Objective [4.1], the model development on Objective [4.2] incorporates a game-theoretical decision-making approach with the individual rationality, which ensures that all terminals will be better off from the coopetition strategy than their state of extreme competition. The nomenclature associated with the model development is listed as follows. Since the analysis of Objective [4.2] incorporates the actual vessel handling data with varying handling volumes, handling time, and arrival time, among other, at three main container terminals in Colombo, and also considers the vessel transfer decisions made by terminal operators with a MIPO model, the model development for Objective [4.2] is significantly different from that of Objective [4.1]. Although we consider the vessel transfer decisions from the perspective of terminal operators, in the practical scenario, terminals may decide their vessel transfers based on negotiations between them. Therefore, this study can be considered as a guide for the port authority when encouraging its terminal operators on appropriate vessel transfer decisions by highlighting maximum possible benefits when executing all possible vessel transfers. Besides, the analysis of vessel transfer decisions with different objectives such as minimizing total penalty costs related to berthing delays (Min.PC) and maximizing total profit (Max.TP) of terminals and with different policy scenarios enable us to provide appropriate recommendations on vessel transfer arrangement made by terminals in Port of Colombo.

Nomenclature

Sets

S	set of terminals $s = a, b, c$ $(s \in S)$
V^a, V^b, V^c	sets of desired vessels of contracted terminal *a*, *b*, and *c* respectively
$V^{a\to a}$	set of desired vessels handled by terminal *a* without transferring to other terminals, similarly, $V^{b\to b}$ and $V^{c\to c}$ represent the sets of desired vessels handled by terminal *b* and *c*, respectively
$V^{a\to b}$	set of vessels transferred from terminals *a* to *b*, similarly $V^{a\to c}, V^{b\to a}, V^{b\to c}, V^{c\to a}, V^{c\to b}$ represent the sets of vessels transferred between two respective terminals

Parameters

i, j, q	individual desired vessels of contracted terminals *a*, *b*, and *c* respectively $(i \in V^a), (j \in V^b), (q \in V^c)$
O_i	operation time of vessel *i* (hours), O_j, and O_q for vessel *j* and *q*
P_s	container handling charges (USD/TEU) of terminal $s \in S$
P_{min}	minimum container handling charges (USD/TEU) among three terminals
C_s	operation cost (USD/TEU) of terminal $s \in S$
C_{max}	maximum operation cost (USD/TEU) among three terminals
F_s	terminal fee (USD/TEU) paid by private terminal $s \in S$ to the port authority
M_i	number of TEUs handled from vessel *i*; M_j, and M_q for vessel *j* and *q*
μ	maximum tolerable waiting time (hours) of shipping lines
g	penalty charge (USD/TEU) for berthing delays
δ, γ	dummy variables related to the terminal fee collection policies with vessel transfers

Decision Variables

$U_{i(a)}, U_{j(b)}, U_{q(c)}$	1 if the vessels i, j, and q are handled by their contracted terminals a, b, and c, respectively without transferring, 0 otherwise $(\forall i \in V^a, \forall j \in V^b, \forall q \in V^c)$
$U_{i(b)}, U_{i(c)}$	1 if the vessel *i* is transferred to terminal *b* or *c* respectively, 0 otherwise $(\forall i \in V^a)$, similarly $U_{j(a)}, U_{j(c)}$ for vessel *j* and $U_{q(a)}, U_{q(b)}$ for vessel q while transferring from their contracted terminal to other terminals
$U_{i(a)}^{penalty}$	1 if the vessel *i* is handled at the terminal a with berthing delay, 0 otherwise; similarly, $U_{j(b)}^{penalty}$ and $U_{q(c)}^{penalty}$ for vessel *j* and q if they are handled with berthing delays
$P_{a \to b}$	transfer price (USD/TEU) paid by terminal *a* to *b* if the vessel is transferred from a to *b*, similarly $P_{a \to c}, P_{b \to a}, P_{b \to c}, P_{c \to a}, P_{c \to b}$ represent transfer prices between the respective two terminals

Outputs

$\pi_{s,\, competition}$	terminal profit (USD) under competition
$\pi_{s,\, coopetition}$	terminal profit (USD) under coopetition
WT_i	waiting time of vessel *i* (hours); WT_j, and WT_q for vessel *j* and q

4.3.1.1. Terminal profit under competition

As mentioned earlier, the analysis of Objective [4.2] is limited only for case E in Table 4.2, which implies that all three terminals execute the coopetition strategy collectively. Thus, to develop a detailed MIPO model, it is necessary to derive terminals' profit functions associated with both the competition and coopetition strategies. First, when considering the competition strategy, terminals handle only their desired vessel calls received from the contract stage because they maintain only competitive interactions in both contract and operation stages without executing any vessel transfers. Similar to the Objective [4.1], the profit functions associated with the public terminal, JCT and two private terminals, CICT and SAGT are given as follows, although the equations are adopted with the MIPO model' structure and notations of Objective [4.2]. For an easy representation, we refer $S = \{a, b, c\}$ as the set of terminal operators, such that $s \in S$ $(s = a, b, c)$ is defined as any terminal out of three focused terminals. Therefore, here onwards, we refer to a as the public terminal and *b* and *c* as the two private terminals, CICT and SAGT, respectively. The profit functions associated with three terminals are given with Equations (4.15) to (4.17).

$$\pi_{a,competition} = (P_a - C_a)\left[\sum\nolimits_{i\in V^a} M_i\right] + F_b\left[\sum\nolimits_{j\in V^b} M_j\right] + F_c\left[\sum\nolimits_{q\in V^c} M_q\right] - \text{g}\left[\sum\nolimits_{i\in V^a}\left(U_{i(a)}^{penalty} * M_i\right)\right] \quad (4.15)$$

$$\pi_{b,competition} = (P_b - C_b - F_b)\left[\sum\nolimits_{j\in V^b} M_j\right] - \text{g}\left[\sum\nolimits_{j\in V^b}\left(U_{j(b)}^{penalty} * M_j\right)\right] \quad (4.16)$$

$$\pi_{c,competition} = (P_c - C_c - F_c)\left[\sum\nolimits_{q\in V^c} M_q\right] - \text{g}\left[\sum\nolimits_{q\in V^c}\left(U_{q(c)}^{penalty} * M_q\right)\right] \quad (4.17)$$

Although the calculation process of Objective [4.2] is different from that of Objective [4.1], the fundamental components of the profit functions are similar in both cases except the fact that we do not consider the opportunity cost of idle container berths when analyzing Objective [4.2] for the simplicity. Accordingly, the profit function of a public terminal consists of the direct operating profit, terminal fees collected from private terminals, and the penalty charges related to the berthing delays. Similar to the assumption made with Objective [4.1], the public terminal and the port authority are assumed to be represented by the same economic entity. As one of the main differences between profit functions of Objective [4.1] and Objective [4.2], although Objective [4.1] considers the vessel calls within a given day, Objective [4.2] considers each individual vessel call represented by vessel i, j, q for terminals a, b, c, respectively, and varying handling volumes associated with each vessel call (M_i, M_j, M_q). Although Objective [4.1] assumes that a penalty charge is imposed if a vessel's operation cannot be commenced during the arrival day of the vessel, Objective [4.2] decides berthing delays and penalty charges considering the actual arrival time of individual vessels. Therefore, we define a maximum tolerable waiting time of shipping lines (μ), which is the maximum duration of berthing delay time that a terminal operator can expect from shipping lines to wait without paying a penalty charge for berthing delays. Thus, if the vessel operation cannot be commenced within the maximum tolerable waiting time of shipping lines, a terminal operator has to pay a penalty charge for shipping lines, which can be considered as a loss of goodwill of a particular terminal owing to the long waiting time. Similar to the Objective [4.1], in the practical situation, the penalty charge paid by a terminal operator to the shipping line is considered as a discount given to the container handling charge, which is paid by shipping lines to the terminal operator. This is reasonable because a penalty charge is assumed to be paid depending on the number of containers handled from the delayed vessel. Since a penalty call is defined with a dummy variable, $U_{i(a)}^{penalty} = 1$ when the waiting time of vessel i, WT_i is longer than μ ($WT_i > \mu$), and $U_{i(a)}^{penalty} = 0$ otherwise. Thus, the last component of the profit function indicates the penalty cost of a terminal operator, which is calculated corresponding to the number of containers handled from vessel calls with berthing delays. Equations (4.16) and (4.17) indicate the profit functions of two private terminals, which have two main components, direct operating profit and penalty charges associated with berthing delays. As the main difference from a public terminal, a private terminal has to pay terminal fees to the port authority, which follows a similar explanation with that of Objective [4.1].

4.3.1.2. Terminal profit under coopetition strategy and vessel transfer policy

a) Vessel transfer policy with coopetition

Since we utilize the actual vessel handling data, with varying handling times, arrival times, and handling volumes, among others, the vessel transfer policy of Objective [4.2] is different from that of Objective [4.1]. Moreover, the pattern of vessel arrivals and the arrival times have significant influences on the effectiveness of vessel transfer policy, thus Figure 4.6 illustrates a vessel transfer decision of a terminal operator. Therefore, considering each container vessel arrival, the contracted terminal checks the availability of an idle berth at its own terminal within the next μ hours. If the contracted terminal has no idle berth available within the next μ hours, it decides whether to transfer the vessel to another terminal or handle at own terminal with a penalty charge paid to the shipping lines for berthing delays. As mentioned before, the term "operation terminal" refers to the terminal who actually conducts the vessel operation. Thus, when there is no vessel transfer, the contracted terminal itself acts as the operation terminal as well. In order to execute a vessel transfer, another terminal in the same port should have a possibility to accept a transferring vessel. However, we consider the vessel transfers among different terminal operators who operate as separate individual economic entities, thus each terminal would give a higher priority for desired vessel calls of own customers before accepting any vessel transferred from another terminal. Hence, the accepting terminal checks the availability of at least one berth at the idle stage during the entire target operation hours (O_i) of the transferring vessel considering the upcoming vessel arrivals at its own terminal during next O_i hours, which allows it to give a high priority for its own customers. Here, the availability of idle berth also means that the availability of its required handling equipment and resources as well because the transferred vessel is handled with the resources attached to the operation terminal.

However, rather than maintaining berths at the idle stage, the operation terminal is willing to accept transfer vessels from another terminal because it can receive a transfer price from the contracted terminal for handling transfer vessels. This happens because even in case of vessel transfers, the shipping lines pay the container handling charges directly to their contracted terminal based on the negotiations made during the contract stage and the contracted terminal pays a transfer price to the operation terminal for handling its transfer vessels. Such an arrangement enhances the applicability of the vessel transfer policy in the practical context because shipping lines are not required to re-negotiate the handling charges with the operation terminal. However, when there is no possibility to execute a vessel transfer or the contracted terminal decides not to transfer the vessel even when there is a possibility of transferring, the contracted terminal handles the vessel at its own terminal with paying a penalty charge to the shipping lines for berthing delays. Since the payment of penalty charge is considered as a discount given from the container handling charges to the shipping lines, we assume that the contracted terminal handles the vessel at a lower charge in case of berthing delays.

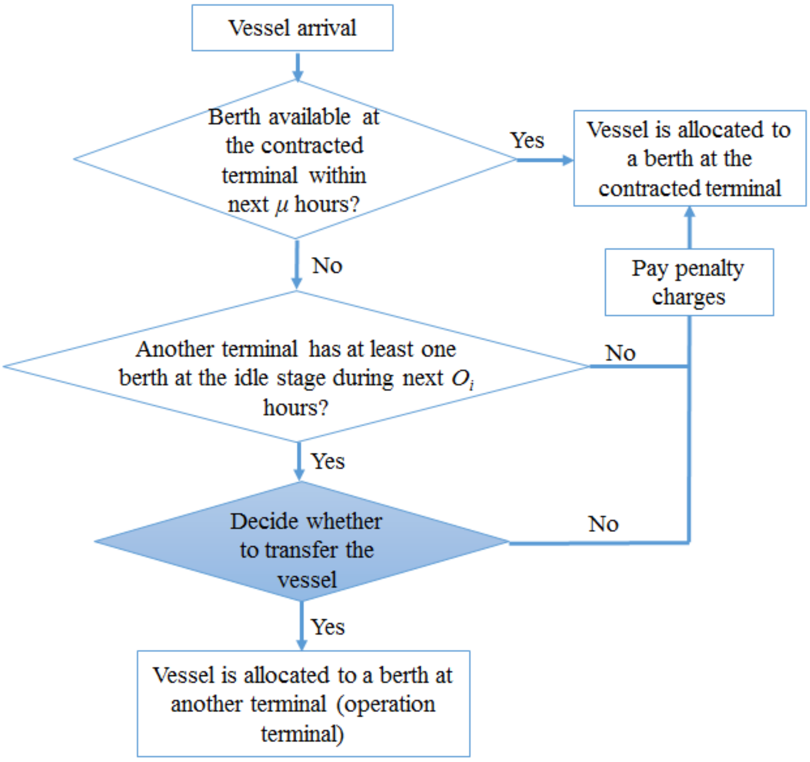

Figure 4.6. Vessel Transfer Policy

b) *Berth allocation process*

Although we discuss vessel transfers between terminals, these decisions are made considering the individual berths at the terminals. Therefore, a berth allocation process of a vessel is briefly explained here considering a simplified scenario with two terminals in one port and two berths at each terminal as given in Figure 4.7. For a simple illustration, we assume a situation with an arrival of a vessel at Terminal A. The vessels that are arriving at a container terminal have following set of deterministic attributes: expected arrival time (A_i), target operation hours (O_i), number of TEUs to be handled (M_i). This set of attributes is communicated to the container terminal operator in advance. Thus, this problem can be considered as a deterministic scenario as the planning activity is carried out even before the arrival of vessels, by considering their expected arrival times. Therefore, each terminal has information on upcoming vessel arrivals at own terminal including arrival time of the next vessel and the completion time of current operation at its each container berth. As the main assumptions on the berth allocation decision, the berths are assumed to be discrete and can handle only one vessel at a time. Besides, it is assumed that no service interruptions occur during vessel handling activities and physical restrictions at the terminal are not considered. Besides, the handling time of a vessel does not depend on the berth to which it is assigned. Information on vessel arrival to the terminals during the planning period is assumed to be known in advance. Moreover, it is assumed that the earliest time from which each berth becomes available is also considered when allocating a vessel to a berth at a given terminal.

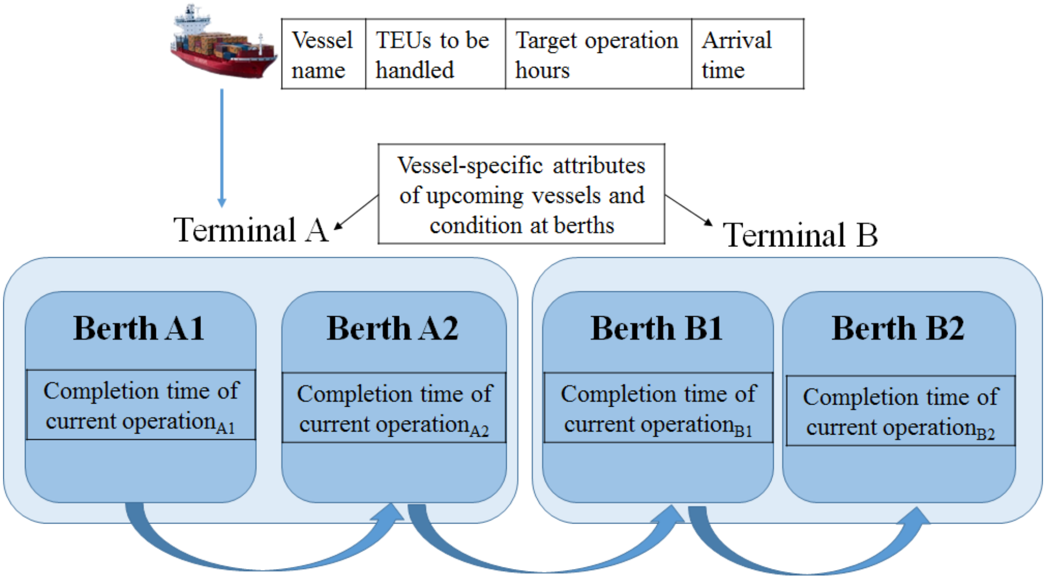

Figure 4.7. Simple Illustration Considering the Arrival of a Vessel at Terminal A

✓ ***Deciding berthing at the contracted terminal***

Since we consider an example with a vessel arrival at terminal A, first, the decision-making on berthing at the first berth of terminal A (A1) is given as follows. Accordingly, we check whether the vessel will arrive after the competition of current operation at berth A1 and if so, we allow vessel berthing at berth A1. If not, in case of vessel will arrive before the completion of current operation at both berths of terminal A, then we check whether the current operation at berth A1 can be completed before the maximum tolerable waiting time (μ) of shipping lines after the vessel arrival ($Arrival\ Time + \mu$), if yes, we allow vessel berthing at berth A1. In this case, the vessel is handled with berthing delay, but the terminal does not have to pay a penalty charge because the waiting time does not exceed the μ hours. However, if it is not possible to berth the vessel with the above two scenarios, then we do not allow vessel berthing at berth A1.

<u>Terminal A: berth A1</u>

$IF\ (AND\ \ (Contracted\ Terminal = A, (Arrival\ Time > Completion\ time\ of\ Current\ Operation_{A1})),\ \rightarrow$
$Berth\ at\ A1$

$IF\ (AND(Arrival\ Time < Completion\ Time\ of\ Current\ Operation_{A1}), (Arrival\ Time <$
$Completion\ Time\ of\ Current\ Operation_{A2}),\qquad (Completion\ time\ of\ Current\ Operation_{A1} \leq$
$Arrival\ Time + \mu)),\qquad \rightarrow Berth\ at\ A1\ with\ delay\ but\ without\ penalty,$
$\rightarrow Do\ not\ Berth\ at\ A1$

In case if the vessel was not berthed at berth A1, then we check the possibility of berthing at the second berth of terminal A (A2) as follows. Similar to the previous case, we check whether the vessel will arrive after the competition of current operation at berth A2 if so, we allow vessel berthing at berth A2. In case of the vessel will arrive before the competition of current operation at berth A2, then we check whether the vessel operation can be commenced before the μ hours and if yes, the vessel is allocated to the berth A2 and handled without penalty.

Terminal A: berth A2

$IF\ (AND\big(Contracted\ Terminal = A, Do\ not\ Berth\ at\ A1, (Arrival\ Time >$
$Completion\ Time\ of\ Current\ Operation_{A2})\big),\ \rightarrow Berth\ at\ A2$
$IF\ (AND(Contracted\ Terminal = A, Do\ not\ Berth\ at\ A1, (Arrival\ Time <$
$Completion\ Time\ of\ Current\ Operation_{A2}),\ (Completion\ Time\ of\ Current\ Operation_{A2} \leq$
$Arrival\ Time + \mu)), \rightarrow Berth\ at\ A2\ with\ delay\ but\ without\ penalty,$
$\rightarrow Do\ not\ Berth\ at\ A2$

✓ ***Deciding berthing in case of a vessel transfer***

In case if the vessel was not berthed at both berths of terminal A, we allow a binary decision variable related to the vessel transfer decision which is equal to 1 in case of allowing a vessel transfer and 0 otherwise. In case of allowing a vessel transfer, then we check the possibility of vessel transfer to the terminal B. Therefore, we check the condition at the first berth in terminal B (B1) as follows. Similar to the previous cases, we check whether the vessel will arrive after the competition of current operation at berth B1. Here, we consider vessel transfers between different terminals who act as individual economic entities, so each terminal gives higher priority for vessels of own customers before accepting any transfer vessels. Therefore, we check whether the arrival of the next vessel at terminal B will be after the completion of transferred vessel operation or after the completion of current operation at second berth of terminal B (B2), thereby we ensure that the berth availability for the next upcoming vessel from own customers of terminal B will not be affected by the handling of transfer vessel given by terminal A. If above conditions are not satisfied, we do not allow vessel berthing at berth B1.

Terminal B: berth B1

$IF\ (AND(Contracted\ Terminal = A,\ \ Transfer\ = Yes, Do\ not\ Berth\ at\ A1,\ \ Do\ not\ Berth\ at\ A2,$
$(Arrival\ Time > Completion\ Time\ of\ Current\ Operation_{B1}), OR(Arrival\ Time\ of\ Next\ Vessel_B \geq$
$Target\ Operation\ Hours\ of\ Transferring\ Vessel, Arrival\ Time\ of\ Next\ Vessel_B \geq$
$Completion\ Time\ of\ Current\ Operation_{B2}),\ \rightarrow Berth\ at\ B1,$

$\rightarrow Do\ not\ Berth\ at\ B1$

If the vessel was not berthed at any of the three berths; A1, A2, and B1, then we check the possibility of vessel berthing at berth B2 as follows. Similar to the previous case with berth B1, we check whether the transferred vessel can be handled by berth B2 without affecting the berth availability for the next upcoming vessel from its own customers of terminal B. If yes, we allow vessel berthing at berth B2. If there is no possibility of handling the vessel either by berth B1 and B2, then the vessel is handled by terminal A with paying penalty for berthing delays. Thus, when updating conditions at individual berths, we incorporate those vessels handled with the penalty, which will be explained later.

Terminal B: berth B2

$IF\ (AND(Contracted\ Terminal = A,\ Transfer\ = Yes, Do\ not\ Berth\ at\ A1,\ Do\ not\ Berth\ at\ A2,$
$Do\ not\ Berth\ at\ B1, (Arrival\ Time >$
$Completion\ Time\ of\ Current\ Operation_{B2}), OR(Arrival\ Time\ of\ Next\ Vessel_B \geq$
$Target\ Operation\ Hours\ of\ Transferring\ Vessel,\ Arrival\ Time\ of\ Next\ Vessel_B \geq$
$Completion\ time\ of\ Current\ Operation_{B1}),\ \rightarrow Berth\ at\ B2,$
$\rightarrow Do\ not\ Berth\ at\ B2$

Thus, as a result of the above berth allocation process, we can determine whether each individual vessel is handled by the contracted terminal itself at own berth or transfer to a berth at another terminal in the same port. Although we explained the berth allocation decisions with a simplified scenario, in our focused case in Colombo, we have three terminal operators which are represented by a (JCT), b (CICT) and c (SAGT). Thus, we allow a priority rule when deciding an alternative terminal for vessel transfer as follows to reduce possible inter-terminal transfer cost of containers. When transferring a desired vessel of any private terminal, we give higher priority for the remaining private terminal and only if it cannot accept the vessel, we check the possibility to transfer to the public terminal. We allow this priority rule because two private terminals are located proximity to each other, which can reduce possible inter-terminal transfer cost of containers. Besides, when transferring vessels from the public terminal (JCT), we give high priority for SAGT than CICT because JCT locates closer to the SAGT than CICT. Only if SAGT cannot accept the vessel, we check the possibility of transfer to the CICT. Thus, at the end of the above berth allocation process, the model can decide the berth allocation decision for each individual vessel (i, j, q), such as whether is it handled at a berth of contracted terminal or transfer to a berth of another terminal and whether is it handled with penalty or without penalty, which in return affect on terminals' profit.

✓ ***Deciding "Target Operation Competition Time" of individual vessels***

Since the berth allocation decisions of individual vessels are made considering the updated conditions at individual berths, the target operation completion time of a vessel is influenced by whether it is handled with a berthing delay or not. However, this "*Target Operation Competition Time*" is the real-time for completing the vessel operation and is different from the vessel's "*Target Operation Hours*" which implies the duration for vessel operation. Thus, we update the target operation completion time of a vessel as follows. First, if the vessel is handled without a berthing delay, then the target operation completion time of the vessel can be decided by simply adding the target operation hours of the vessel to its arrival time. However, if a vessel is handled with a berthing delay but without penalty, then the target operation completion time of the vessel is determined by adding the target operation hours of the vessel to the "*Completion Time of Current Operation*" at the assigned berth. However, when considering a vessel handed with the penalty, the target operation completion time is determined by adding the target operation hours of the vessel to the earliest "*Completion Time of Current Operation*" among berths at the contracted terminal.

<u>If without Berthing Delay</u>

$$Target\ Operation\ Completion\ Time\ of\ a\ Vessel\ without\ Delay$$
$$= Arrival\ Time\ of\ the\ Vessel + Target\ Operation\ Hours\ of\ the\ Vessel$$

<u>If Berthing Delay but without Penalty</u>

$$Target\ Operation\ Completion\ Time\ of\ a\ Vessel\ with\ Delay\ but\ without\ Penalty$$
$$= Completion\ Time\ of\ Current\ Operation_{Assigned\ Berth}$$
$$+ Target\ Operation\ Hours\ of\ the\ Vessel$$

<u>If Berthing Delay with Penalty</u>

$$Target\ Operation\ Completion\ Time\ of\ a\ Vessel\ with\ Penalty$$
$$= IF\ (AND(Contracted\ Terminal = A, Did\ not\ Berth\ at\ A1, A2, A3, A4,)$$
$$\rightarrow (Min\ (Completion\ Time\ of\ Current\ Operation_{A1}, Completion\ Time\ of\ Current\ Operation_{A2})$$
$$+ Target\ Operation\ Hours\ of\ the\ Vessel)$$

✓ ***Updating the Condition at Individual Berths***

Since the berth allocation decisions of individual vessels are made considering the updated conditions at individual berths, we update the condition at each berth as the "*Completion Time of Current Operation*" considering each individual vessel arrival. The updating process is given as follows for the first berth in terminal A (A1) as an example. Therefore, first, we have to decide a berth from terminal A for handling the vessel with the penalty. Thus, in case if the vessel was not allocated to any berth at the initial berth allocation decision, we consider that the vessel is handled with the penalty by the terminal A itself. Thus, we select a berth from terminal A, which has the earliest completion time of current operation to minimize the delay time. Accordingly, if the earliest available berth among two berths in terminal A is A1, then the vessel is allocated to the berth A1. Therefore, the "*Completion Time* *of Current Operation$_{A1}$*” is updated as the "*Target Operation Completion Time of a Vessel with Penalty*" of the corresponding vessel. This is simply done by adding the target operation hours of the vessel with penalty to the previous completion time of current operation at berth A1 as explained previously. However, in case if the vessel was initially decided to berth at A1 without berthing delay or with berthing delay but without penalty, then the “*Completion Time of Current Operation$_{A1}$*” is updated as the latest time between the “*Target Operation Completion Time of a Vessel without Delay*” and the “*Target Operation Completion Time of a Vessel with delay but without Penalty*”. However, if the vessel was not allocated to berth A1 in any of the above scenarios, then the “*Completion Time of Current Operation$_{A1}$*” is not updated and remained the same as its condition with the immediate previous vessel handling at the port.

$$Completion\ Time\ of\ Current\ Operation_{A1} = IF(AND(Contracted\ Terminal =$$
$$A, Did\ not\ Berth\ at\ A1, A2, A3, A4), \big(Completion\ Time\ of\ Current\ Operation_{A1} =$$
$$Min\ (Completion\ Time\ of\ Current\ Operation_{A1}, Completion\ Time\ of\ Current\ Operation_{A2})\big) \rightarrow$$
$$Target\ Operation\ Completion\ Time\ of\ a\ Vessel\ with\ Penalty,$$
$$IF\ (Berth\ at\ A1,\ \rightarrow (MAX\ (Target\ Operation\ Completion\ Time\ of\ a\ Vessel\ without\ Delay,$$
$$Target\ Operation\ Completion\ Time\ of\ a\ Vessel\ with\ delay\ but\ without\ Penalty)),$$
$$\rightarrow Do\ not\ change\ the\ "Completion\ Time\ of\ Current\ Operation_{A1}"$$

A similar process is followed for each individual berth to update the “Completion Time of Current Operation” as necessary in terms of all vessel arrivals although the vessel is allocated to only one berth because the condition of a berth can be updated not only from vessels of own customers but also from vessels transferred by other terminals in the same port. Therefore, conditions at individual berths will be updated in terms of the “Completion Time of Current Operation”, and this information will be available for terminal operators even in the practical scenario as the basic information in their vessels’ berth allocation decisions. In case if the vessel was not allocated to a particular berth in any of previous cases, then the “Completion Time of Current Operation” of that berth will not be changed and remained similar to its previous “Completion Time of Current Operation”.

As results of the berth allocation decisions in the operation stage, we can obtain the total number of vessels handled by each terminal operators at their own terminals ($U_{i(a)}, U_{j(b)}, U_{q(c)}$), the total number of vessel transfers between each terminal pairs ($U_{i(b)}, U_{i(c)}, U_{j(a)}, U_{j(c)}, U_{q(a)}, U_{q(b)}$) and the number of vessels handled with penalty ($U_{i(a)}^{penalty}, U_{j(b)}^{penalty}, U_{q(c)}^{penalty}$) including the numbers of TEUs handled from each vessel ($M_i,\ M_j,\ M_q$). Depending on these components, the profit functions of individual terminals are affected as given from Equation (4.18), (4.19) and (4.20). For the convenience in representation, the components of the profit functions are discussed considering the terminal level such as vessel transfers between terminals and vessels handled by own terminals, etc, although these decisions are made considering the conditions at individual berths. This is reasonable because the purpose of this study is not to solve a pure berth allocation problem which is discussed by an extensive number of previous studies but to analyze the coopetition with vessel transfer decisions among competing terminals. Thus, our main focus is on terminal level vessel handling and transfer decisions considering their ownership types, profit, transfer prices among others which are not discussed by previous studies. However, since the components of profit function such as operation cost, terminal handling charges, terminal fee, etc are not changed across different berths in the same terminal, the representation of profit function with terminal level is reasonable. Thus, even we consider the individual berth level, the results will not be changed. Since we also discuss the additional benefits of proposed vessel transfer policy such as vessels emission reduction at anchorage by reducing total delay time, the summation of delay times of all vessels handled with berthing delay (WT_i, WT_j, WT_q) with or without penalty is calculated by considering the difference between the vessel arrival time and the actual starting time of vessel operation.

c) Terminal fee collection policies of the port authority

Since this study considers the co-existence of both the public and private terminals in the same port, it may influence the effectiveness of the vessel transfer policy. Before developing a detailed model, we conducted several interviews with the port authority and the terminal operators in the Port of Colombo to understand the practical implications related to the vessel transfer policy. As per the nature of the concession agreement, the private terminals are required to pay a terminal fee to the port authority depending on the number of containers handled, as discussed earlier. However, according to our interviews with the SLPA, in case of a vessel transfer, the port authority can come up with different policies when collecting terminal fees for the containers handled from a transferred vessel. Thus, to analyze the impacts of various policies of the port authority in collecting terminal fees, two dummy variables; δ and γ are introduced as described in Table 4.5. Accordingly, the dummy variable δ indicates whether or not the port authority excludes the terminal fee only for the containers handled from vessels, which are transferred from private terminals to the public terminal. The dummy variable γ indicates whether the port authority collects the terminal fee from the contracted terminal or from the operation terminal in case of a vessel transfer between two private terminals. Aligned with our previous assumption, since the port authority and the public terminal are represented by the same economic entirety, the profit functions of all three terminal operators derived from the coopetition strategy are affected by the values of δ and γ.

Table 4.5. Variables for the Policy Scenarios

Dummy variable	Description
$\delta = 1$	In the case of a vessel transfer between a public terminal and a private terminal, the port authority excludes the terminal fee only for the containers of vessels transferred from the private terminal to the public terminal.
$\delta = 0$	In the case of a vessel transfer between a public terminal and a private terminal, the port authority does not exclude the terminal fee even for the containers of vessels transferred from the private terminal to the public terminal.
$\gamma = 1$	In the case of a vessel transfer between two private terminals, the port authority charges terminal fees from the operation terminal regardless of which the contracted terminal is.
$\gamma = 0$	In the case of a vessel transfer between two private terminals, the port authority charges terminal fees from the contracted terminal regardless of which the operation terminal is.

d) Terminal Profit under Coopetition

When considering the profit functions of terminal operators with the coopetition strategy, although the fundamental components of the profit functions are similar to that of Objective [4.1], the calculation process is different for Objective [4.2] owing to its MIPO approach and the consideration of policy variables δ and γ. Thus, Equations (4.18) calculates the profit of a public terminal, JCT and the Equation (4.19) and (4.18) calculate the profits of two private terminals, CICT and SAGT, respectively. When considering the main difference between profit functions of terminals with competition and coopetition strategies, the latter consists of transfer prices among terminals related to their vessel transfers, the dummy variables associated with their vessel transfer decisions, and the terminal fee collection policies of the port authority. Therefore, the second and third components of Equation (4.18) represent the portions of terminal a's profit derived from vessels transferred from terminal a to other two terminals, and the fourth and fifth components represent the portions of terminal a's profit derived by handling the vessels transferred to the terminal a from other two terminals. Similarly, the profit functions of two private terminals consist of components associated with vessel transfers between the remaining two terminals in the same port. Following the MIPO approach, the decision variables associated with vessel transfers are included in the profit calculation together with the number of TEUs handled from each vessel call. Moreover, the terminal fees collected and paid by the public terminal and private terminals, respectively are affected by the δ and γ, which are introduced in Table 4.5, because the terminal fees related to the transfer vessels are dependent on these policies. Apart from the terminal fees, the remaining components of the profit functions; the direct operating profit, transfer prices paid or collected for respective vessel transfers and the penalty charges for berthing delays are calculated with a similar approach for all three terminals.

$$\pi_{a,coopetition} = \sum_{i \in V^{a \to a}} (P_a - C_a)[U_{i(a)} * M_i] + \sum_{i \in V^{a \to b}} (P_a - P_{a \to b})[U_{i(b)} * M_i] + \sum_{i \in V^{a \to c}} (P_a - P_{a \to c})[U_{i(c)} * M_i] + \sum_{j \in V^{b \to a}} (P_{b \to a} - C_a)[U_{j(a)} * M_j] + \sum_{q \in V^{c \to a}} (P_{c \to a} - C_a)[U_{q(a)} * M_q] + F_b \left[\left[\sum_{j \in V^b} M_j \right] - \delta \left[\sum_{j \in V^{b \to a}} [U_{j(a)} * M_j] \right] + \gamma \left[\sum_{q \in V^{c \to b}} (U_{q(b)} * M_q) - \sum_{j \in V^{b \to c}} (U_{j(c)} * M_j) \right] \right] + F_c \left[\left[\sum_{q \in V^c} M_q \right] - \delta \left[\sum_{q \in V^{c \to a}} [U_{q(a)} * M_q] \right] + \gamma \left[\sum_{j \in V^{b \to c}} (U_{j(c)} * M_j) - \sum_{q \in V^{c \to b}} (U_{q(b)} * M_q) \right] \right] - \mathrm{g} * \sum_{i \in V^{a \to a}} [U_{i(a)}^{penalty} * M_i] \tag{4.18}$$

$$\pi_{b,coopetition} = \sum_{j \in V^{b \to b}} (P_b - C_b)[U_{j(b)} * M_j] + \sum_{j \in V^{b \to a}} (P_b - P_{b \to a})[U_{j(a)} * M_j] + \sum_{j \in V^{b \to c}} (P_b - P_{b \to c})[U_{j(c)} * M_j] + \sum_{i \in V^{a \to b}} (P_{a \to b} - C_b)[U_{i(b)} * M_i] + \sum_{q \in V^{c \to b}} (P_{c \to b} - C_b)[U_{q(b)} * M_q] - F_b \left[\left[\sum_{j \in V^b} M_j \right] - \delta \left[\sum_{j \in V^{b \to a}} [U_{j(a)} * M_j] \right] + \gamma \left[\sum_{q \in V^{c \to b}} (U_{q(b)} * M_q) - \sum_{j \in V^{b \to c}} (U_{j(c)} * M_j) \right] \right] - g * \sum_{j \in V^{b \to b}} [U_{j(b)}^{penalty} * M_j] \tag{4.19}$$

$$
\begin{aligned}
\pi_{c,coopetition} = & \sum\nolimits_{q \in V^{c \to c}} (P_c - C_c)\left[U_{q(c)} * M_q\right] \\
& + \sum\nolimits_{q \in V^{c \to a}} (P_c - P_{c \to a})\left[U_{q(a)} * M_q\right] \\
& + \sum\nolimits_{q \in V^{c \to b}} (P_c - P_{c \to b})\left[U_{q(b)} * M_q\right] \\
& + \sum\nolimits_{i \in V^{a \to c}} (P_{a \to c} - C_c)\left[U_{i(c)} * M_i\right] \\
& + \sum\nolimits_{j \in V^{b \to c}} (P_{b \to c} - C_c)\left[U_{j(c)} * M_j\right] - F_c \Bigg[\left[\sum\nolimits_{q \in V^{c}} M_q\right] \\
& - \delta \left[\sum\nolimits_{q \in V^{c \to a}} \left[U_{q(a)} * M_q\right]\right] + \gamma \left[\sum_{j \in V^{b \to c}} \left(U_{j(c)} * M_j\right) - \sum_{q \in V^{c \to b}} \left(U_{q(b)} * M_q\right)\right]\Bigg] \\
& - g * \sum\nolimits_{q \in V^{c \to c}} \left[U_{q(c)}^{penalty} * M_q\right]
\end{aligned}
\tag{4.20}
$$

4.3.1.3. MIPO model for the vessel transfer decisions

Considering the operation stage, a MIPO model is formulated, which decides the vessel transfers and transfer prices among terminals. The coopetition strategy focuses on two different objectives namely; the minimizing total penalty cost associated with berthing delays (Min.PC) and the maximizing the combined profits of all terminal operators (Max.TP) in the same port as expressed in Equations (4.21) and (4.22), which are analyzed as two separate cases. Since we incorporate a game-theoretical decision-making approach aligned with the individual rationality condition for deciding vessel transfers, the terminals' profits derived from both competition and coopetition strategies are used with the MIPO model. Thus, Equation (4.23) implies the individual rationality condition to ensure that the profit of each terminal derived with coopetition strategy is greater than or equal to the profit derived from its competition strategy. Thus, each terminal will be better off from the coopetition strategy than its initial competition strategy. Moreover, as given with Equation (4.24), the transfer prices among terminals should be greater than the maximum operation cost among terminals, C_{max}, and should be lower than the minimum handling charges, P_{min}, among terminals. As per Equations (4.25) to (4.27), each vessel must be allocated to only one container terminal and the binary variables associated with the MIPO model are expressed with Equation (4.28). Thus, the proposed MIPO model, given by Equations (4.15) to (4.28) is solved with the analytical solver platform 2018-C version with its evolutionary solver.

$$Minimize;\ Penalty\ Cost = g\left[\sum_{i\in V^{a\to a}}\left[U_{i(a)}^{penalty} * M_i\right] + \sum_{j\in V^{b\to b}}\left[U_{j(b)}^{penalty} * M_j\right] + \sum_{q\in V^{c\to c}}\left[U_{q(c)}^{penalty} * M_q\right]\right] \tag{4.21}$$

$$Maximize;\ Profit = \sum_{s\in S}\pi_{s,coopetition} \tag{4.22}$$

$$\pi_{s,coopetition} \geq \pi_{s,competition} \quad \forall s \in S \tag{4.23}$$

$$C_{max} \leq P_{a\to b}, P_{a\to c}, P_{b\to a}, P_{b\to c}, P_{c\to a}, P_{c\to b} \leq P_{min} \tag{4.24}$$

$$U_{i(a)} + U_{i(b)} + U_{i(c)} = 1 \tag{4.25}$$

$$U_{j(a)} + U_{j(b)} + U_{j(c)} = 1 \tag{4.26}$$

$$U_{q(a)} + U_{q(b)} + U_{q(c)} = 1 \tag{4.27}$$

$$U_{i(a)}, U_{i(b)}, U_{i(c)}, U_{j(a)}, U_{j(b)}, U_{j(c)}, U_{q(a)}, U_{q(b)}, U_{q(c)}, U_{i(a)}^{penalty}, U_{j(b)}^{penalty}, U_{q(c)}^{penalty} \in \{0,1\} \tag{4.28}$$

When considering the calculation process with the overall framework associated with the coopetition strategy including both the contract and operation stages, initially we decide the number of vessel calls, their associated handling volume, and target operation hours, among others from the contract stage for each container terminal. However, this chapter does not focus on the model development related to the contract stage to analyze the competitive interactions among terminal operators to obtain more vessel calls towards their own terminal, which was discussed by Chapter 3. Therefore, here we utilize the actual vessel handling data at the Port of Colombo to reflect the situation at the contract stage. Considering the current competitive situation among terminal operators in Colombo as illustrated in Figure 4.2, it is reasonable to utilize the actual vessel handling data at Colombo as the output from the contract stage. Thus, these vessel arrival data are used as the inputs to the operation stage, which decides the vessel transfers and transfer prices between terminals aligned with the proposed MIPO model as illustrated in Figure 4.8. However, the vessel transfer decisions can be considered as a type of operational decision made by terminal operators because the vessel transfers are varied depending on the vessel arrival pattern. Therefore, a monthly planning horizon is assumed for the operation stage, which is reasonable because terminal operators can negotiate their transfer prices on a monthly basis depending on the prospective vessel arrivals. Hence, the number of vessel transfers and the transfer prices among terminals are varied on a monthly basis because they are decided at the operation stage.

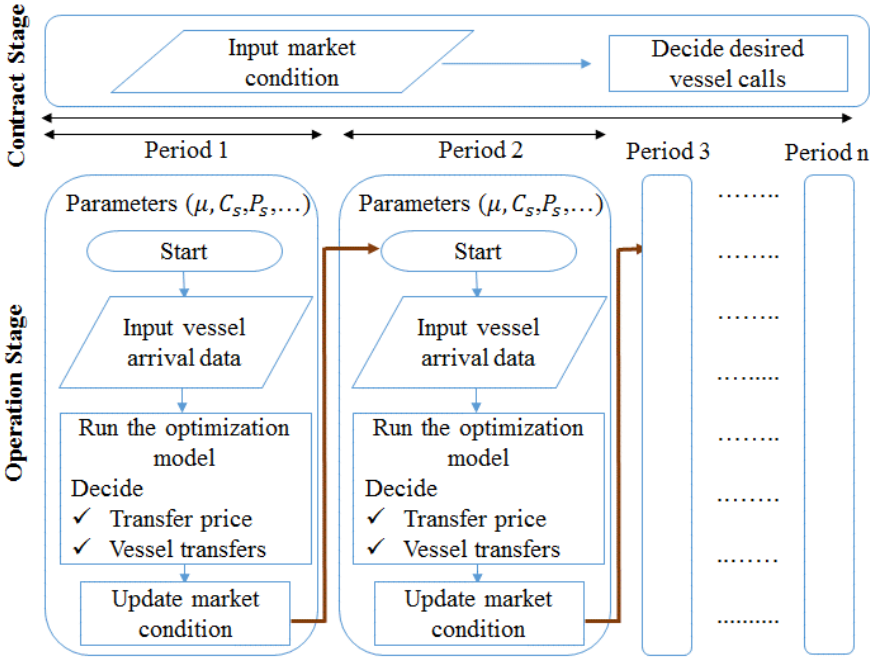

Figure 4.8. Calculation Process for the Coopetition Strategy

4.3.2 Results and Discussion for the Objective [4.2]

Since we utilize the actual vessel handling data of the Port of Colombo to test the results of the coopetition strategy, three consecutive periods of the operation stage are analyzed considering the vessel handling data during the 3rd quarter of 2017 (from 01st August to 31st September). Thus, we refer period-1, period-2, and period-3 for the July, August and September months, respectively considering the monthly planning horizon of the operation stage. The analysis with three consecutive months is sufficient for understanding the model dynamics with multiple periods, owing to the changes in vessel transfer decisions on a monthly basis.

For the Objective [4.2], most of the input data are similar to that of Objective [4.1]. Thus, the terminal handling charge of JCT is taken as 42 USD/TEU and that of CICT and SAGT is taken as 40 USD/TEU each. The operation costs of JCT, CICT, and SAGT are considered as 25, 18, and 20 USD/TEU respectively. Therefore, P_{min} and C_{max} are taken as 40 USD and 25 USD respectively, which are the upper and lower limits of transfer prices. The μ is assumed as one hour targeting the significant reduction of waiting time and g is assumed to be 3 USD/TEU following a nearly similar value derived as the results of Objective [4.1], although their sensitivity analysis has been conducted as explained in Section 4.3.2.1. The terminal fees for CICT and SAGT are considered as 5 USD/TEU and 4 USD/TEU respectively. Since the coopetition strategy is affected by the port authority's policy in collecting terminal fees, four possible policy scenarios are derived as shown in Table 4.6, each considering different δ and γ values. Thus, the port authority may enforce especially scenario-3 and scenario-4 as the policy instruments on encouraging private terminals to transfer more vessels to the public terminal.

Table 4.6. Policy Scenarios for Terminal Fee Collection

Policy Scenario	Description
Scenario-1 $\delta = 0, \gamma = 0$	The port authority collects terminal fees from the private terminals even for the transfer vessels based on the **contracted terminal**
Scenario-2 $\delta = 0, \gamma = 1$	The port authority collects terminal fees from the private terminals even for the transfer vessels based on the **operation terminal**
Scenario-3 $\delta = 1, \gamma = 0$	The port authority collects terminal fees based on the **contracted terminal** but **excludes** the containers of **vessels transferred from the private terminal to the public terminal**
Scenario-4 $\delta = 1, \gamma = 1$	The port authority collects terminal fees based on the **operation terminal** but **excludes** the containers of **vessels transferred from the private terminal to the public terminal**

4.3.2.1. Sensitivity analysis with model dynamics

Since one of the motivations on coopetition strategy is to increase the port competitiveness by reducing vessels' waiting time, the Objective [4.2] assumes a maximum tolerable waiting time for shipping lines (μ) as the maximum waiting time that shipping lines would wait at anchorage without receiving any discounts on the container handling charge as the penalty for berthing delays. Since the coopetition strategy aims to reduce the berthing delays, the duration of μ would have a significant influence on the vessel transfer decisions of terminal operators. Hence, a sensitivity analysis of μ is done considering both objectives of the MIPO model, namely Min.PC and Max.TP, separately as illustrated in Figure 4.9. For the brevity, the sensitivity analysis is discussed here only considering Scenario-3 with the vessel arrival data in period-1. As per the results, when increasing the duration of μ, the numbers of vessel transfers and penalty calls decrease in both objectives. This is reasonable because the longer duration of μ can possibly reduce the number of penalty calls, hence terminal operators can be demotivated to transfer vessels to other terminals as they are not required to pay a high penalty cost. However, coopetition with Min.PC objective always generates a higher number of vessel transfers than the number of penalty calls, although the Max.TP objective generates a lower number of vessel transfers than the penalty calls at a longer duration of μ, which is reasonable due to the lower significance of penalty cost in the terminal profit when increasing the duration of μ.

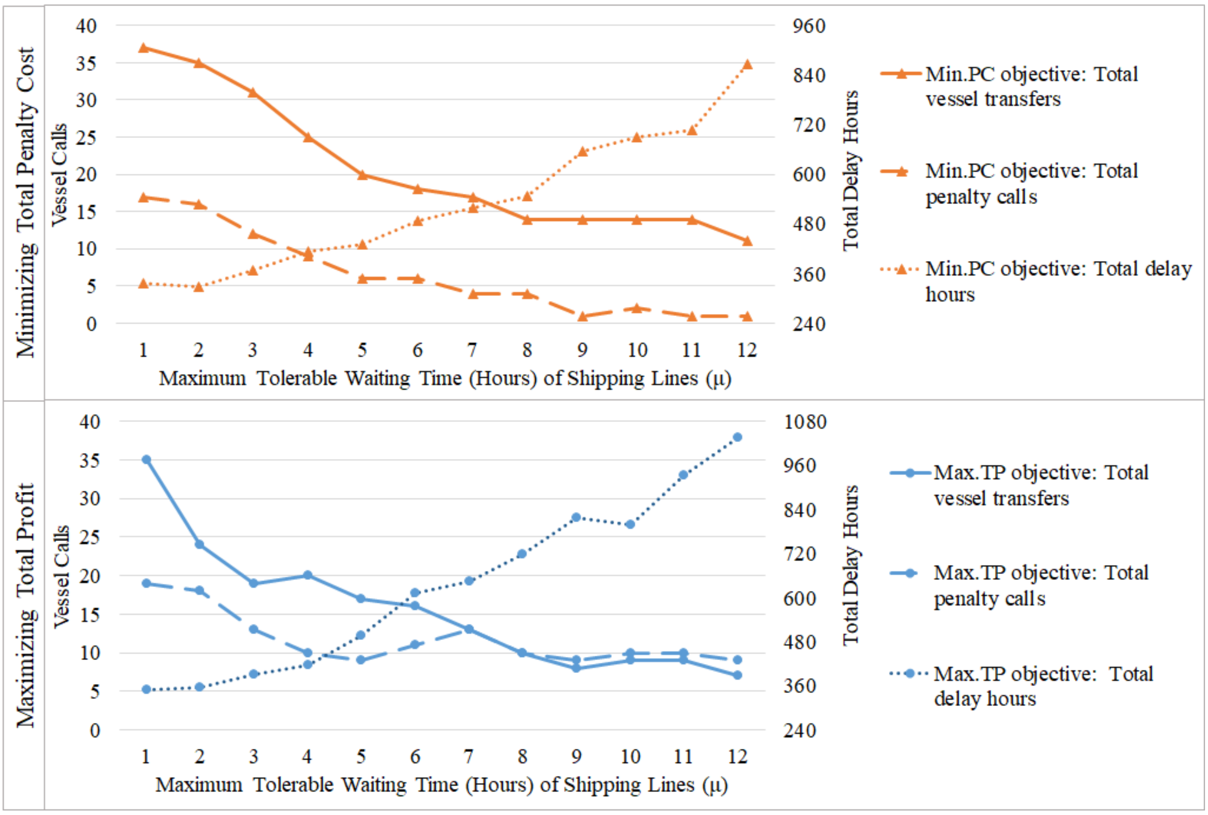

Figure 4.9. Sensitivity Analysis of the Maximum Tolerable Waiting Time

As per our proposed approach on enforcement of penalty charge for berthing delays, the total penalty cost is escalated in proportionate to the number of occurrences of berthing delays rather than the actual duration of delay time because it is assumed that a terminal has to pay a penalty charge if the vessel operation cannot be commenced within μ hours after the vessel arrival. However, apart from enhancing the port competitiveness by reducing the number of penalty calls associated with the occurrences of berthing delays, the vessel transfer policy can also reduce the total duration of the delay time of vessels waiting at anchorage, which can result in additional benefits such as emissions reduction of vessels at anchorage. Thus, when considering the variation of total delay time (hours) related to both objectives as illustrated in Figure 4.9, a significant increase of the total number of delay hours can be observed when increasing the duration of μ, despite the lower number of penalty calls. Thus, when imposing policies related to the penalty charge by the port authority, it is important to decide an appropriate short duration of μ considering the target reduction of the average vessel waiting time at the entire port from the coopetition strategy, which also can reduce the total number of delays hours of vessels at anchorage.

Apart from the duration of μ, the effectiveness of the coopetition strategy also depends on the penalty charges, g (USD/TEU) imposed by the port authority, which is considered as a discount to the container handling charges in case of berthing delays. Therefore, the impact of the penalty charge on the coopetition strategy is analyzed considering both objectives; Min.PC and Max.TP as illustrated in Figure 4.10. Accordingly, with the Min.PC objective, terminals execute a high number of vessel transfers even at a small value of g. In the case of Max.TP objective, terminals execute a high number of vessel transfers at high value of g because it directly influences on the terminals' profits. However, at a small value of g, terminals are not motivated to execute more vessel transfers with their Max.TP objective. Thus, the coopetition strategy with Min.PC objective always derives a higher number of vessel transfers than the number of penalty calls, although the Max.TP objective derives a lower number of vessel transfers than the number of penalty calls at a small value of g. When considering the additional benefits by reducing the total number of delay hours such as the vessels' emissions reduction at anchorage, a slight reduction of the total number of delay hours could be observed when increasing the value of g with both objectives could be due to the high number of vessel transfers.

When considering the results of sensitivity analysis with both μ and g, it seems that the benefits of coopetition strategy are limited when terminals focus on maximizing combined profits together with a longer duration of μ and a small value of g. Hence, when a port has many private terminals that purely focus on maximizing operating profits, the port authority should enforce a short duration of μ and a sufficiently high value of g while deciding policies on penalty charges, which confirm the continuous benefits from the coopetition strategy. However, a very high value of g is not appropriate because it cannot further reduce berthing delays after achieving an optimal number of vessel transfers despite its negative influence on terminals' profits. Moreover, to confirm the long-term viability of the proposed coopetition strategy in economic aspects, it is not advisable to enforce a high g (USD/TEU) value, because such policy will lead to a conflicting situation between the port authority and its terminal operators. Apart from that, a very high value of g (USD/TEU) is not beneficial for the entire port because this amount of money related to the penalty charge is not retained inside the port because it is paid to the shipping lines, who are outsider from the port, as the discounts from container handling charges. Thus, it will negatively influence the port financial performance and the market value of the port's assets especially due to the discounted average port charge while reducing the interests of investors on the port development in the long term.

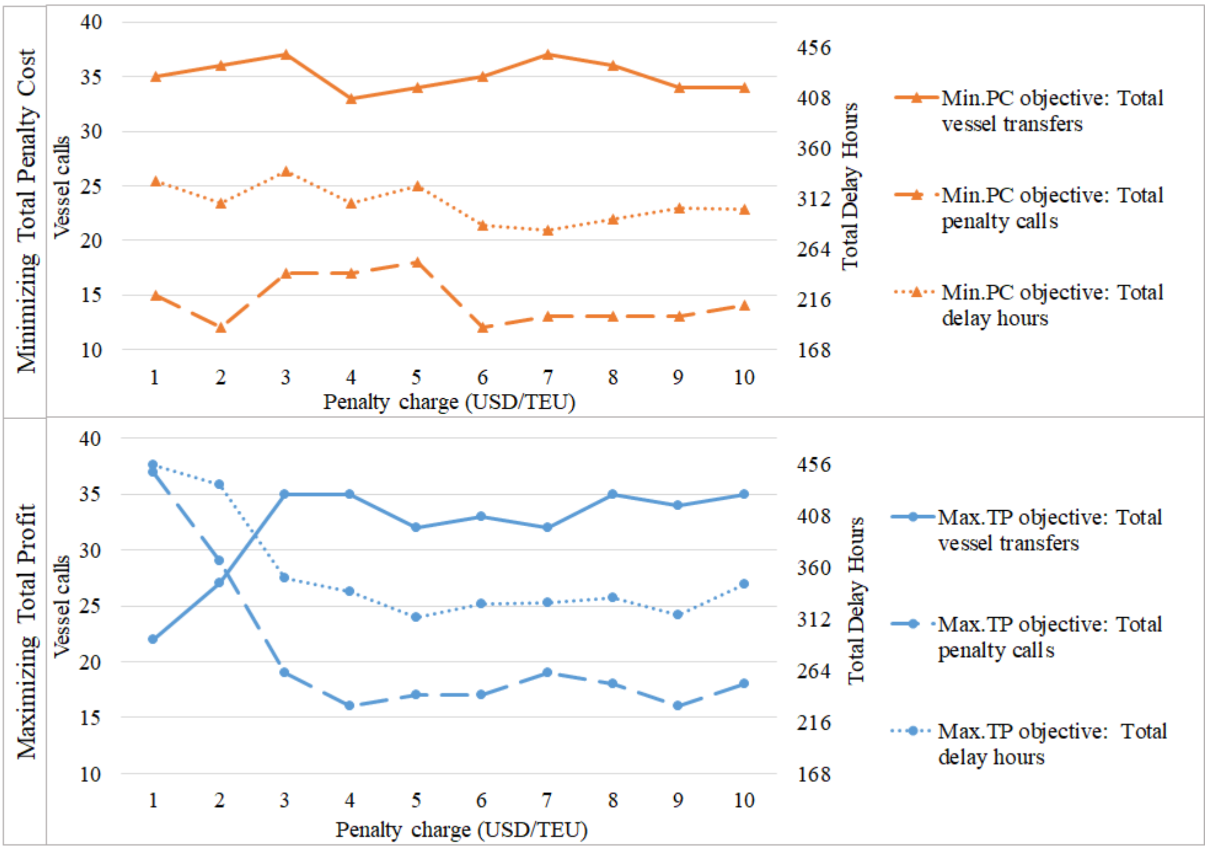

Figure 4.10. Sensitivity Analysis of the Penalty Charge

4.3.2.2. *Results of coopetition while minimizing total penalty cost*

Since the total penalty cost is proportionate to the occurrences of berthing delays, the results of the coopetition strategy with Min.PC are discussed in this section. Thus, the results of coopetition with all four scenarios introduced in Table 4.6 and the results of the competition strategy are summarized in Table 4.7. However, the detailed results are presented only for the period-1 to maintain the brevity, although the results of period-2 and period-3 are summarized in the discussion. Accordingly, when considering the vessel arrival data in period-1, the least and highest number of desired vessel calls are received by JCT and CICT, respectively. However, JCT and SAGT receive the least and highest number of penalty calls with the competition strategy and with all four scenarios related to the coopetition strategy. Moreover, when comparing to the results with the competition strategy, the coopetition strategy with all four scenarios significantly reduces the total number of penalty calls. The highest total profit of terminal operators is obtained with scenario-4 possibly due to the least number of penalty calls associated with it. However, as per the individual rationality, all terminal operators obtained higher profits from the coopetition strategy than their profits from the competition strategy.

Table 4.7. Results from Coopetition with Minimizing Total Penalty Cost Objective

Terminal Consideration		**Results from Competition**	**Results from Coopetition**			
			Scenario-1	**Scenario-2**	**Scenario-3**	**Scenario-4**
Desired vessel calls/TEUs handled on their own	JCT	107/158142	105/154455	105/154455	102/150199	104/152565
	CICT	137/192130	127/177416	127/174273	126/176163	127/177548
	SAGT	114/179959	94/149484	94/150577	93/148381	91/146461
Vessel calls/TEUs handled with penalty	JCT	3/5483	2/2747	2/2747	1/1796	2/2747
	CICT	21/27258	3/4241	5/6662	7/9684	3/5051
	SAGT	94/147093	11/14252	9/14969	9/13063	8/12021
	Total	118/179834	16/21240	16/24378	17/24544	13/19819
Profit (Thousand USD)	JCT	4353	4478	4467	4427	4471
	SAGT	3184	3325	3251	3292	3240
	CICT	2438	2542	2603	2604	2635
	Total	9,975	**10,345**	**10,321**	**10,323**	**10,346**

Besides, the vessel transfers between different terminal pairs and the transfer prices associated with them are summarized in Figure 4.11 considering all four scenarios related to the coopetition strategy. As per the results, comparatively high numbers of vessels are transferred from scenario-3 and scenario-4 than scenario-1 and scenario-2 could be due to the port authority's policy on exempting terminal fees for the containers handled from vessels that are transferred from private terminals to the public terminal. Thus, private terminals may have a high motivation to transfer more vessels to the public terminal. Although, both scenario-1 and scenario-2 generate an equal and the least number of transfer vessels, the least number of transfer TEUs are generated with scenario-1 owing to the varying number of handling TEUs associated with individual vessel calls. However, the highest number of transfer vessels is received by JCT from the other two terminals. Although CICT receives more transfer vessels from SAGT than JCT, the least number of transfer vessels is received by SAGT in all scenarios.

When comparing the results of scenarios with and without terminal fee exception policies, the total number of transfer vessels received by JCT from two private terminals and the transfer prices charged by JCT from them are slightly increased in scenario-3 and scenario-4 than in scenario-1 and scenario-2. Thus, it implies that although container handling charges are directly paid to the contracted private terminal by the shipping lines, the public terminal, JCT might increase its transfer prices when handling vessels transferred by private terminals in scenario-3 and scenario-4, to offset the revenue loss incurred due to the exception of terminal fees for those transfer vessels. Therefore, a greater number of vessel transfers can be generated with such policy scenarios owing to the high possibility of JCT in accepting transfer vessels with its large capacity and the least number of desired vessel calls received from its own customers in period-1. Although we discuss these implications considering the results obtained with vessel arrivals in period-1, the results could be different if the vessel arrival pattern significantly changes in another period. The highest number of vessel transfers is obtained with scenario-3, which is reasonable because the port authority collects the terminal fees from the contracted terminal in this case while excluding the vessels transferred from private terminals to the public terminal. Since shipping lines pay container handling charges directly to their contracted terminal, the contracted terminal has high potential to pay the terminal fees to the port authority rather than it is being paid by the operation terminal.

Since the numbers of vessel transfers and the effectiveness of the coopetition strategy depend on the number and patterns of vessel arrivals at individual terminals, the analysis is done for three consecutive periods. When considering the results of coopetition strategy derived in period 2 and 3, although CICT receives the highest number of desired vessel calls, similar to the period-1, the least number of desired vessel calls is obtained by SAGT in both periods. However, when considering the number of handling TEUs associated with their desired vessel calls, the JCT and SAGT receive the highest number of handling TEUs in period-2 and period-3, respectively. Similar to the results obtained in period-1, scenario-3 obtains the highest number of total penalty calls in both period-2 and period-3. However, when comparing the results of policy scenarios in period-2, higher numbers of vessels are transferred with scenario-1 and scenario-2 than with scenario-3 and scenario-4, in contrast to the results in period-1. This is reasonable because the public terminal, JCT receives the highest number of TEUs from own desired vessels in period-2, which discourages JCT from handling more transfer vessels given by other two private terminals when compared to the period-1, where JCT receives the least number of handling TEUs from own desired vessels. However, scenario-4 obtains the highest number of transfer vessels in period-3, which could be due to the more vessels transferred from private terminals to the public terminal with the terminal fee exception policy. Moreover, the public terminal receives a smaller number of TEUs from its own desired vessels in period-3, which encourages it to accept more transfer vessels given by private terminals. However, in all three periods, the lowest number of vessel transfers is derived from JCT to SAGT and relatively high numbers of vessel transfers are derived from CICT to JCT, SAGT to CICT, and SAGT to JCT.

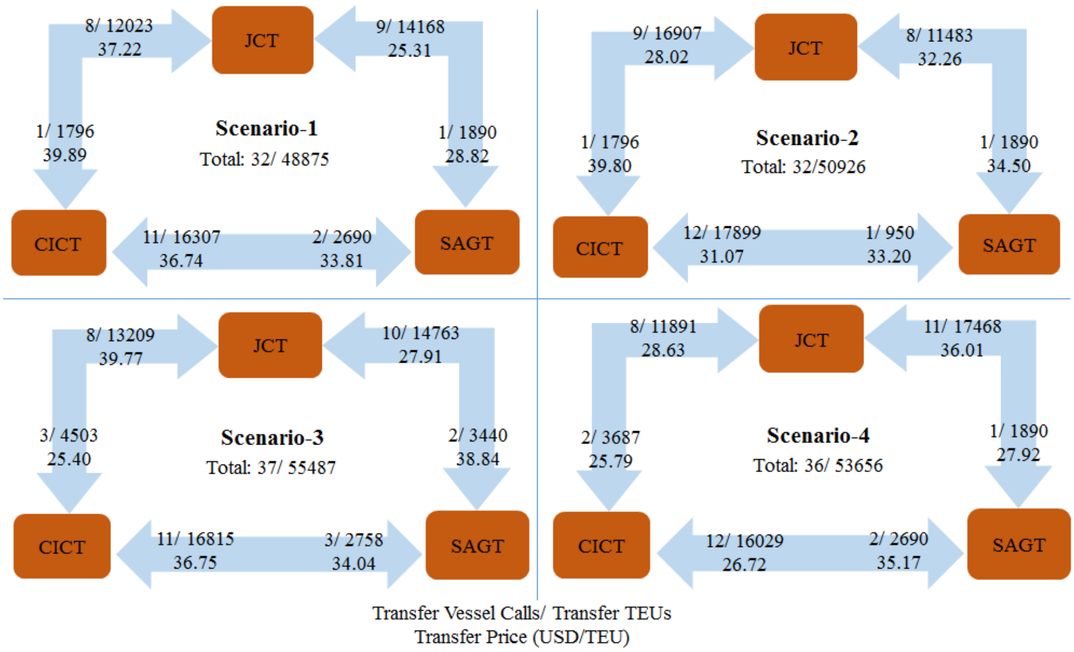

Figure 4.11. Vessel Transfers with Minimizing Total Penalty Cost Objective

4.3.2.3. Results of coopetition while maximizing total profit

Apart from minimizing total penalty cost, we also analyze the coopetition strategy if terminal operators aim to maximize the total profit. Similar to the Min.PC case, the results of the coopetition strategy with Max.TP objective derived from the vessel arrival data in period-1 are summarized in Table 4.8 and Figure 4.12 considering all four policy scenarios. Accordingly, scenario-4 obtains the least number of TEUs handled with penalty cost similar to the results obtained with Min.PC objective, and scenario-1 obtains the highest profit, although it has the least number of transfer TEUs. Thus, in the case of Max.TP objective, the scenario associated with the least number of penalty calls does not derive the highest profit, although the highest profit and the least number of penalty calls are derived from the same scenario with the Min.PC objective. Considering this, the highest profit derived from the Min.PC objective is lower than that of Max.TP objective and the least number of penalty calls derived from the Max.TP objective is higher than that of Min.PC objective.

As illustrated in Figure 4.12, scenario-3 obtains the highest number of vessel transfers with Max.TP objective, following a similar trend with Min.PC objective. Despite its highest number of transfer TEUs, scenario-4 generates a relatively lower total profit than scenario-1 and scenario-3. Moreover, the highest number of penalty calls results from scenario-2, which also derives the least number of transfer vessels and the lowest total profit. This implies that, with Max.TP objective, a high number of transfer vessels can effectively reduce the number of penalty calls. Besides, the terminal fee exception policy associated with scenario-3 does not encourage terminals to transfer a greater number of vessels than that of scenario-1, although the terminal fee exception policy associated with scenario-

4 encourages terminals to transfer a greater number of vessels than that of scenario-2. Hence, to encourage private terminals to transfer more vessels to the public terminal with the Max.TP objective, the port authority may collect the terminal fees based on the operation terminal while excluding the vessels transferred from private terminals to the public terminal. However, the terminal fee exception policy in scenario-3 encourages a greater number of vessel transfers between two private terminals than that of scenario-1, possibly due to the collection of terminal fees from the contracted terminal.

Table 4.8. Results from Coopetition with Maximizing Total Profit Objective

Terminal Consideration		**Results from Competition**	**Results from Coopetition**			
			Scenario-1	**Scenario-2**	**Scenario-3**	**Scenario-4**
Desired vessel calls/TEUs handled on their own	JCT	107/158142	103/150545	105/153891	102/150199	102/149388
	CICT	137/192130	128/181258	129/182102	128/180226	128/177667
	SAGT	114/179959	93/150554	93/144806	93/148381	94/150992
Vessel calls/TEUs handled with penalty	JCT	3/5483	2/2747	3/5483	1/1796	2/3346
	CICT	21/27258	8/13448	15/25944	9/13559	5/6800
	SAGT	94/147093	6/10102	11/13768	9/13063	9/13960
	Total	118/179834	16/26297	29/45195	19/28419	16/24107
Profit (Thousand USD)	JCT	4353	4660	4444	4386	4467
	SAGT	3184	3257	3376	3355	3253
	CICT	2438	2447	2504	2619	2621
	Total	9,975	**10,364**	**10,324**	**10,360**	**10,341**

Following a similar approach with the Min.PC objective, the coopetition strategy with Max.TP objective is analyzed considering vessel arrival data of three consecutive periods at the operation stage. Accordingly, the scenario-1 obtains the highest profit and the scenario-4 obtains the highest number of transfer TEUs in period-2, following a similar trend with period-1's results. When considering period-3, although scenario-4 generates the least number of penalty calls similar to the period-1's results, the scenario-1 generates the highest number of transfer TEUs. When considering the results from all three periods, the lowest number of vessel transfers are derived from JCT to SAGT and comparatively high numbers of vessel transfers are derived from CICT to JCT, SAGT to CICT, and SAGT to JCT. The total number of TEUs handled from transfer vessels with the Min.PC objective is usually higher than those obtained with the Max.TP objective, which implies that Min.PC objective encourages terminal operators on vessel transfers than the Max.TP objective does. However, the coopetition strategy with both objectives can significantly reduce berthing delays than the competition strategy.

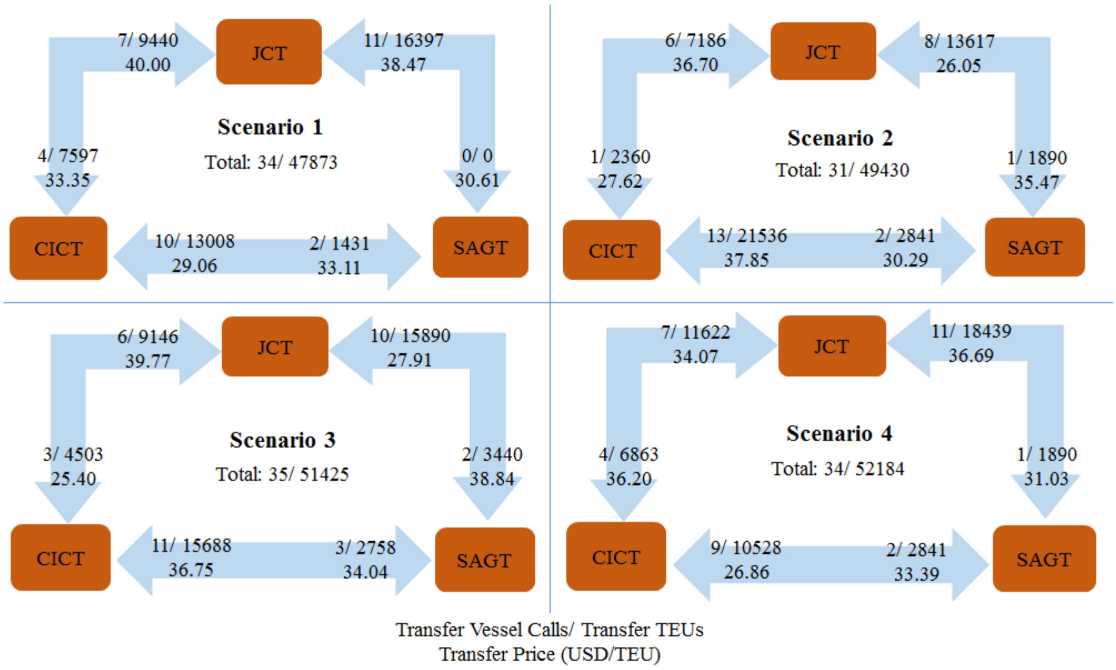

Figure 4.12. Vessel Transfers with Maximizing Total Profit Objective

4.3.2.4. Total delay time reduction at anchorage

Based on the proposed vessel transfer policy in this Chapter, the penalty charge is assumed to be paid in proportionate to the occurrences of berthing delays rather than considering the actual duration of delay time. This is reasonable because it may not be possible to impose penalty charge by proportionate to the duration of delay time in the practical case, as it generates a huge cost to the terminal operators in terms of penalty when compared to their operating profits, and would lead to a conflicting situation between the port authority and its terminal operators. However, even we did not consider the penalty charge by proportionate to the duration of delay time, still, our proposed coopetition strategy can significantly reduce the total delay hours. The reduction of total delay hours is significant for a port not only in operational perspectives but also in environmental perspectives because it can derive additional benefits such as vessels' emissions reduction at anchorage. As discussed by the International Maritime Organization, the emissions generated by vessels at the port can be reduced significantly by reducing vessels' waiting time and a study conducted with the Port of Rotterdam implies a CO_2 emissions reduction equals to 134,000 tons per year after implementing its "Just-in-time" sailing approach (World Maritime News, 2018).

If we assume an average emission factor for all container vessels, the production of emissions by vessels waiting at anchorage can be directly proportionate to the total duration of berthing delay hours of all vessels, because the vessels' waiting at anchorage also produce a considerable amount of emissions due to the functions of their auxiliary engines. Thus, this section discusses the reduction of the total number of delay hours from the coopetition strategy considering all three periods of operation stage. However, due to the variations in vessel arrival patterns across the three periods, the reduction of the number of delay hours in each period can be effectively analyzed in comparison to the number of delay hours associated with the competition strategy in the same period. Hence, the reduction of the total number of delay hours is calculated as the difference between total delay hours from competition and coopetition strategies. As per the results illustrated in Figure 4.13, the reduction of the total number of delay hours follows a nearly similar variation with both the Max.TP and Min.PC objectives of the coopetition strategy. However, a slightly higher number of delay hours' reduction is observed with the Min.PC objective than the Max.TP objective in most scenarios could be due to the comparatively higher number of vessel transfers associated with the Min.PC objective. When comparing the results derived from three different periods, period-2 and period-3 indicate the least and highest reductions in the total number of delay hours, respectively. This is reasonable owing to the high number of TEUs received by JCT from its own vessels in period-2 may discourage JCT from handling a greater number of transfer vessels given by private terminals. Such a situation can limit the possible delay hours' reduction from coopetition because the JCT, the largest terminal is the only one public terminal, which can effectively motivate the other two private terminals on vessel transfers by enforcing different policy scenarios related to the terminal fee exceptions. As indicated in Figure 4.13, the coopetition strategy with all four scenarios analyzed with both objectives considering the vessel arrival data in all three periods can significantly reduce the total number of delay hours of vessels at anchorage. This confirms the effectiveness of the coopetition strategy in enhancing the port competitiveness in the environmental arena as well by reducing the vessels' emissions at anchorage, apart from the port competitiveness attained by operational aspects.

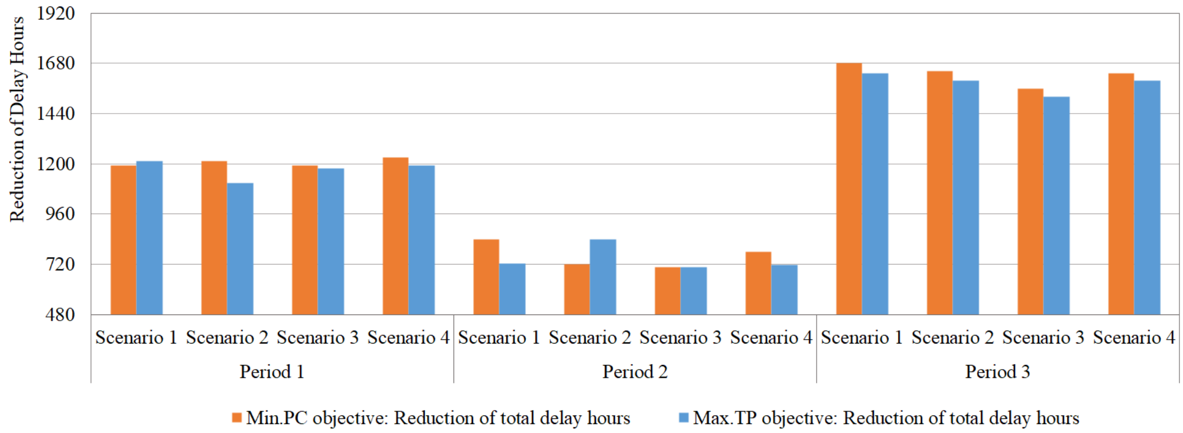

Figure 4.13. Total Delay Time Reduction at Anchorage

4.3.2.5. Equity concerns with profit distribution from coopetition

Although the coopetition strategy satisfies the individual rationality condition of all terminal operators, which ensures a higher profit for each terminal operator from the coopetition strategy than the competition strategy, the potential issues related to the profit-sharing or equality concerns can be raised if one terminal receives considerably higher profit than the others when compared to their profit distribution with the initial competition strategy. Therefore, the relationship between the individual terminals' profits derived from the competition and coopetition strategies in all three periods are analyzed, while simultaneously considering the results from both objectives. Accordingly, strong relationships between the terminal's profits from two strategies are observed in terms of all four scenarios as represented by their high R-square values over 0.9800. The scenario-4 in where the port authority collects the terminal fees based on the operation terminal while excluding the vessels transferred from private terminals to the public terminal indicates the strongest relationship with the highest R-square value (0.9959). Moreover, this scenario generates the least number of penalty calls and comparatively high numbers of vessel transfers with both objectives. Hence, if the coopetition strategy can generate a smaller number of penalty calls, it will not create serious equity issues among terminals, which encourages all terminals to execute more vessel transfers. However, scenario-3 in where the port authority collects terminal fees from the contracted terminal while excluding transfer vessels derives the least R-square value, thus this policy has lower effectiveness in terms of profit distribution than the other three policies.

4.4 Conclusions from Chapter 4

4.4.1. Conclusions and Policy Implications from Objective [4.1]

The objective [4.1] proposes an intra-port coopetition strategy to overcome challenges related to the excess vessel calls, and idle container berths, as a case study for the Port of Colombo. The coopetition strategy assumes that terminal operators in one port have competitive interactions with each other during the contract stage, which decides the desired vessel calls at each terminal. Moreover, the terminal operators have cooperative interactions in the operation stage, which enable vessel transfers between two terminals when one terminal has idle berths and the other terminal has excess vessel calls, simultaneously. We analyze five different cases considering different combinations of terminal operators and their strategies. A game-theoretical decision-making approach is used for evaluating the effectiveness of coopetition strategy over the initial competition strategy in the context of individual rationality. A minimum satisfying condition is derived for successfully implementing the coopetition strategy in each case, while simultaneously confirming higher profits for terminal operators who implement the coopetition strategy than their profits with the initial competition strategy.

As the significant findings, when considering terminal combinations, both JCT-CICT and JCT-SAGT indicate the highest probabilities for the occurrence of Status 4, where one terminal has excess vessel calls while the other terminal has idle container berths on the same day. JCT receives the highest numbers of vessel transfers from both CICT and SAGT. All coopetition cases indicate lower numbers of berthing delays and idle container berths than the initial competition strategy. Moreover, the case related to the coopetition strategy among all three terminals generates a higher benefit than the cases related to the coopetition strategy between only two terminals at once. Furthermore, the minimum satisfying condition for implementing the coopetition strategy varies depending on the different combinations of terminal operators. A relationship between the penalty charge and the cost of the idle berth is derived as the minimum satisfying condition for each case except the case related to the coopetition strategy between SAGT and CICT. The coopetition strategy between these two private terminals is unstable because it cannot simultaneously generate higher profits for both terminals than their profits from the competition strategy. Moreover, the coopetition strategy among all three terminals could be executed at a lower penalty charge than the strategies between only two terminals at once. The port authority requires to impose a higher penalty charge for executing all possible vessel transfers between JCT and SAGT than the penalty charge required for that of between JCT and CICT. However, since the minimum satisfying condition varies depending on the policies related to the penalty charges and cost of idle berths; the port authority should decide these policies to encourage terminal operators on vessel transfers. Since the penalty charges and cost of idle berths can be associated with the loss of goodwill due to terminal congestion and the opportunity cost of idle container berths, respectively, the enforcement of such policy instruments may enhance the overall port competitiveness than the external competing ports.

4.4.2. Conclusions and Policy Implications from Objective [4.2]

The Objective [4.2] analyzes the coopetition behavior among terminal operators in a single port for minimizing the total penalty cost related to the berthing delays (Min.PC) and maximizing the combined profits of all terminals (Max.TP). Moreover, four different policy scenarios are analyzed considering the terminal fee collection from private terminals by the port authority in case of vessel transfers. A MIPO model is formulated and tested with three main terminal operators in the Port of Colombo. As per the results, the proposed coopetition strategy not only generates higher profits for all terminals but also increases the efficiency of the entire port and individual terminals. A longer duration of maximum tolerable waiting time is not appropriate because it increases the total number of delay hours while discouraging vessel transfers among terminals due to the smaller number of penalty calls. Thus, the port authority may decide an appropriate short duration considering the target reduction of delay hours from the coopetition strategy, which results in additional benefits such as vessels' emissions reduction at anchorage. Despite lower numbers of penalty calls than the number of transfer vessels are derived from the Min.PC objective, the Max.TP objective derives a higher number of penalty calls than the number of transfer vessels at a small value of penalty charge per TEU owing to the lower significance of penalty cost in the terminal profit. However, a very high-value penalty charge is not appropriate because it cannot further reduce berthing delay after achieving an optimal number of vessel transfers, despite its negative influence on terminals' profits.

When considering the results of coopetition with four different policy scenarios, scenario-4 in where the port authority collects terminal fees based on the operation terminal while excluding vessels transferred from private terminals to the public terminal generates the least number of penalty calls with both objectives. The highest number of vessel transfers is obtained with scenario-3 with both objectives, in where the collection of terminal fees is done based on the contracted terminal while excluding vessels transferred from the private terminals to the public terminal. Regardless of the variations in numbers of transfer vessels and penalty calls across three analysis periods owing to the variations in vessel arrival patterns, the SAGT and JCT receive the least and highest number of transfer vessels from other terminals in all three periods. Moreover, the coopetition strategy generates the least reduction of the total number of delay hours when the public terminal, JCT receives a high number of handling TEUs from its own desired vessels because it discourages JCT from handling a greater number of transfer vessels given by private terminals. Although similar variations in total delay hours' reduction are observed from both the Max.TP and Min.PC objectives across different scenarios and analysis periods, the Min.PC objective generates a slightly higher number of delay hours' reduction than the Max.TP objective in most scenarios, possibly due to the higher number of transfer vessels generated by Min.PC objective than the Max.TP objective.

Results imply that the coopetition with all four policy scenarios does not create serious equity issues in terms of profit distribution, hence all terminal operators can be motivated to execute all possible vessel transfers. Since the coopetition strategy has high potential to reduce terminal congestion, berthing delays and the total number of delay hours and to increase berth utilization than the competition strategy, the port authority should encourage such kind of coopetition strategy among its terminal operators to enhance the competitiveness of the entire port. Considering the significant concerns on the overall port competitiveness in the midst of port competition and the high level of services expected by the port users, mainly mega carriers, future concession agreements in container ports may include provisions on coopetition indicating the willingness of terminal operators to engage in vessel transfers between them. Besides the operational benefits, since coopetition derives additional benefits such as the reduction of vessels' emissions at anchorage resulted from the reduction in the total number of delay hours, it can increase the port competitiveness in both the operational and environmental aspects. Apart from the port competitiveness attained by minimizing berthing delays in the operation stage, terminals' competitive interactions in the contract stage help to maintain a competitive average price at the entire port while enhancing the port competitiveness than the external competing ports.

4.5 Limitations of Chapter 4

This chapter empirically tested the market outcomes of competition and coopetition among container terminals operating in a port, with proposing an intra-port coopetition strategy with a vessel transfer policy to reduce congestion and delays at container terminals. Although the results of the proposed coopetition strategy are discussed as a case study on the Port of Colombo, derived implications could be varied in the case of different ports and terminals depending on their vessel arrival patterns. The practical implementation of the proposed coopetition strategy could have some implications and constraints depending on different market conditions. Since the terminal handing charges are varied based on the negotiations made with individual shipping lines, sharing such kind of revenue information among terminals may be hindered, which may act as a constraint when implementing the coopetition strategy. Moreover, the coopetition strategy may require support from the competition policy directives of those countries where the port industry behavior and the rates they charged on port users are subjected to monitoring by a regulatory tribunal. The varying depths of the alongside berths at different terminals could be a constraint on the vessel transfer policy because the varying depth levels limit the maximum drafts of vessels that can be handled at terminals while limiting the use of an idle terminal by the vessels' draft limitations. Therefore, the vessel transfers between terminals are not possible in all ports especially when terminals have significant differences in draft limitations, thus the terminal with deep draft level may receive higher benefits than those with shallow drafts, enabling the former to act as the leader in the coopetition strategy.

Besides, the availability of efficiency inter-terminal transportation services for possible container movements between terminals can be considered as a supportive service for successfully implementing a vessel transfer policy. In the case of the Port of Colombo, all inter-terminal transportation of containers is outsourced to a single service provider, who has the capacity to integrate the demands given by all three terminals, thus has the potential to act as an efficient supportive service on the vessel transfer policy. Although we did not consider, the practical issues such as compatibility of handling equipment, labor requirements and terminal information systems among others across different terminals can have a significant influence on vessel transfers. Moreover, the calculation of penalty charge is done in proportionate to the occurrences of berthing delays rather than the actual delay time, thus further studies may consider the impacts of coopetition strategy by considering the actual delay time as well. Although we proposed a coopetition strategy with both the contract and operation stages, we consider the actual vessel handling data of terminals in the Port of Colombo as inputs to the operation stage given from the contract stage, owing to the current competitive scenario among these terminals. However, further studies may consider the model development for the contract stage to analyze the terminals' competitive interactions. Moreover, the impacts from intra-port coopetition on the external competing ports and terminals in the same market can be analyzed in further studies.

Note: Related Journal Publications from Chapter 4

- ✓ Kavirathna C.A., Kawasaki, T., Hanaoka, S. and Bandara, Y.M. (2020) Cooperation with a vessel transfer policy for coopetition among container terminals in a single port. Transport Policy, 89: 1-12. https://doi.org/10.1016/j.tranpol.2020.01.010

CHAPTER 5: IMPACTS OF PORTS AND TERMINALS COOPETITION AT THE INTER-PORT LEVEL

5.1 Introduction

Since Chapter 4 purely focuses on the intra-port level interactions for enhancing the port competitiveness, Chapter 5 focuses on the interactions between ports and terminals considering the inter-port level as well. To discuss the implications related to the inter-port level, we consider a case study based on the Colombo and Hambantota ports in Sri Lanka owing to their current port development projects. The main contribution of this chapter can be discussed as follows. First, this chapter analyses the potential competitive scenario between Colombo and Hambantota ports considering both the domestic and transshipment container handling and discuss implications related to their developments. Secondly, we analyze the behavior of a global terminal operator (GTO), who has own container terminals in two competing ports in the same market and the behavior of the port authority of a port which has both the public terminal operated by the port authority and the private terminals operated by a GTO in the same port. Due to the lack of previous studies, this is one of the first studies to analyze the behaviors of the port authority and a GTO considering their reactions to each other's decisions.

5.1.1 Case Introduction

Sri Lanka has a great potential to be developed as a maritime hub because it is located strategically along the East-West trunk sea route, which is one of the busiest sea routes in the world connecting the Far East and Europe trades. Therefore, its Port of Colombo has been developed as the main transshipment hub in the South Asian region to connect Indian feeder ports to the rest of the world. The Sri Lanka Port Authority (SLPA), which was established under the act of parliament, is the main administrator of all local ports in Sri Lanka. Therefore, SLPA considers several infrastructure developments including the Colombo port's expansion projects, and the national port master plan, especially targeting Colombo and Hambantota ports, which are the two largest ports in Sri Lanka.

5.1.1.1 Port of Colombo

The Port of Colombo is a major port in the South Asian region, and strategically located at the center of the Indian Ocean just close to the main sea routes from the Far East and Australia to Europe and America. The port plays a significant role as a transshipment hub in the region serving mainly the South Asian feeder market and a part of the African feeder market with having about 75% of port throughput represented by transshipment cargo. The port is ranked among the top 30 container ports worldwide (World Shipping Council, 2016). Currently, Colombo is the only container port in Sri Lanka as the SLPA's primary source of revenue and this port is a major port of call for about 30 mainline carriers and more than 15 feeder carriers. The port has advantages in the feeder markets connected with the Indian sub-continent because most of the major shipping lines services do not call at these feeder ports due to their infrastructure limitations, which prevent them from accommodating larger vessels. Besides, these Indian feeder ports are located with a high deviation from the East-West trunk sea routes, thus shipping lines have to incur high journey costs when accessing these Indian ports. The Port of Colombo has 6.8 million TEUs capacity and expects over 20 million TEUs capacity by 2040 after completing its ongoing development projects (SLPA, 2016). As per the statistics of SLPA, the container throughput of Colombo was over 5.7 million TEUs in 2016, indicating a significant growth during the last decade as illustrated in Figure 5.1, including both domestic and transshipment container handling. Further, Colombo plays a significant role by providing husbandry services like chandlery, ship repairing, and bunkering, among others for ocean crossing vessels due to its strategic location.

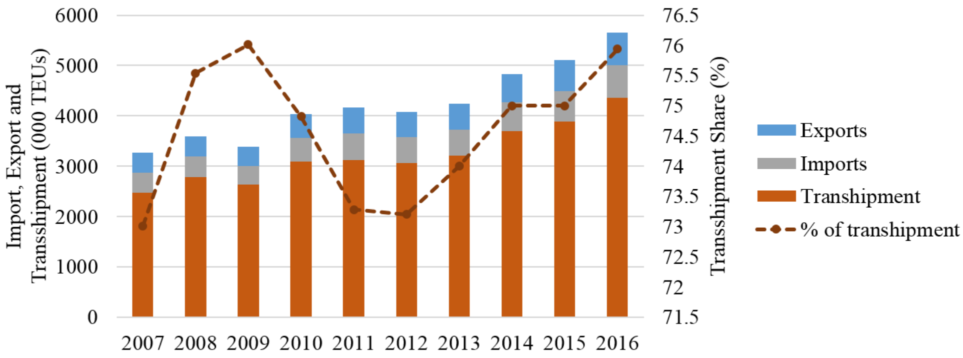

Figure 5.1. Container Throughput of the Colombo Port

(Source: data collected from the SLPA)

With over 75% of port throughput represented by transshipment cargo in Sri Lanka, shipping lines' transshipment port selection decisions significantly influence not only on the port container throughput but also on local shippers and consignees because the ports with high transshipment shares are vulnerable with high throughput volatility (Notteboom et al., 2019). However, the Port of Colombo locates in the Colombo city, the commercial capital of Sri Lanka, which is affected by serious traffic congestion amplified by freight transport vehicles as well. Thus, SLPA decides to develop the Colombo port mainly for container handling while transferring bulk cargo handling to other local ports, including the Hambantota port.

5.1.1.2 Port of Hambantota

The port of Hambantota is considered as the second largest port in Sri Lanka and is located in the Southern province of the country with approximately ten nautical miles of short deviation from the

East-West main sea route as illustrated in Figure 5.3. In 2008, SLPA initiated the Hambantota port development as an industrial port mainly to support the Southern province's economic development. From the Prase-1 development cost, 85% was funded by the loans from the China EXIM Bank and the remaining 15% was funded by the SLPA (Kotelawala, 2017). However, owing to an unexpected cost increase, the port development plan was not successful and could not make the anticipated profits, thereby the port was earning losses for several years while increasing the financial liability of SLPA and Sri Lankan government to China due to the outstanding loan settlements issues (Wijenayake, 2017). Considering the substantial investment required for bringing the port to the operational level, the private sector participation is considered as a feasible solution (Ministry of Ports and Shipping, 2017). As a result, in 2017, a new agreement was signed between the SLPA and the China Merchant Port Holdings (CMPH), which is a reputable global terminal operator, to least the Hambantota port for 99 years.

The main objectives of this agreement were to increase the foreign investment for the development of Hambantota port and to overcome the outstanding loan settlement issues related to the previously taken loans from China EXIM Bank for the Hambantota development project (Ministry of Ports and Shipping, 2017). Therefore, this new agreement converted the outstanding debt of SLPA as the equity from the Chinese side, while releasing the SLPA's financial liability. Moreover, two private-public partnership companies were formed: the Hambantota International Port Group (Pvt) Ltd, which is responsible for the planning, operations, and management of commercial port functions; and the Hambantota International Port Services (Pvt) Ltd, for the provision of common user facilities, and security, among other functions. Despite a 50.7% share of SLPA in the Hambantota International Port Services (Pvt) Ltd, it has only a 15% share in the Hambantota International Port Group (Pvt) Ltd, which receives a majority of cargo-handling revenues (Kotelawala, 2017). Therefore, SLPA would not receive substantial benefits from the Hambantota port, when compared to the Port of Colombo, in where the SLPA operates its own container terminals and conventional cargo-handling facilities in addition to the provision of common user facilities. Although Hambantota was to be developed as an industrial port, this new agreement signed in 2017 would encourage its development as the second-largest container port in Sri Lanka. As per Tonchev (2018), Sri Lanka has a strategic location with the Belt and Road Initiative of China, and Hambantota port lies almost halfway between China's major ports and the Mediterranean Sea and also locates close to the African gateway ports, which increase the interests of China in developing Hambantota port with a large scale.

When comparing to the SLPA and the other private port operators in Sri Lanka, the CMPH has competitive advantages as a GTO due to its globe wide terminals networks including several coastal hub ports across China and Hong Kong, as well as South Asia, Africa, Mediterranean, and South

America, which all create a port network portfolio with 36 ports covering 18 different countries that represent five continents (http://www.hipg.lk/about-us/). Besides, CMPH is an award-winning port operator in the cargo logistics sector due to its international tract records for the best practices with sustainable cargo transportation and operates as a subsidiary of the China Merchant Group. Therefore, as the majority shareholder of the Hambantota International Port Group (Pvt) Ltd, there is a possibility that CMPH will significantly enhance the performance of the Hambantota port while utilizing its market power and competitive advantages as a GTO.

5.1.1.3 Sri Lanka Port Authority

The SLPA was established under the act of parliament (Sri Lanka Ports Authority Act, No. 15 of 1979 on the 1st of August 1979) and the main administrator of Sri Lankan ports. It does not receive financial allocations from the government and operates on its own revenue and resources. SLPA mainly consists of a board of directors including the chairman and other directors, general treasury, managing director and principal collector of customs, among others. As the main duties of SLPA, it provides efficient and regular services for stevedoring, lighterage, landing and warehousing of dry and wet cargo and cargo in bulk and other supplementary services for vessels, among others, with port common user facilities as explained in the Appendix E. Besides, it provides tally services, and regulate and control navigation and other activities within the port limit. Besides, SLPA involves in business and conduct in such a manner that will secure that the revenue of the Authority is not less than sufficient for meeting the charges which are proper to be made to the revenue of the Authority. SLPA can replace assets, make new investments and establish and maintain an adequate general reserve; among others. As the powers of the SLPA, it has the power to acquire/hold, take/give on lease, hire, pledge and sell or otherwise dispose of any movable or immovable property, to employ officers and servants and to do anything for the purpose of improving the efficiency of port operations, and others (Appendix E). Additionally, SLPA has power to construct, manufacture, purchase, operate, maintain and repair anything required for the purposes of the business; to coordinate and execute any Government project relating to the any port and to enter into any agreement with port users for the utilization of such facilities; to control the entry of vehicles, persons, goods, and animals within the limits of any specified port and to regulate their movements within such limits; to engage in such other activities as appear to the Authority to be beneficial. Besides, SLPA has the power to borrow money from any person, organization or institution within or outside Sri Lanka or from the Government; the repayment of any loan, or the performance of the obligations in which the Ports Authority has an interest.

Besides, as per our interviews with the SLPA and terminal operators in Colombo, SLPA involves in marketing and other promotional activities on the entire port. SLPA can monitor the activities of the terminal operators and influence the handling charges, terminal fees collected from private terminals, terminal rent and enforcing minimum throughput requirements, among others. Additionally, the commercial activities carried out at individual terminals are subject to the rules and regulations of the port authority and the performances of terminals are evaluated by the port authority as the main port administrator.

5.1.2 Problem Statement and Objectives of Chapter 5

The port infrastructure development requires massive investments and has a significant influence on the country's economy. However, the over-developments of these infrastructures would lead to the devastating financial losses for stakeholders (UNCTAD, 2013; Xiao et al., 2016), thereby it is significant to ensure the social acceptance of port development projects through an effective communication between the port authorities and other stakeholders, such as local communities, the government, and other public agencies engaged in port financing and aspects of hinterland development (Dooms et al., 2015). Considering Sri Lanka's strategic role as a transshipment hub in the region, it is significant for Sri Lankan container ports to have strong network connectivity from liner services. The development of two large scale container ports would potentially split the liner services between them while reducing the network connectivity of the Port of Colombo than the current situation. Moreover, considering the less than 25% share of domestic container throughput in Sri Lankan container ports, the massive investments on two container ports may not be economically viable. Therefore, the investigation on container port development issues in Sri Lanka is significant not only for maintaining the strategic role of Sri Lanka in the global maritime network but also for securing the country's long-term economic well-being.

This chapter aims to achieve two main objectives as follows. The Objective [5.1] is to analyze the potential competitive scenario between Colombo and Hambantota ports in Sri Lanka considering both the domestic and transshipment container handling. To achieve this objective, first, we analyze the domestic cargo flow assuming the presence of both Colombo and Hambantota ports for container handling, which derives the most favorable distribution of domestic container handling market shares between two ports considering the generalized cost of local shippers and consignees. Secondly, the potential competitive scenario between the Colombo and Hambantota ports on transshipment container handling is analyzed by considering the generalized cost of shipping lines. Then, the impacts of transshipment cargo flow on the local shippers and consignees are discussed because the realization of local shippers' and consignees' most favorable condition depends on the availability of slots from liner services et each port, which is highly influenced by the shipping lines' transshipment port selection decisions owing to the high percentage of transshipment (i.e., 75%) in Sri Lankan container ports' throughput. Moreover, we analyze several scenarios to discuss the implications of port developments on the local shippers and consignees, shipping lines, SLPA, and the other port service providers. However, the Objective [5.1] considers the competition within the port level without considering the implications related to the terminal operators in these two ports.

Objective [5.1]: To analyze the potential competitive scenario between Colombo and Hambantota ports in Sri Lanka
Objective [5.2]: To understand the coopetition at the inter-port level considering the involvement of a global terminal operator and the port authority with Colombo and Hambantota ports in Sri Lanka

Regardless of the availability of previous studies on the port competition aspects as summarized in Chapter 2, none of them analyzed the impacts from the port competition on the local shippers and consignees in a country, where the port throughput is highly represented by the transshipment cargo, which is addressed by the Objective [5.1]. As per the previous studies, the port selection decisions of shipping lines and that of shippers and consignees could be varied significantly due to their different expectations from port service providers and the cost consideration, which is also addressed by the Objective [5.1]. Besides, this chapter further contributes to the existing literature by analyzing distinct roles of a port in both the domestic and transshipment container handling, which is significant for Sri Lanka owing to the ongoing port development projects and the active discussions on port development issues.

After understanding the competitive scenario between two ports with the first objective, Objective [5.2] analyzes the behaviors of the SLPA and the CMPH, considering the reactions on each other's decisions. However, considering the lack of previous studies on the behavior of GTOs, the second objective mainly focuses on the theoretical contribution by assuming different interests associated with each decision-maker as the objective function of an optimization model. Therefore, as its significant contribution, the Objective [5.2] addresses the behavior of the port authority who has both the public terminal, operated by the port authority and the private terminal, operated by a GTO in the same port and the behavior of a GTO who has own terminals in two competing ports, which are not focused by previous studies. Although the Objective [5.1] provides recommendations considering the practical port development issues in Sri Lanka, the Objective [5.2] considers a terminal pricing scenario to analyze the decisions with the different ownership types and interests of the port authority and a GTO.

Although Chapter 3 and Chapter 4 quantitatively analyzed the impacts of coopetition among terminals considering different strategies to the intra-port level with unique definitions for value creation and value appropriateness in each chapter, the coopetition in Chapter 5 is discussed conceptually due to the complexity when considering both the intra-port and inter-port levels. Although the Objective [5.1] focuses on the competition between Colombo and Hambantota ports in Sri Lanka, the potential ways of coopetition between two ports to enhance the competitiveness of the whole country as a maritime hub can be discussed depending on the results. Moreover, by considering both the port and terminal levels in the Objective [5.2], the possibilities for coopetition among terminals in one port and among terminals owned by the same GTO are discussed by endogenously considering their behaviors resulted from the model.

Since the coopetition in Chapter 5 focuses on inter-port level as well considering the involvements of the port authority and a GTO in two competing ports, it derives significant policy implications on these two decision-makers, both Colombo and Hambantota ports, and users of both ports including shipping lines and shippers/consignees as well as feeder ports located in target feeder markets. The Objective [5.1] discusses policy implications on local shippers and consignees, shipping lines, and port operators with analyzing scenarios on transport infrastructure development, slot capacity limitation, port charges, and port efficiencies. With different competitive approaches, port operators attempt to obtain a large handling volume toward own port while causing serious impacts on the other competing port. Moreover, policy implications are discussed on port development aspects in Sri Lanka to reduce negative impacts on current port development projects. Since the Objective [5.2] primarily discusses terminal pricing decisions made by SLPA and CMPH, the port users are highly affected by the coopetition strategy because they can utilize port facilities at a lower cost. Besides, terminal operators are affected by the coopetition strategy because they can receive high demand due to the rebates and incentives given by port authority and GTO on the price reduction and private terminals receive more benefits due to the rebates received on terminal fees. Feeder ports and feeder operators can be affected by this kind of coopetition strategy of port operators because the volumes handled by each hub port from individual feeder ports are changed. Besides, local shippers and consignees and shipping lines are greatly affected by the competition between two local ports because their decision-making power can be increased due to the availability of multiple alternative ports.

5.2 Analysis for Objective [5.1]

5.2.1 Model Development for the Objective [5.1]

Since this chapter focuses on two objectives, the model development associated with each objective is explained separately. Since Objective [5.1] considers both the domestic and transshipment container handling, two different choice models are used for the analysis by incorporating criteria relevant to the gateway port choices of shippers and consignees and the transshipment hub port choices of shipping lines, separately.

5.2.1.1 Domestic cargo flow analysis

To analyze the domestic container handling with the presence of both Colombo and Hambantota ports, a logit model is used which estimates the domestic container throughputs of each port considering a situation after Hambantota has begun its container vessel operation. Thus, we incorporate the gateway port choices of shippers and consignees, where the Equation (5.1) expresses the generalized cost function of local shippers and consignees when using each gateway port to handle the import and export cargo generated from individual districts in Sri Lanka and all 25 districts (Figure 5.2) in Sri Lanka are considered for the analysis. The generalized cost function consists of three components, namely terminal handling charges (THC^h), time cost, and container haulage costs. Considering the Sri Lankan industrial practices, the imported laden containers are assumed to be transported directly to the consignee's premises for unloading the cargo; and then, empty containers are stored in private empty container yards. In the case of exports, after picking an empty container from the yard and taking to the shipper's premises for loading cargo, then the laden containers are transported to the gateway port before the cutoff time of the loading vessel.

$$GC^{(x,h)} = THC^h + (VOT * T^{(x,h)}) + HC^{(x,h)}, \tag{5.1}$$

Where;

h	Any of two alternative gateway ports such that h= {Colombo, Hambantota}
x	Individual districts of Sri Lanka (*x=1, 2, 3, ….25*)
$GC^{(x,h)}$	Generalized cost of shippers and consignees in district *x* when using port *h* for handling import/ export cargo
THC^h	Charges at port *h* (USD) for domestic container handling
VOT	Value of time (USD/TEU/hour) of shippers and consignees
$T^{(x,h)}$	Time for transporting containers between district *x* and port *h* (hours)
$HC^{(x,h)}$	Haulage cost when transporting containers between district *x* and port *h* (USD)

As given in the first component of the *GC* function, the THC^h is paid by the shippers and consignees for handling import/export containers at port *h*. The second component of the *GC* function represents the time cost of shippers and consignees when using each gateway port for handling import/export cargo related to individual districts. When calculating time cost, the value of time (*VOT*) approach is used and a representative point in each district automatically selected by the Google Maps software is considered as the local origin or destination of the export or import cargo, respectively. Since the time cost is calculated in proportionate to the time taken for transporting containers between the gateway port and the individual districts, the average transport time for each district is taken after observing the travel times for different periods of days, using the real-time Google Maps navigation application, which incorporates roads' traffic congestion as well. Following the Shibasaki and Kawasaki (2016), who also addressed Sri Lanka as a focused country in their study for developing a network assignment model for containerized cargo, the value for *VOT* is assumed to be 0.5 USD/TEU/hour.

Figure 5.2. Study Area for the Domestic Cargo Flow Analysis

As the third component of the *GC* function, the haulage cost of shippers and consignees when transporting containers between the gateway port and individual districts are calculated. Before developing the model, we conducted several interviews with the reputable container haulage companies in Sri Lanka to understand the real industrial practices and the composition of haulage charges. Based on the interviews, the container haulage cost is calculated with two main components namely the basic haulage charges and the detention fee, as given in Equation (5.2). First, the basic haulage charge consists with a fixed charge (α) associated with the loading/unloading process of a container with the vehicle and a variable charge that corresponds to the transport distance between the gateway port and the local origin/destination $(D^{(x,h)})$. According to our interviews, the average value of α is 54 USD for a 20ft container and 64 USD for a 40ft container, and the average value of β, which is the transport cost per km is 0.85 USD/km for a 20ft container and 1.12 USD/km for a 40ft container. However, since we use a logit model for estimating ports' market shares, all cost components are converted into "cost per TEU" for the convenience of calculation. As per data collected from the SLPA, the 20ft and 40ft containers currently represent 60% and 40% of the total domestic container boxes, respectively. Therefore, 20ft and 40ft containers represent 43% and 57% of all domestic TEUs. When converting all cost values into the cost per TEU, we multiply the fixed charges (α) of 20ft and 40ft (i.e., 54 USD and 64 USD) by their respective shares of total TEUs (43% and 57%), and the summation of this (54×0.43 + 64×0.57) is taken as the fixed charge per TEU, which is nearly equal to 60USD /TEU. Following a similar approach, the transport cost per Km (β) per TEU is calculated as 1 USD/TEU/Km (0.85×0.43 + 1.12×0.57). Thus, the values of α and β per TEU are taken as 60 USD and 1 USD/km, respectively for the model estimation.

As the second component of the haulage cost, we calculate the detention fee, which is charged by the haulage companies from shippers and consignees if the transportation time exceeds the maximum detention-free time allowed by them. Based on the data collected during our interviews, haulage companies allow a maximum duration of 12 hours as the detention-free time for exports that starts from the time when the empty container taken to the shipper's premises for loading of cargo. In the case of imports, 12 hours duration of detention-free time is allowed that starts from the time when the imported laden container is taken out from the gateway port. Therefore, a detention fee is charged from the shippers and consignees by the haulage companies in proportionate to the additional numbers of hours after exceeding the detention-free time. Thus, for the calculations, the detention charge per hour (USD/TEU/hour), is assumed to be 0.85 USD/TEU/hour as per data collected from the interviews. Moreover, the average duration for loading/unloading of a container ($T^{(L/U)}$) is assumed to be 4 hours based on the data collected from interviews.

$$HC^{(x,h)} = (\alpha + \beta * D^{(x,h)}) + g(\sigma * \left[\left(T^{(x,h)} + T^{(L/U)}\right) - 12\right]) \quad (5.2)$$

Where;

$D^{(x,h)}$ Transport distance between district x and port h (km)

α The fixed charge for loading/unloading process of a container with a vehicle (USD/TEU)

β Transport cost per km (USD/TEU/km)

g Detention dummy; $g = 1$ if the inland transportation and handing time exceeds the detention-free time allowed by the haulage company $\left(T^{(x,h)} + T^{(L/U)} > 12\right)$, and $g = 0$ otherwise

σ Detention charge (USD/TEU/hour)

$T^{(L/U)}$ Average time for loading/unloading a container with a vehicle (hours)

After calculating all components of the *GC* function, the total *GC* of shippers and consignees for using each gateway port for handling imports/exports containers associated with each district is calculated with Equation (5.1). Thereafter, these calculated *GC* values are used with a logit model to calculate the total domestic container throughput of each gateway port as a summation of the import/export container volumes given by all 25 districts as per Equation (5.3) and the value of θ is assumed to be 0.05 following Shibasaki and Kawasaki (2016). The import/export container throughputs of two ports depend on the market shares given for them from individual districts and the import/export container volumes associated with those districts. However, the imports and exports volumes of each district (V^x) depend on its industrial and consumption activities. Due to the unavailability of district-wise import/export statistics, we disaggregate the country's total future domestic container volume at the district level to represent the volume generated from each district (V^x). Therefore, the autoregressive integrated moving average model is used to forecast the country's total import/export container volume for the year 2040 (Appendix F), which is assumed as the target year for the analysis considering the timelines of the port development projects (SLPA, 2016).

According to the data collected from the SLPA, the imports and exports represent 70% and 30% of the total domestic containerized cargo, respectively. Since imports are used for both the industrial and household consumption purposes, 50% of imports are distributed in proportionate to the districts' average expenditure levels (household-expenditure × district-population / household-size), assuming their usage for the household consumption and the remaining 50% of imports are distributed in proportionate to the districts' level industrial output by assuming their usage for industrial purposes. However, in the case of exports, the total export volume is disaggregated at the district level in proportionate to the district level's industrial output. These district-wise industrial and household statistics are obtained from the Department of Census and Statistics of Sri Lanka (http://www.statistics.gov.lk).

$$V^h = \sum_{x=1}^{x=25} V^x * \frac{e^{-\theta GC^{(x,h)}}}{\sum_{h=1}^{h=2} e^{-\theta GC^{(x,h)}}} \quad (5.3)$$

Where;

V^h Total import and export TEUs handled by port *h*

V^x Total import and export TEUs associated with district *x*

θ Parameter of the logit model

Therefore, the domestic cargo flow analysis estimates the import/export container volume handled at each gateway port considering the generalized cost of local shippers and consignees. These derived market shares of two ports can be considered as the most favorable distribution of import/export container handling between two local ports as per the shippers' and consignees' perspectives. Thus, these estimated market shares can be used to discuss the potential competition between Colombo and Hambantota ports in domestic container handling.

5.2.1.2 Transshipment cargo flow analysis

This section discusses the model development for the transshipment cargo flow analysis. We analyze the transshipment container handling at Colombo and Hambantota ports with a logit model, which incorporates transshipment port selection decisions of shipping lines. Kavirathna et al. (2018.a) analyze the transshipment hub port competition between the Port of Colombo and the major Southeast Asian ports to serve the Indian sub-continent feeder market with a logit model, which incorporates a range of hub port selection criteria, including both quantitative and non-quantitative criteria. Following an approach similar to the Kavirathna et al. (2018.a), this chapter analyses the transshipment container handling at Colombo and Hambantota ports, although several modifications are made considering the context of the current study area. As the target feeder market, 12 feeder ports located in the Indian sub-continent are considered as illustrated in Figure 5.3, due to the high dependency of Sri Lankan container ports' throughput on this feeder market. Considering the geographical characteristics, six feeder ports namely; Chittagong, Kolkata, Haldia, Visakhapatnam, Krishnapathnam, and Chennai are grouped as the Indian East-coast feeder market, two feeder ports namely, Cochin, and Tuticorin as the Indian South-coast and four feeder ports namely; Mundra, Pipavav, Nava Sheva, and Mangalore as the Indian West-coast feeder market. This grouping helps to understand the competitiveness of two ports in different feeder markets owing to their different geographical characteristics. As an example, the Port of Colombo has advantages in the Indian West-coast and South-coast feeder markets over the East-coast market. This is because when transporting cargo between the Indian East-coast feeder ports and the Colombo port, vessels cannot pass through the sea-segment between the Northern tip of Sri Lanka and the South of India due to the geographical constraints (shallow depth level and underwater rocks), thus, vessels have to move around the Southern coast of Sri Lanka, which accounts for considerable high journey cost and time for feeder operators when serving East-coast feeder market from Colombo. However, the Hambantota port has great advantages because it locates closer to the East-West truck sea route that would significantly reduce the deviation cost and time of ocean crossing mainline vessels.

The generalized cost related to the shipping lines' transshipment hub port selection is calculated with Equation (5.4), following a similar approach of Kavirathna et al. (2018.a). Accordingly, the generalized cost function consists of four main components namely, MPC^h, $JC^{f,h}$, $TC^{f,h}$ and $VNQC^h$. The MPC^h represents the average transshipment handling charges at hub port *h*; and $JC^{f,h}$ and $TC^{f,h}$ represent the journey cost and time cost when using the hub port *h* to serve feeder port *f* (USD). The last component of the generalized cost function is the value of non-quantitative criteria ($VNQC^h$), which implies the perceived generalized cost reduction of shipping lines owing to the high performance of hub port *h* related to the non-quantitative hub port selection criteria. Each component of the generalized cost function and their estimation methods are described in detail as follows.

$$GC^{(f,h)} = MPC^h + JC^{(f,h)} + TC^{(f,h)} - VNQC^h \qquad \forall f, \forall h \qquad (5.4)$$

Where;

h	Any of two alternative hub ports such that h= {Colombo, Hambantota}
f	Any of twelve feeder ports in Figure 5.3
$GC^{(f,h)}$	The generalized cost of shipping lines when using hub port *h* to serve feeder port *f* (USD)
MPC^h	Port charges paid by shipping lines when using hub port *h* to serve feeder port *f* (USD)
$JC^{(f,h)}$	Journey cost of shipping lines when using hub port *h* to serve feeder port *f* (USD)
$TC^{(f,h)}$	Time cost of shipping lines when using hub port *h* to serve feeder port *f* (USD)
$VNQC^h$	The value of non-quantitative criteria (USD), which indicates the perceived generalized cost reduction of shipping lines owing to the performance of hub port *h* related to the non-quantitative hub port selection criteria mentioned within the port traffic-, location-, operation-, and liner-related categories in Figure 5.4.

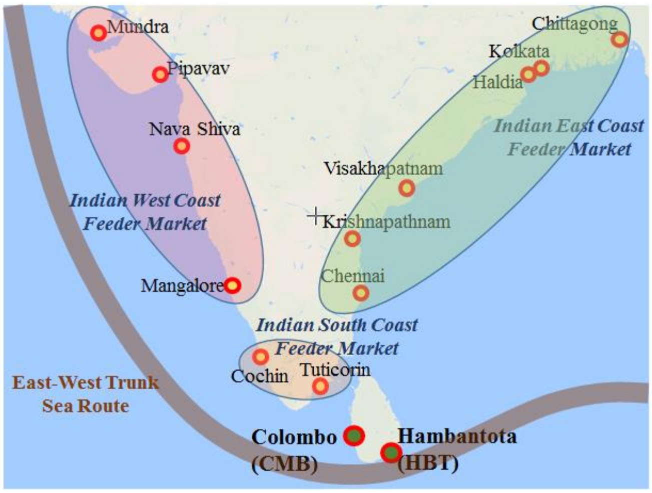

Figure 5.3. Study Area for the Transshipment Cargo Flow Analysis

As mentioned with the first component of the *GC* function, shipping lines pay MPC^{h} at hub port *h* for the handling of transshipment containers. As per the second component, the journey cost ($JC^{(f,h)}$) is calculated with two main criteria namely, the deviation cost and the feeder link cost as given with Equation (5.5). Here, the deviation cost refers to the journey cost of shipping lines that incurred when deviating from the trunk sea route to access the hub port. To calculate the deviation cost, the deviation distances associated with two alternative hub ports are obtained after analyzing their vessel's access and departure routes through www.marinetraffic.com. The feeder link cost refers to the cost associated with transporting containers between a hub port and a feeder port and the journey distances related to the feeder links between each feeder port and two alternative hub ports are obtained from www.searoutes.com, which has port-to-port voyage distances.

To calculate these journey cost components, we incorporate a unit distance cost (UDC) approach, and the UDC represents the journey cost of one nautical mile. Therefore, UDCs of deviation cost and feeder link cost are calculated separately with Equation (5.6). To calculate the UDC, this study incorporates the significance score (*SS*) of criteria, which indicates the level of significance of individual criteria in the hub port selection decision from the perspective of shipping lines. To determine *SS* values, Kavirathna et al. (2018.b) conducted a questionnaire survey with thirteen reputable shipping lines that handle 75.26% of transshipments related to the focused feeder ports according to the MDS Transmodal data. Respondents were asked to evaluate the significance of each hub port selection criterion given in Figure 5.4 on a scale ranging from 0 (no significance at all) to 5 (very significant), and the SS was calculated as the average score over the entire sample. Thus, a higher SS indicates a more significant criterion in the hub port selection decision. Since the SS represents an individual criterion's significance level, $SS^{(Port\ Charges)}$ and $SS^{(j)}$ represent the significance of "port charges" and the significance of j^{th} journey cost-related criterion (feeder link cost or deviation cost), respectively. Thus, when calculating the *UDC*, the real monetary value of port charges, MPC^{h}, is divided by the *SS* of "port charge" ($SS^{(Port\ Charges)}$), to represent the monetary value of one significant level. This result is then multiplied by the *SS* of the j^{th} criterion to indicate its monetary value. Next, the derived value is divided by the average of the journey distances related to the two hub ports for j^{th} criteria to calculate the journey cost of one nautical mile in monetary terms (*UDC*) for j^{th} criteria. After the *UDC*s of both the feeder link cost and deviation cost are calculated, they are multiplied by the journey distances of the respective criteria of a particular hub port to calculate the total journey cost for that hub port with Equation (5.5). The "port charges" is used for the monetization considering the availability of its data in monetary terms.

$$JC^{(f,h)} = \sum_{j=1}^{j=2}\left[D^{(j,f,h)} * UDC^{(j,f,h)}\right] \qquad \forall f, \forall h \qquad (5.5)$$

$$UDC^{(j,f,h)} = \frac{\left(\frac{MPC^{h}}{SS^{(Port\ Charges)}}\right) * SS^{(j)}}{\left(\sum_{h=1}^{h=2} D^{(j,f,h)}/2\right)} \qquad \forall i, \forall f, \forall h \qquad (5.6)$$

Where;

j	Any journey cost-related criterion, such that j = {feeder link cost, deviation cost}
$UDC^{(j,f,h)}$	Unit distance cost, which reflects the journey cost of one nautical mile of the *j*th criterion (USD)
$D^{(j,f,h)}$	The journey distance (nautical miles) associated with the *j*th criterion of port h. When j equals the deviation cost, $D^{(j,f,h)}$ signifies the quantitative deviation distance for calculating the "deviation cost" of hub port h
$SS^{(j)}$	The "significant score" of the *j*th journey cost-related criterion, which reflects its level of significance in the hub port selection decision. Similarly, $SS^{(Port\ Charges)}$ indicates the significance of "port charges".

As the third component of Equation (5.4), $TC^{(f,h)}$ represents the time cost of shipping lines when using hub port h to serve feeder port f. $TC^{(f,h)}$ is calculated with the value of time (*VOT*) approach, considering four time cost-related criteria mentioned in Figure 5.4, that are, deviation time, vessel turnaround time, waiting time, and feeder link time. The deviation time is the average time taken to access the hub port after deviating from the trunk sea route, estimated from www.marinetraffic.com. The vessel turnaround time represents the average time that a vessel stays inside the port, taken from the Japan Maritime Center. The waiting time represents the average waiting time of vessels at the anchorage area, obtained from the SLPA, and the feeder link time represents the time taken to transport containers between hub and feeder ports, obtained from www.searoutes.com. Following a similar approach to that of calculating the *UDC*, the time cost of one hour, *VOT* (USD/hour) is calculated for each time cost-related criterion, separately with Equation (5.8) and then multiplied by their respective quantitative time values associated with a particular hub port to calculate the total time cost associated with that port with Equation (5.7).

$$TC^{(f,h)} = \sum_{w=1}^{w=4}\left[T^{(w,f,h)} * VOT^{(w,f,h)}\right] \qquad \forall f, \forall h \qquad (5.7)$$

$$VOT^{(w,f,h)} = \frac{\left(\frac{MPC^{h}}{SS^{(Port\ Charges)}}\right) * SS^{(w)}}{\left(\sum_{h=1}^{h=2} T^{(w,f,h)}/2\right)} \qquad \forall t, \forall h \qquad (5.8)$$

Where;

w Any time cost-related criterion, such that *w*= {deviation time, vessel turnaround time, waiting time, feeder link time}

$VOT^{(w,f,h)}$ Value of time, which reflects the value of one hour for the w^{th} criterion (USD/hour)

$T^{(w,f,h)}$ The quantitative time value (hours) associated with the w^{th} criterion of port h. When w equals the deviation time, $T^{(w,f,h)}$ indicates the quantitative "deviation time" duration of port h

$SS^{(w)}$ The "significant score" of the w^{th} time cost-related criterion, which reflects its level of significance in the hub port selection decision of shipping lines

The last term of Equation (5.4) is the value of non-quantitative criteria ($VNQC^h$), which indicates the perceived generalized cost reduction of shipping lines due to a hub port's performance across all criteria in the port traffic-, location-, operation-, and liner-related categories in Figure 5.4. Because these performances are evaluated based on the shipping lines' perceptions instead of real quantitative data, the term "value of non-quantitative criteria" is used (Kavirathna et al., 2018.a). $VNQC^h$ is calculated with Equation (5.9), where *SS* indicates the significance of individual criteria, similar to the explanation given for the journey cost calculation. Because $VNQC^h$ considers the criteria within four different categories, we develop a port performance index (*PPI*) as given with Equation (5.10), which reflects the overall performance of a hub port for all criteria in those four categories. The performance score (*PS*) indicates the level of performance of a hub port for each criterion from the shipping lines' perception and is estimated by Kavirathna et al. (2018.b) with the same questionnaire survey mentioned previously regarding the *SS* calculations. When estimating the *PS* values, the respondents were asked to evaluate the performance of a hub port for each criterion listed in the port traffic-, location-, operation-, and liner-related categories in Figure 5.4 based on a scale ranging from -3 (very negative performance) to +3 (very positive performance). Thereafter, the *PS* is calculated as the average score over the entire sample, and a high *PS* value of a criterion indicates a high performance of the port in that criterion.

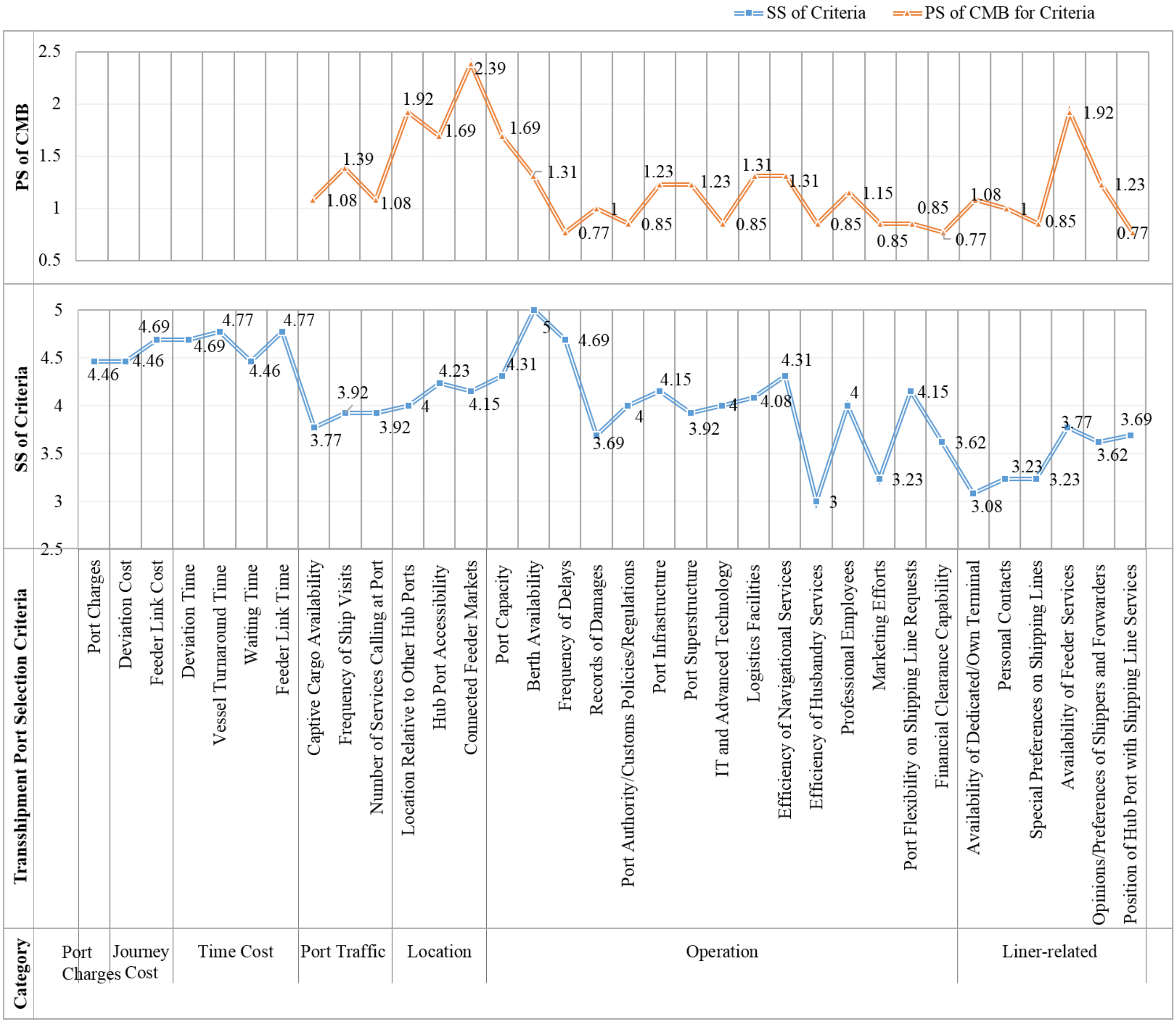

Figure 5.4. Significance of Individual Criteria and Performance of Colombo

(Source: Kavirathna et al., 2018.b)

Note: port performance for criteria in port charges, journey cost and time cost categories are analyzed with quantitative data instead of *PS*

To calculate the *PPI*, the *SS* of a criterion and the *PS* of the hub port for that criterion are multiplied, and then, the products for all criteria within the same category are summed, and the total is divided by the number of criteria in that category (*n*). The sum of these calculated values from all four categories is defined as the *PPI*. After deriving the *PPI* of a hub port with Equation (5.10), $VNQC^h$ is calculated by using the "port charges" for the monetization, similar to the journey and time costs calculations, where the real port charges, MPC^h, is divided by the $SS^{(Port\ Charges)}$ to indicate the monetary value of one significance level. Thus, $VNQC^h$ expresses the monetary value of hub port performance in all non-quantitative criteria. Because the "port charges" is used for the monetization, $VNQC^h$ represents the perceived generalized cost reduction due to the hub port's performance on non-quantitative criteria, compared to the port charges paid by shipping lines.

$$VNQC^{h} = \left[\left(\frac{MPC^{h}}{SS^{(Port\ Charges)}}\right) * PPI^{h}\right] \qquad \forall h \qquad (5.9)$$

$$PPI^{h} = \sum_{c=1}^{4}\left[\frac{\sum_{q=1}^{q=n} PS^{(q,h)} * SS^{(q)}}{n}\right] \qquad \forall h \qquad (5.10)$$

Where;

PPI^{h}	The port performance index of hub port *h*
c	Any of four categories considered in PPI such that *c*= {port traffic, location, operation, liner-related}
q	Any criteria in the category *c*
$SS^{(q)}$	The "significant score' of the q^{th} criterion in the category *c*
$PS^{(q,h)}$	The "performance score" of hub port *h* for the q^{th} criterion
n	Number of criteria in the category *c*

After calculating the generalized cost with its all components, it is converted into the utility with Equation (5.11) following Koi (2006) and Kavirathna et al (2018). Thereafter, the total transshipment volume handled at each hub port is estimated with a logit model as the summation of the transshipment volumes provided by all feeder ports, as per Equation (5.12). These estimated transshipment volumes are incorporated to discuss the potential competition between Colombo and Hambantota ports in transshipment container handling.

$$Utility^{(f.h)} = \frac{1}{\frac{GC^{(f.h)}}{GC^{(f,least)}}} \qquad \forall f, \forall h \qquad (5.11)$$

$$TS^{h} = \sum_{f=1}^{f=12} TS^{f} * \frac{e^{Utility^{(f.h)}}}{\sum_{h=1}^{h=2} e^{Utility^{(f.h)}}} \qquad \forall h \qquad (5.12)$$

Where;

$GC^{(f,least)}$	The lowest generalized cost across two alternative hub ports when serving feeder port *f*
$Utility^{(f.h)}$	The shipping line's utility when using hub port *h* to serve feeder port *f*
TS^{f}	Total transshipment TEUs handled in Sri Lanka from feeder port *f*
TS^{h}	Total transshipment TEUs handled in hub port *h* from all feeder ports

5.2.2 Results and Discussion for the Objective [5.1]

Since we analyze the potential competition between Colombo and Hambantota ports considering a future scenario, the container volumes in 2040 are forecasted with an autoregressive integrated moving average model (Appendix F). Accordingly, 1.88 million export and 1.92 million import TEUs are forecasted for the year 2040. As per the data collected from the SLPA, since a 60% of export and a 5% of import containers are currently represented by the empty containers, the laden export and import containers in 2040 are estimated as 0.75 million and 1.83 million TEUs, respectively. Moreover, the total transshipment containers are forecasted as 16.8 million TEUs. Since 46% of total transshipment is currently given by the twelve focused feeder ports in this study, the transshipment volume for this study is assumed to be 7.73 million TEUs in 2040, which will be distributed between Colombo and Hambantota ports because of their competition. To discuss the impacts of potential competition between Colombo and Hambantota ports, several scenarios are analyzed for both the domestic and transshipment container handling as listed in Figure 5.5. In terms of domestic cargo flow analysis, first, the current situation is analyzed where only the Colombo port handles all container cargo. Thereafter, a future scenario is analyzed with the presence of both Colombo and Hambantota ports for container handling. Since a high attractiveness of Colombo port as a gateway port is revealed by the second scenario, the third scenario analyses the impacts with an incentive scheme for local shippers and consignees at the Hambantota port. The domestic cargo flow is analyzed considering the gateway port choice of local shippers and consignees without considering the impacts from shipping lines' port selection decisions because we aim to understand the most favorable condition for local shippers and consignees. However, in the practical situation, the development of the Hambantota port would split the liner services between two container ports, whereby the shippers and consignees port selection decision will be affected by the availability of liner services at each port, which is influenced by ports' transshipment handling. Therefore, six different scenarios are considered for the transshipment cargo flow analysis and the descriptions on individual scenarios are given in the relevant sub-sections.

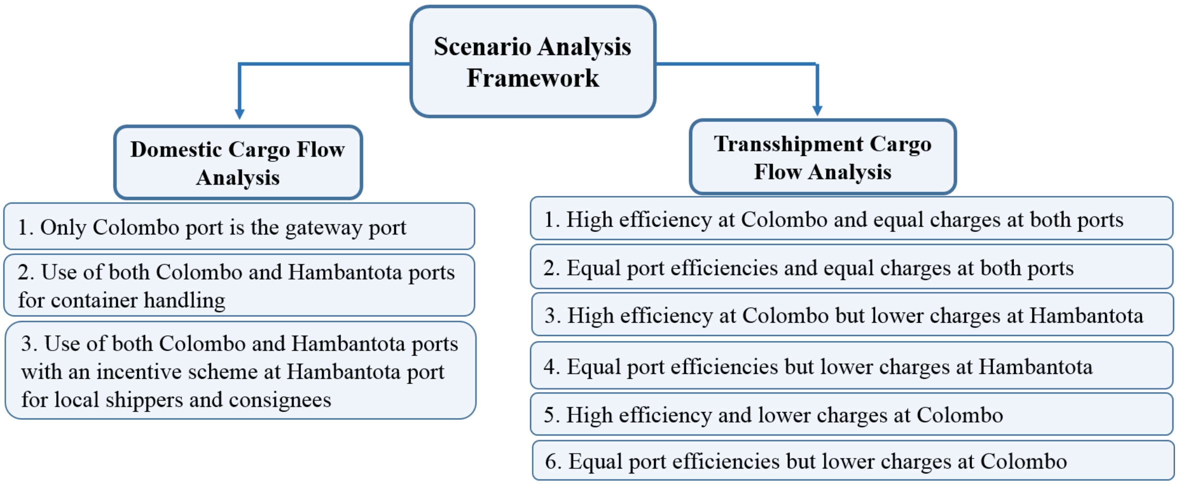

Figure 5.5. Scenario Analysis Framework

5.2.2.1 Domestic cargo flow analysis

Initially, the current situation is considered, where only the Colombo port handles all domestic container cargo and thereafter, the second scenario with the presence of both Colombo and Hambantota ports is considered. Initially, the equal port charges are assumed with both ports. The total generalized cost of shippers and consignees in both cases are calculated as in Table 5.1, which indicates a 3.5% of the lower generalized cost with the presence of both ports than the first scenario.

Table 5.1. Total Generalized Cost of Shippers and Consignees

Scenario	Total Generalized Cost of Shippers and Consignees
Only Colombo port is the gateway port	779,986,581 USD
Use of both Colombo and Hambantota ports for container handling	752,916,659 USD

Since the total generalized cost is reduced by 3.5% with the presence of both ports, the distribution of laden import/export container handling between two gateway ports from each district are illustrated in Figure 5.6. The results are not only dependent on geographical proximity, but also on the available transport access roads, and congestion, among other factors, because the generalized cost is calculated with the real transport cost and time data, considering different routes options and traffic conditions. Therefore, 86% of import/export containers are handled at Colombo and the remaining 14% are handled at the Hambantota port. These results are reasonable as the Colombo port is located close to the major production/consumption centers of the country with high accessibility to/from other districts. Further, Colombo can receive a high market share owing to the significantly high percentage of the total country's import/export cargo generated within the Colombo district. However, the Hambantota port is located in a less developed area with minor industrial development and population density and has poor accessibility to/from other districts. Therefore, most shippers and consignees may not choose the Hambantota port except those from nearby districts. Although the presence of the Hambantota port reduces the total generalized cost compared to the current situation, the Colombo port has a significantly high market share. Therefore, even the Hambantota port is developed for container handling, over 80% of domestic containers should be handled in Colombo to minimize total generalized cost. However, in a practical situation, it is difficult to control the ports' market shares by only considering the benefits of local shippers and consignees especially in Sri Lanka, where more than 75% container throughput is represented by transshipment cargo and also with the private sector, CMPH, involvement with the Hambantota port.

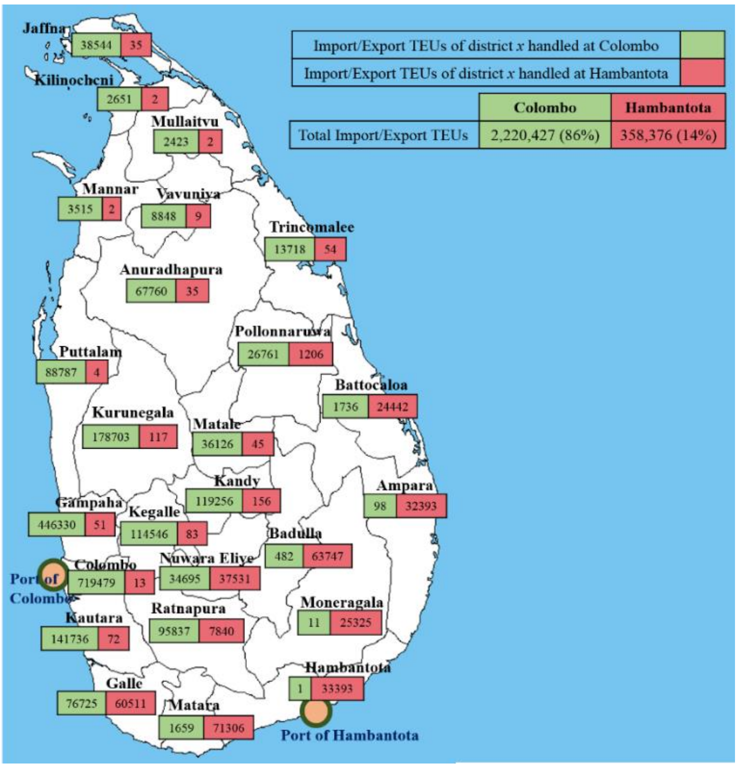

Figure 5.6. Domestic Container Handling from Individual Districts

By considering the negative impacts on the local shippers and consignees due to the large-scale development of the Hambantota port, different incentives are assumed as possible ways of encouraging shippers and consignees to use the Hambantota port. Prakoso et al. (2017) highlight the significance of tariff progressive policy and access road development for increasing the effectiveness of port development in Indonesia, which reduce the negative impacts on the shippers and consignees. Since the lower attractiveness of the Hambantota port mainly results from the comparatively high container haulage cost related to the Hambantota, the development of transport infrastructure for connecting Hambantota port with other districts is assumed with the completion of the large-scale port development project. Considering the significant role of Chinese investors in Sri Lankan infrastructure development aspects (Wheeler, 2012), the scenario related to the transport infrastructure development can be realistic because the China EXIM bank has agreed to provide loans for the "Hambantota hub development project" approved in 2012. Moreover, for the road constructions in Hambantota, Sri Lanka's Road Development Authority and the China State Construction Engineering Corporation Ltd have signed an agreement in 2013, with an estimated investment of USD 252 million. As per the AidData (2017) database, in 2014, Sri Lanka has borrowed USD 412 million from China EXIM Bank for the construction of an expressway between the Hambantota Port and the Mattala International Airport. Therefore, as the third scenario, a reduction of average transport time by 10% and a reduction of unit transport cost from 1 USD/km/TEU to 0.8 USD/km/TEU are assumed when transporting containers between Hambantota port and the other local origins/destinations represented by individual districts.

Additionally, a tariff progressive policy is assumed as another incentive from the Hambantota port on local shippers and consignees, which considers a 10% reduction in domestic container handling charges at Hambantota port than at the Colombo port. This is reasonable owing to the significant involvement of CMPH on the Hambantota port with its 85% stake, which allows CMPH to make a significant influence on deciding handing charges at Hambantota port. As the nature of GTOs, CMPH can have advantages with its extensive network of terminals in different parts of the world, economic of scale with the central purchasing at the headquarters that involves in making large contracts with suppliers, and also with the extensive research and development efforts and knowledge sharing among own terminals, which all enable CMPH to have lower handling charges than the other individual terminal operators in the market.

Figure 5.7 summarizes the resulting ports' market shares with the incentives related to the transport infrastructure development, and the reduction of port charges at Hambantota port, separately, and also the combined impacts if both incentives are applied simultaneously, in comparison to the results obtained without these incentives at Hambantota port. Accordingly, the incentive related to the transport infrastructure development generates a slightly higher market share for the Hambantota port than its market share generated by reducing its port charges. Although the Hambantota port receives a 27% market share with the simultaneous deployment of both incentives, which can be considered as a significant improvement than its 14% market share received with the absence of these incentives, still the shippers and consignees prefer to handle a majority of import/export containers at the Colombo port. Although we analyze the domestic cargo flow considering only the generalized cost of shippers and consignees without considering decisions of shipping lines, the shipping lines may prioritize the advantages in transshipment handling than the captive cargo handling when selecting ports in Sri Lanka due to the high transshipment ratio (over 75%). Therefore, the next section analyzes the scenarios related to transshipment container handling.

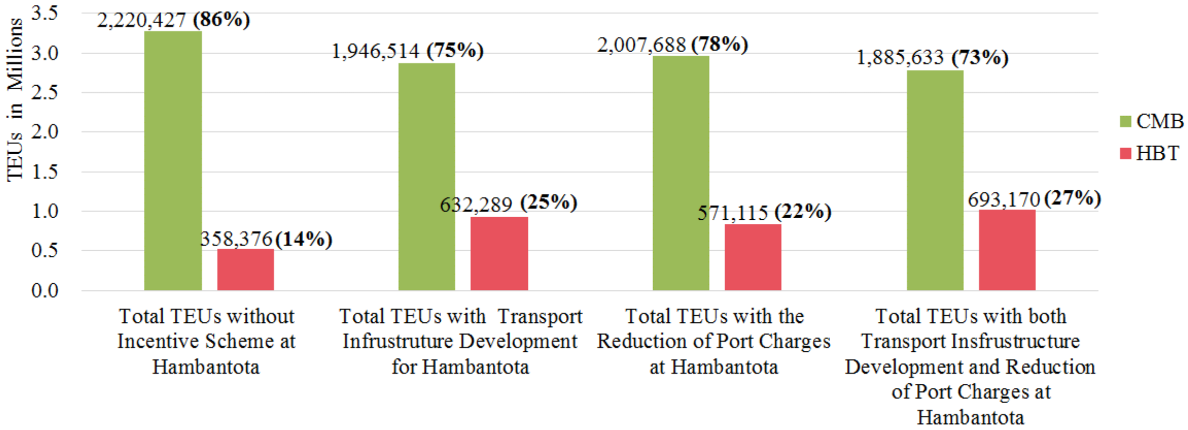

Figure 5.7. Impacts of Incentives at Hambantota for Shippers and Consignees

5.2.2.2 Transshipment cargo flow analysis

This section estimates the transshipment market shares of both ports from the Indian sub-continent feeder market considering the generalized cost of shipping lines. Since the "availability of captive cargo" is one of the criteria for the transshipment port selection in Figure 5.4, the results of the domestic cargo flow analysis are endogenously considered in the transshipment cargo flow analysis.

a) High efficiency at Colombo and equal charges at both ports

The transshipment hub port selection of shipping lines is influenced by multiple selection criteria and the performance of hub ports are varied depending on individual criteria. As explained in the methodology section, *VNQC* is calculated considering the overall performance of hub ports related to the criteria in the port traffic, location, operation, and liner-related categories, from the perspectives of shipping lines. Although *PS* reflects the port's performance from the perspective of shipping lines, currently, Colombo is the only container port in Sri Lanka and the container handling facilities at Hambantota port are still under construction. Also, Colombo port has a higher reputation as a transshipment hub than the Hambantota port because shipping lines already experienced the performance of Colombo. Moreover, the infrastructure related to the Hambantota first and second phase port's development plans are still inferior to that of the current Colombo port (SLPA, 2016).

Therefore, as the first scenario, it is assumed that the Hambantota port will have a comparatively lower port efficiency than that of the Colombo port. The port efficiency is discussed in terms of the *PS* of ports related to the criteria in port traffic, location, operation, and liner-related categories, and the time efficiencies related to the vessel turnaround time and waiting time, which are not depended only on the geographical features. Thus, *SS* of all criteria and the *PS* of Colombo for the relevant criteria are directly obtained from the Kavirathna et al. (2018.b), who conduct a questionnaire survey with the shipping lines to generate *SS* and *PS* values as per Figure 5.4. Thereafter, *PS* values of Hambantota are assumed to be 50% lower than that of Colombo for all criteria except the *PS* of "captive cargo availability", which is decided from the results of previous domestic cargo flow analysis. When considering the captive cargo availability, the domestic cargo flow analysis's results are considered endogenously, thus Colombo port is assumed to have a 75% higher *PS* than the Hambantota port as shippers and consignees prefer to handle a majority of domestic cargo in Colombo port. Moreover, due to the limited infrastructure at the Hambantota port, the average vessel turnaround time of Hambantota is assumed to be 20% longer and the average waiting time is assumed to be two hours longer than that of Colombo, for the initial analysis. However, these assumptions are not valid for the deviation and feeder link-time/cost-related components in the generalized cost function because they are depended on the geographical features rather than the port efficiencies.

When considering the transshipment handling charges, the SLPA publishes the port charges through an official tariff, thus, the handling charges of Colombo are taken from the SLPA. However, since we analyze a future scenario and the Hambantota port currently does not handle containers, we still cannot confirm the handling charges at Hambantota port. Thus, as the first scenario, we assume equal transshipment handling charges for both ports. Considering the influence of CMPH on deciding Hambantota's port charges, together with the possible price controls imposed by the SLPA, several scenarios are analyzed later, which can be considered as a sensitivity analysis of the port charges and the port efficiencies. The resulted transshipment market shares of both ports from each feeder port are summarized in Figure 5.8. Accordingly, the Colombo port obtains comparatively higher market shares from the Indian West-coast and South-coast feeder ports and the Hambantota port obtains higher market share from the East-coast feeder ports. Owing to the short deviation from the trunk sea route, the Hambantota port can highly compete with the Colombo port, which is reflected by its 48% market share. Besides, the East-coast feeder ports give larger transshipment handling volumes than those of West-coast and South-coast feeder ports, thus creating a significantly high market share for the Hambantota port in total.

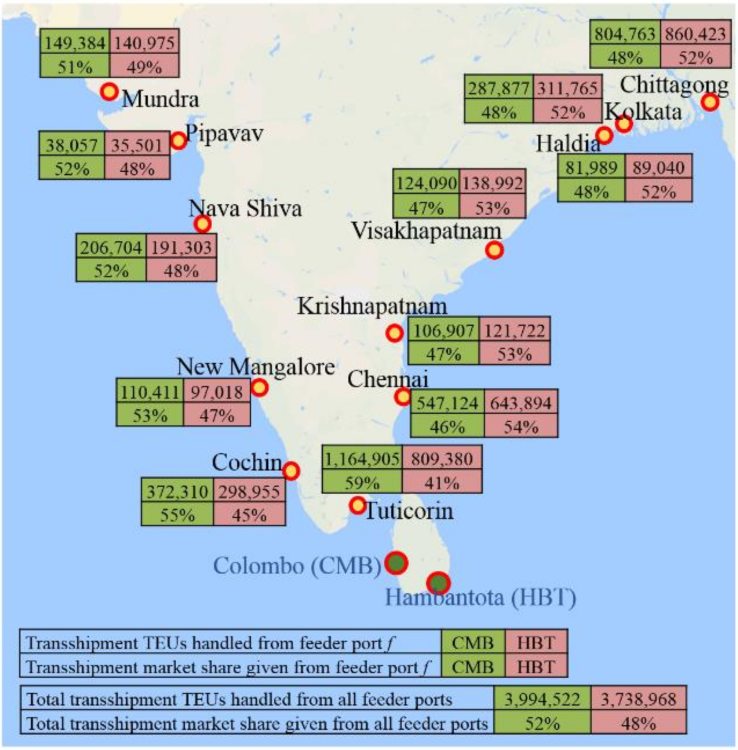

Figure 5.8. Transshipment Cargo Flows from Individual Feeder Ports

b) Sensitivity analysis of port charges and efficiencies

Since a comparatively lower port efficiency of Hambantota port than the Colombo port is assumed with the first scenario, the second scenario analyzes the impacts if both ports have equal port efficiencies, represented by equal *PS* values and the time efficiencies for the relevant criteria. Considering the involvement of CMPH, one of the high performing global terminal operators in the world, Hambantota and Colombo ports could have equal port efficiencies in the future. As per the results in Table 5.2, the second scenario highlights the Colombo's lower market share than the Hambantota owing to the equal port efficiencies of both ports. Assuming the Hambantota port will be developed as a major container port, they may consider different incentives to attract more shipping lines as a newly developed container port in the market. Similar trends were observed from emerging hub ports such as Tanjung Pelepas, where Maersk Sealand experienced about 30% cost reduction after relocating its transshipment operations from Singapore to Tanjung Pelepas. Therefore, third and fourth scenarios are assumed with 10% lower transshipment handling charges at Hambantota port than Colombo, since first and second scenarios are analyzed with equal port charges. The third scenario assumes a higher efficiency at Colombo port with 10% lower charges at Hambantota and the fourth scenario assumes equal port efficiencies with 10% lower charges at Hambantota. Accordingly, the lower charges at Hambantota port has further increased its transshipment market share. However, when comparing the scenarios with and without lower port charges at Hambantota, it seems, Hambantota port can receive a higher market share by increasing its port efficiency than just by reducing its port charges because the scenario with equal port efficiency generates over 10% additional market share for the Hambantota port, which is considerably higher than the additional market share, generated from the scenario with only lower port charges.

Since the impact of reducing transshipment handling charges at Hambantota port is analyzed with the third and fourth scenarios, the last two scenarios discuss the impacts of reducing handling charges at Colombo port by 10%, for understanding whether Colombo can secure its transshipment market share by reducing handling charges and improving port efficiency. Therefore, the fifth scenario assumes a higher port efficiency and 10% lower charges at the Colombo port and the sixth scenario assumes equal port efficiencies but 10% lower charges at the Colombo port. Accordingly, a slight increment of Colombo port's market share can be observed after reducing its handling charges especially when Colombo port has a higher port efficiency than the Hambantota port.

Table 5.2. Sensitivity Analysis of Port Charges and Efficiencies

Scenarios	**Total Transshipment TEUs**		**Transshipment Market Share (%)**	
	CMB	**HBT**	**CMB**	**HBT**
1. High efficiency at Colombo and equal charges at both ports	3,994,522	3,738,968	51.65	48.35
2. Equal port efficiencies and equal charges at both ports	3,133,409	4,600,081	40.52	59.48
3. High efficiency at Colombo but lower charges at Hambantota	3,835,491	3,897,999	49.60	50.40
4. Equal port efficiencies but lower charges at Hambantota	3,026,624	4,706,866	39.14	60.86
5. High efficiency and lower charges at Colombo	4,157,194	3,576,296	53.76	46.24
6. Equal port efficiencies but lower charges at Colombo	3,252,752	4,480,738	42.06	57.94

All scenarios related to the transshipment cargo flow are analyzed assuming the competition between two local ports without considering market share shifts to/from external competitive ports in the market (ex: Singapore, Kelang) because we assumed that the forecasted total transshipment throughput of the country (estimated with current container handling statistics of the Colombo port) for the year 2040 will be distributed between the Colombo and Hambantota ports in the future. However, the split of liner services between two container ports would create several implications, especially when comparing the port's network connectivity with external competitors. Although the quantitative analysis of such impacts is beyond the scope of this chapter, several implications are discussed as follows. A high concentration of liner services with strong network connectivity is a significant factor for a hub port to maintain its competitiveness. Due to the low volume of captive cargo, the development of two container ports may not be economically viable in Sri Lanka unless those ports are being maintained with different scales. A split of liner services between two container ports may reduce the network connectivity of both ports. Moreover, CMPH, who has a number of container terminals in different parts of the world, may have high influencing power on the shipping line's port section decision especially on Chinese national carriers to shift from Colombo port to Hambantota port. Such a situation may reduce the overall competitiveness of Sri Lanka as a maritime hub, compared to the external competitive hubs. Furthermore, the presence of the Hambantota port would reduce the shipping lines' deviation cost and the availability of multiple transshipment/gateway ports would increase their bargaining power, which encourages hub hopping nature. The situation is more complicated when considering the shipping lines' alliances because the port selection decision of one shipping line may influence on the other members of the alliance.

When considering the impacts on the SLPA, with the Colombo port, SLPA receives all revenue from the container handling at the public terminal, terminal fees from private terminals and the revenue from common user facilities and ancillary services used by vessels. With the split of container handling between two ports, the revenue of SLPA would be reduced in case if the expected throughput of Colombo port is reduced. However, the SLPA receives only a15% revenue from the cargo handling and only a 50.7 % revenue from the common user facilities at Hambantota port. Considering the high attractiveness of Hambantota as a transshipment port, there is a possibility for reducing the expected revenue of Colombo port and SLPA, if the Hambantota port is developed with a large scale.

5.2.2.3 Impacts of the transshipment cargo flow on the local shippers and consignees

Previously, the domestic cargo flow was analyzed independently from the transshipment cargo flow to understand the most favorable distribution of domestic container handling market shares between Colombo and Hambantota ports based on the perspectives of local shippers and consignees. However, these derived domestic container handling market shares may not be practically realized in a country with a large transshipment ratio. The transshipment cargo flow analysis highlights the high attractiveness of the Hambantota port for shipping lines, especially when both ports have equal port efficiencies. Therefore, this section discusses the impacts of transshipment cargo flow on the local shippers and consignees.

The domestic cargo flow was analyzed previously without considering the additional waiting time, which possibly can occur owing to the split of liner services between two container ports, compared to the frequency of services when having a single port with high network connectivity. Therefore, this section analyses the impacts of additional waiting time experienced by local shippers and consignees from liner services after the split of liner services between two container ports, which reduces the frequency at one port. Results are summarized in Figure 5.9, where the horizontal axis indicates the different combinations of waiting time ranging from zero to six days. However, this waiting time is different from the waiting time experienced by vessels at the anchorage area, because here only the additional waiting time for liner services, experienced by local shippers and consignees in the future is considered when compared to the current situation. As an example, currently, shippers and consignees may able to find a service for their overseas destination or origin every two days, but in the future, they find an appropriate service only every four days, which creates two days additional waiting time. Although the availability of liner services is depended on the overseas origin and destination, an average value for the entire port is assumed for simplicity. As per the results, high waiting time at Colombo and a low waiting time at Hambantota have increased the total generalized cost due to the high market share of Hambantota. However, even with additional six days of waiting time, Colombo still maintains about 70% of market share could be due to the less time sensitivity (*VOT* is 0.5 USD/TEU/hour) of cargo transported via maritime mode, which creates lower significance of waiting time in the total generalized cost, compared to the high container haulage cost.

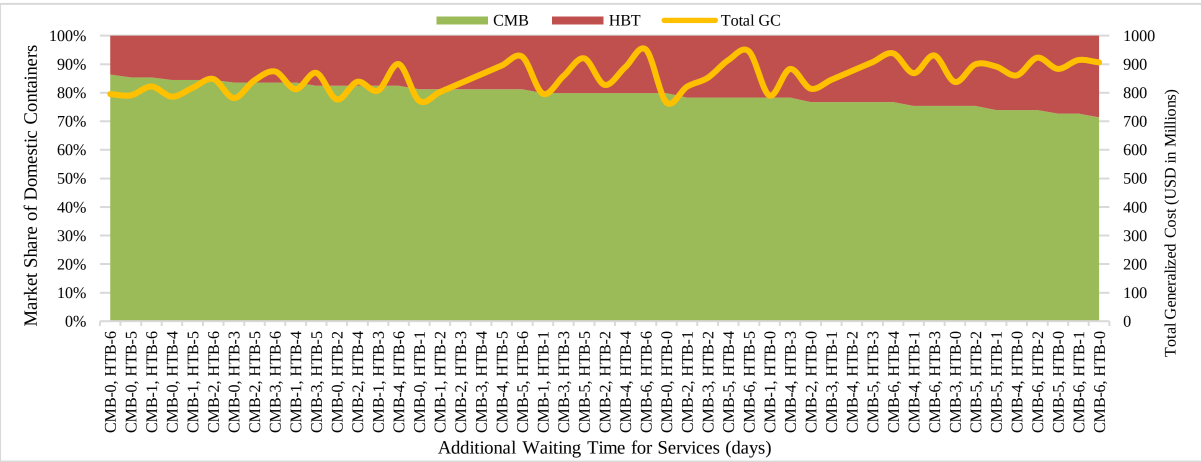

Figure 5.9. Impacts from Additional Waiting Time for Liner Services

Regardless of the high willingness of local shippers and consignees to use the Colombo port even with a longer waiting time, shipping lines may consider the higher attractiveness of the Hambantota port for transshipment handling. Hence, there is a possibility for relocating liner services from Colombo port to Hambantota port if the Hambantota is developed with a sufficient scale. Therefore, if shipping lines decide to handle a majority of transshipment at Hambantota, Colombo port will not receive a sufficient slot capacity from liner services to handle more domestic cargo regardless of the high willingness from shippers and consignees to use the Colombo port. This happens because the mainline vessels called at Sri Lankan ports contain a higher number of transshipment containers than the domestic import/export containers. Thus, this section analyzes the impacts of limiting available slot capacities at the Colombo port, which can increase the generalized cost of shippers and consignees than their generalized cost previously obtained with the most favorable distribution of domestic container handling market shares. Therefore, we calculate the additional generalized cost as experienced by the local shippers and consignees if they cannot use the Colombo port up to their desired maximum level.

To calculate the additional generalized cost, a linear programming simplex optimization method is used with an objective function to minimize the total generalized cost of shippers and consignees with the given slot capacity constraint at the Colombo port. Therefore, as the decision variables, "the numbers of containers from each district handled in Colombo and Hambantota ports" are considered to identify the optimal allocation of container handling between two ports with the slot capacity constraint at the Colombo port. However, this slot capacity constraint is an exogenous factor, which is decided by shipping lines and is different from the handling capacity of the port which is decided from the port's infrastructure. Limit on the available slot capacity is assumed as a maximum possible share from the total domestic container volume that can be handled in the Colombo port, considering every 10% reductions as given in Figure 5.10. Moreover, to better understand the impacts of slot capacity constraint at Colombo, the calculated additional generalized cost is represented as a percentage of the generalized cost derived with the most favorable distribution of domestic container handling between two ports, which is estimated previously with the logit model without such slot capacity constraint. As per the results, over 20% of additional generalized cost can be observed when reducing the maximum possible share of Colombo port below 40%, because the shippers and consignees do not have any alternative choices rather than using Hambantota port, regardless of the significantly high economic loss owing to the high container haulage cost and time cost associated with the Hambantota port.

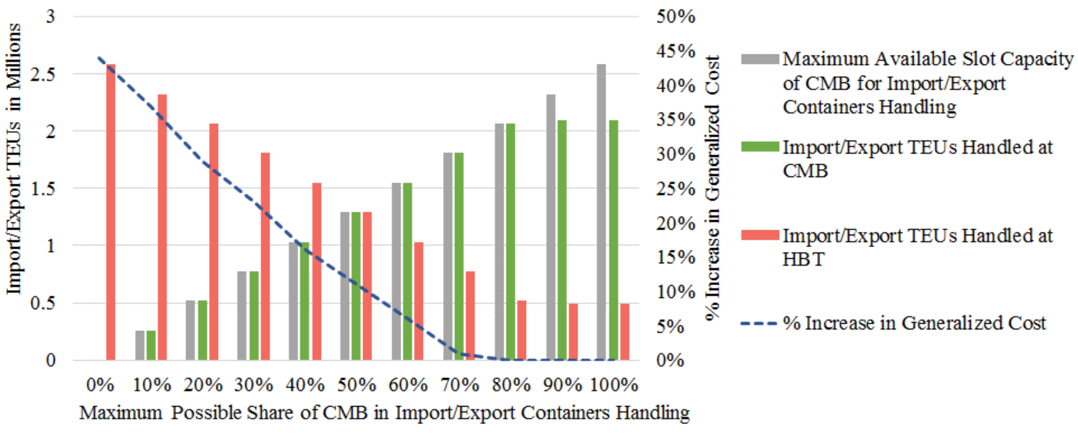

Figure 5.10. Impacts of Limiting Available Slot Capacities at the Colombo Port

5.3 Analysis for Objective [5.2]

Since the first objective of this chapter analyses the potential competition between Colombo and Hambantota ports considering several scenarios, the second objective focuses on the decision-making behavior of the port authority and a GTO considering their different objectives. Since the first objective highlights the high competition between Colombo and Hambantota ports especially in transshipment container handling, the second objective only focuses on the transshipment container handling. Due to their competitive scenario and the different port administrative types and ownership structures, the port operators may consider different strategies to enhance the port competitiveness. Several previous studies emphasize the significance of maintaining lower container handling charges on increasing port competitiveness because it encourages more shipping lines to use the port than using competing ports with higher charges. Since the Objective [5.2] focuses on the theoretical contribution due to the absence of previous studies on analyzing behaviors and interactions between a port authority and a GTO, and their significance on the port competitiveness, we assume a hypothetical scenario related to a pricing strategy on individual terminals in the forms of incentives/rebates given by the authority and a GTO to enhance the competitiveness of their ports/ terminals.

Since this chapter focuses on GTOs, it is important to understand their basic business model. A GTO is considered as a terminal operator who has multiple terminals in different parts of the world. When considering the formation and development of GTOs, historically, most seaport facilities were owned and operated by the public sector, especially in the case of Asian countries. However, by the end of the nineteen-eighties, the demand for these facilities and their operational standards were improved, which made it difficult for many public agencies and government bodies to develop and operate these port facilities aligned with the international standards. Therefore, the public port authorities in many countries decided to invite the private sector especially to raise the investments required for the port developments and also to carry out cargo handling functions at terminals with improved standards. Meanwhile, these private terminal operators enhance their competitiveness with technology and professionalize operational practices. Consequently, a number of major terminals in different parts of the world came into the hand of a few major terminal operating companies, which are known as GTOs. As per the Drewry Maritime statistics, currently, 24 terminal operating companies are considered as GTOs and they control 60% of world container handling capacity (Drewry Maritime Research, 2016). A GTO can act as purely a stevedore, involved in terminal operations as the prime business, or as a part of a major shipping company with a vertical integration or as a part of a financial holding that considers portfolio diversification through investing in container terminals worldwide. However, GTOs can maintain great efficiency in terminal operations by implementing a common system across the terminals in the whole network while spreading the investment risk with an extensive number of terminals representing different markets. Besides, they are benefitted by the economies of scale advantages with a central purchasing process at their headquarters with a high bargaining power over suppliers and knowledge sharing among the terminals in the whole network through an extensive research and development effort.

However, GTOs are always confronted with the conflict of interest when balancing their own company's interests and the interest of the port at where their terminals are belonging to. Meanwhile, when the public port authority acts as the main administrator of a port which has both the public terminal directly operated by the port authority and the private terminal operated by a GTO, the port authority may have conflict of interests as well when balancing its own interests and the interest of the port as a whole including private terminals. The terminal operators in the same port can be equally benefited from enhancing the overall port competitiveness although they can have competitive interactions due to the different ownerships and objectives. Besides, a GTO can have own terminals in two competing ports located in the same market. Thus, these terminals can have competitive interactions because they are belonging to two competing ports in the market while they can have cooperative interactions because they are owned and operated by the same mother company, which is a GTO. Therefore, Objective [5.2] analyzes the decision-making behaviors of the port authority and a GTO with a pricing strategy at the terminal level, to discuss different implications associated with their different objectives. The understanding of such behaviors is important because they would help to increase port performance.

Since we analyze the decision-making behaviors of the port authority and a GTO considering two competing ports, the coopetition concept can be incorporated to discuss the quantitative results derived from different objectives of each decision-maker rather than quantitatively analyzing common value creation and individual value appropriation among ports and terminals. Therefore, when considering the intra-port level, the port authority may consider the value creation for the entire port by reducing its average handling charges in the form of incentives/rebates given to the individual terminals, and enhancing port performance index, which reflects the overall port performance. Moreover, a GTO may have to balance the conflicts of interests when acting as a part of the entire port that requires it to consider the common value creation by enhancing the entire port competitiveness, while simultaneously achieving the individual objective of the own company with value appropriation. Besides, since the port authority receives higher benefits from the public terminal than the private terminals in the same port, it requires to balance the interests on the public terminal considering the individual benefits while simultaneously enhancing the entire port competitiveness as the port authority of the entire port, especially when it has both the profit and non-profit objectives. Due to the consideration of both the ports and terminals aspects for both the intra-port and inter-port levels, and the impacts on multiple economic entities with different ownership types, this chapter discusses the possible coopetition among market players while changing the objectives of decision-makers rather than quantitative estimating the effects from coopetition.

5.3.1 Model Development for the Objective [5.2]

5.3.1.1 Terminal Pricing strategy of the port authority and a GTO

Since we assume a port authority and a GTO as the two decision-makers of this analysis, the Port of Colombo and Hambantota can be considered as an example case where the SLPA and the CMPH are considered as the two decision-makers. As explained in Figure 5.11, Colombo port has three main terminals where JCT is a public terminal, directly operated by the port authority and SAGT and CICT are two private terminals. As explained previously with Objective [5.1], the Hambantota port is operated by the CMPH due to its 85% stake in Hambantota port with the 99 years leasing agreement. When considering the Port of Colombo, three terminals can have cooperative interactions with each other to enhance the overall port competitiveness with different strategies as an example analyzed with Chapter 4. At the same time, they can have competitive interactions due to the differences in ownership types and objectives. When considering the CMPH, apart from operating terminals at the Hambantota port, it also operates the CICT terminal in the Colombo port as per the concession agreement with SLPA.

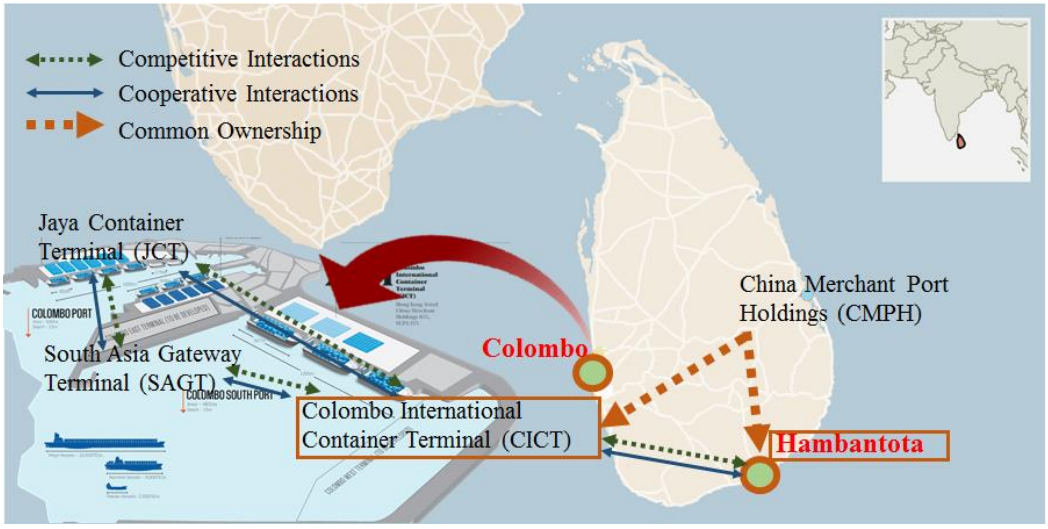

Figure 5.11. Ports and Terminals Coopetition at the Inter-port Level

Although the container handling facilities at the Hambantota port are still under construction, we assume two container terminals namely; HBT_1 and HBT_2 in the Hambantota port, referring to the port development plan (SLPA, 2016) for the purpose of model development. Therefore, CICT in Colombo and HBT_1 and HBT_2 in Hambantota can have cooperative interactions because they all are belonging to the CMPH while simultaneously they can have competitive interactions because they are located in two competing ports in the same market. Since we consider a terminal pricing scenario with Objective [5.2], we assume that the SLPA can influence on the prices (handling charges) at JCT, SAGT, and CICT in the form of incentives/rebates given for terminals to reduce their prices, which eventually helps to maintain a competitive average price at the entire Colombo port. However, we assume seven different objectives of SLPA and two objectives of CMPH for their decision-making on terminal prices as illustrated in Figure 5.12. The detailed model formulations related to each objective of SLPA and its pricing decisions are discussed in a later section of this chapter. When considering the pricing decision on the public terminal JCT, the SLPA decides the price level as a direct discount to the average price at JCT. However, in the case of private terminals, the SLPA offers rebates on their terminal fee that is paid by the private terminals to the port authority as per the landlord port governance model. Similarly, the CMPH can influence on the prices of HBT_1, HBT_2, and CICT because they all are operated under the CMPH. Thus, the price/handling charge of CICT is affected by the decisions of both the SLPA and CMPH, as illustrated in Figure 5.12.

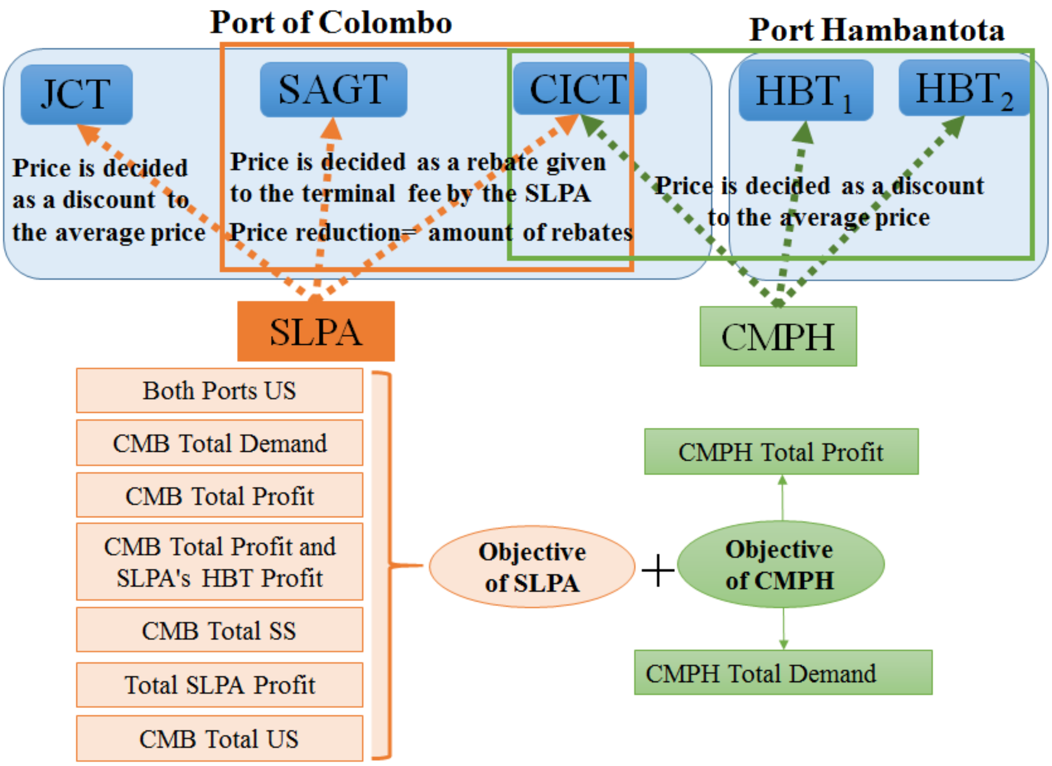

Figure 5.12. Pricing Strategy on the Terminal Level

5.3.1.2 Port and terminal levels analysis

Since the Objective [5.1] focuses on only the port level analysis, the Objective [5.2] considers both the port and terminal levels. The terminal level analysis is important because we analyze the pricing decisions for individual terminals made by the port authority and a GTO. For the port level analysis, we follow the same methodology that we used for the transshipment cargo flow analysis with our first objective of this chapter. Although the analysis with Objective [5.1] considers a single-period model, the analysis with Objective [5.2] considers a multi-period model to understand the reactions of the port authority and a GTO on each other's pricing decisions. The components of the *GC* function for the transshipment hub port selection of shipping lines are similar to the *GC* function discussed with Equation (5.4) with the Objective [5.1] except the fact that we consider the values of individual components at each decision-making period (*t*) as given with Equation (5.13). Therefore, the *GC* function consists of the port charges (MPC_t^h), journey cost ($JC_t^{f,h}$), time cost ($TC_t^{f,h}$) and the value of non-quantitative criteria ($VNQC_t^h$) at t^{th} decision-making period. Therefore, each of these *GC*'s component follows a similar description to that was given with the first objective except the time-varying nature of values. However, when considering the first component, the average port charge, MPC_t^h, although we directly obtained the value of MPC_t^h from the published port tariff for the Objective [5.1], we use a different approach to calculate the value of MPC_t^h for the Objective [5.2] as given with Equation (5.14). Accordingly, the average port charge, (MPC_t^h) at each period is calculated as the average of the handling charges across all terminals in port h. Thus, MPC_t^i represents the handling charges (price) and $Share_t^i$ represents the market share of terminal i from the entire port's demand at the t^{th} decision-making period. Since we assume that a port authority and a GTO make the terminal pricing decisions, the MPC_t^h is changed in each period due to the changes in MPC_t^i and $Share_t^i$ of individual terminals belonging to the port h.

Besides, the journey cost ($JC_t^{f,h}$) is changed in each period due to the changes in $UDC_t^{(j,f,h)}$, which reflects the journey cost of one nautical mile and $UDC_t^{(j,f,h)}$ in each period is calculated with Equation (5.16) considering the updated average port charge, MPC_t^h in that period because the monetization is done with the port charges. Similar to the journey cost calculation, the time cost, $TC_t^{f,h}$ is changed in each period due to the changes in $VOT_t^{(w,f,h)}$, which reflects the value of time and the $VOT_t^{(w,f,h)}$ in each period is calculated with Equation (5.18) considering the updated average port charge, MPC_t^h in that period. However, the other components related to the journey cost and time cost calculations such as journey distances, quantitative time values, and *SS* values, among others, are not changed in different decision-making periods because they are not affected by the pricing decisions made at the terminal level, but mostly depended on the geographical features of the port.

$$GC_t^{f,h} = MPC_t^h + JC_t^{f,h} + TC_t^{f,h} - VNQC_t^h \tag{5.13}$$

$$MPC_t^h = \sum_{i=1}^{i=m^h} (Share_t^i * MPC_t^i) \quad (5.14)$$

$$JC_t^{f,h} = \sum_{j=1}^{j=2} \left[D^{(j,f,h)} * UDC_t^{(j,f,h)}\right] \quad (5.15)$$

$$UDC_t^{j,f,h} = \frac{\left(\frac{MPC_t^h}{SS_{(Port\ Charges)}}\right) * SS_{(j)}}{(\sum_{h=1}^{h=2} D^{(j,f,h)}/2)} \quad (5.16)$$

$$TC_t^{f,h} = \sum_{w=1}^{w=4} \left[T^{(w,f,h)} * VOT_t^{(w,f,h)}\right] \quad (5.17)$$

$$VOT_t^{(w,f,h)} = \frac{\left(\frac{MPC_t^h}{SS_{(Port\ Charges)}}\right) * SS_{(w)}}{(\sum_{h=1}^{h=2} T^{(w,f,h)}/2)} \quad (5.18)$$

Where;

i	Individual terminal operators $i = \mathrm{JCT}, \mathrm{SAGT}, \mathrm{CICT}, \mathrm{HBT_1}, \mathrm{HBT_2}$;
$GC_t^{f,h}$	The generalized cost of shipping lines when using hub port *h* to serve feeder port *f* (USD) in the t^{th} decision-making period;
MPC_t^h	Average port charges paid by shipping lines (USD) in the t^{th} decision-making period;
MPC_t^i	Average handling charges of terminal i in t^{th} decision-making period;
$JC_t^{f,h}$	Journey cost of shipping lines when using hub port *h* to serve feeder port *f* (USD) in the t^{th} decision-making period;
$TC_t^{f,h}$	Time cost of shipping lines when using hub port *h* to serve feeder port *f* (USD) in the t^{th} decision-making period;
$VNQC_t^h$	The value of non-quantitative criteria (USD) in the t^{th} decision-making period, which indicates the perceived generalized cost reduction of shipping lines owing to the performance of hub port *h*;
$Share_t^i$	Market share of terminal $i \in I$ from the entire port in t^{th} decision-making period;
$D^{(j,f,h)}$	The journey distance (nautical miles) associated with the *j*th criterion of port *h*.
$UDC_t^{(j,f,h)}$	Unit distance cost, which reflects the journey cost of one nautical mile of the *j*th criterion (USD) in the t^{th} decision-making period;
$SS_{(j)}$	The "significant score" of the *j*th journey cost-related criterion, which reflects its level of significance in the hub port selection decision;
$VOT_t^{(w,f,h)}$	Value of time, which reflects the value of one hour for the w^{th} criterion (USD/hour) in the t^{th} decision-making period;
$W^{(w,f,h)}$	The quantitative time value (hours) associated with the w^{th} criterion of port *h*;

m^h The number of terminals operated in port h.

The last component of the GC function is the value of non-quantitative criteria, $VNQC_t^h$, which represents the perceived generalized cost reduction of shipping lines owing to the high performance of hub port h in period t. As explained with the Objective [5.1], $VNQC_t^h$ is calculated incorporating the port performance index (*PPI*) of hub port and the *PPI* is estimated with a questionnaire survey conducted with shipping lines as per Kavirathna et al. (2018.b). Thus, the ports' *PPI*s at the initial period ($t=0$), PPI_0^h are taken directly from the Objective [5.1], following a similar approach mentioned with Equation (5.10). However, since the *PPI* reflects the port performance considering a range of hub port selection criteria, the value of *PPI* is assumed to be varied in each period depending on the changes in port's total demand as per Equation (5.19). Thus, the port's total demand is used as a proxy for the port performance level, which is reasonable because a port with a high-performance level can have a high market demand even in a practical situation. Besides, it implies a positive induce impact of the common value creation by terminals located in one port because all terminal operators in a particular port can be benefited from a high *PPI* of that port. Therefore, $VNQC_t^h$ is calculated for each decision-making period considering the updated *PPI* (PPI_t^h) and the updated average port changes (MPC_t^h) in that period because the monetization is done based on the port changes, similar to the Objective [5.1]. Hence, the $VNQC_t^h$ is varied in each decision-making period when changing the total port's demand and the average port changes, which are decided by the pricing decisions made for the terminals by the port authority and the GTO.

$$PPI_t^h = PPI_0^h + e \sum_{i=1}^{i=m^h} (Q_{t-1}^i - Q_0^i) \tag{5.19}$$

$$VNQC_t^h = \left[\left(\frac{MPC_t^h}{SS_{(Port\ Charges)}}\right) * PPI_t^h\right] \tag{5.20}$$

Where;

PPI_t^h The port performance index in the t^{th} decision-making period;

e The degree of influence of the total port demand increment on the PPI_t^h

Q_t^h The number of vessel calls at hub port h in t^{th} decision-making period.

After calculating each component of the GC function, the total transshipment volume at each port can be estimated with a logit model as given by Equations (5.21) and (5.22), following a similar approach of the transshipment cargo flow analysis with Objective [5.1]. Therefore, the descriptions related to the Equations (5.21) and (5.22) are similar to the descriptions previously given with Objective

[5.1] except the fact that the demand of each port is varied in each period. Therefore, the pricing decisions made at the terminal level by the port authority and the GTO can change the demand of two ports at the port level analysis. With this approach, the competition between Colombo and Hambantota ports in the transshipment market can be analyzed by estimating the market shares of them depending on the individual terminals' pricing decisions made by the SLPA and GTO.

$$Utility_t^{(f.h)} = \frac{1}{\frac{GC_t^{(f.h)}}{GC_t^{(f.least)}}} \qquad \forall f, \forall h \qquad (5.21)$$

$$TS_t^h = \sum_{f=1}^{f=12} TS^f * \frac{e^{Utility_t^{(f.h)}}}{\sum_{h=1}^{h=2} e^{Utility_t^{(f.h)}}} \qquad \forall h \qquad (5.22)$$

Where;

f	Any of twelve feeder ports in Figure 5.3
TS^f	Total TEUs handled in Sri Lanka from feeder port *f*
TS_t^h	Total TEUs handled at hub port *h* from all feeder ports in t^{th} decision-making period;
$GC_{t,f}^{(f,least)}$	The lowest generalized cost across alternative hub ports when serving feeder port *f* in the t^{th} decision-making period.

Since we analyze the port level competition incorporating the individual terminals' handling charges (MPC_t^i) and market shares ($Share_t^i$), it is important to understand the distribution of the total port's demand among the terminal operators in that port considering the terminal level analysis. Such a terminal level analysis is important because of the different ownership types associated with the container terminals operated in Colombo and Hambantota ports. The relationship between the port level and the terminal level analysis is illustrated in Figure 5.13. Accordingly, after deciding the total port demand from the port level analysis, this total demand is distributed among the terminals operated in that port based on the generalized cost related to the individual terminals. However, for the terminal level analysis, we use an approach similar to that of Chapter 3. Therefore, the terminal's generalized cost function consists of three main components, namely the terminal handling charges (terminal price) MPC_t^i, navigation charges and the congestion cost as given in Equation (5.23), which are similar to the components of the terminal's generalized cost function discussed in Chapter 3. Therefore, at the terminal level, the port authority and a GTO decide the handling charges at individual terminals, which influence on the terminals' market shares. Since these individual terminals' handling charges and market shares influence on the average port change, and also on the other components of the port's *GC* function at the port level, the pricing decisions influence on both the port and terminal levels. Besides, since we analyze the pricing decisions considering different objectives, the reactions of the port authority and the GTO on each other's pricing decisions would change based on those objectives.

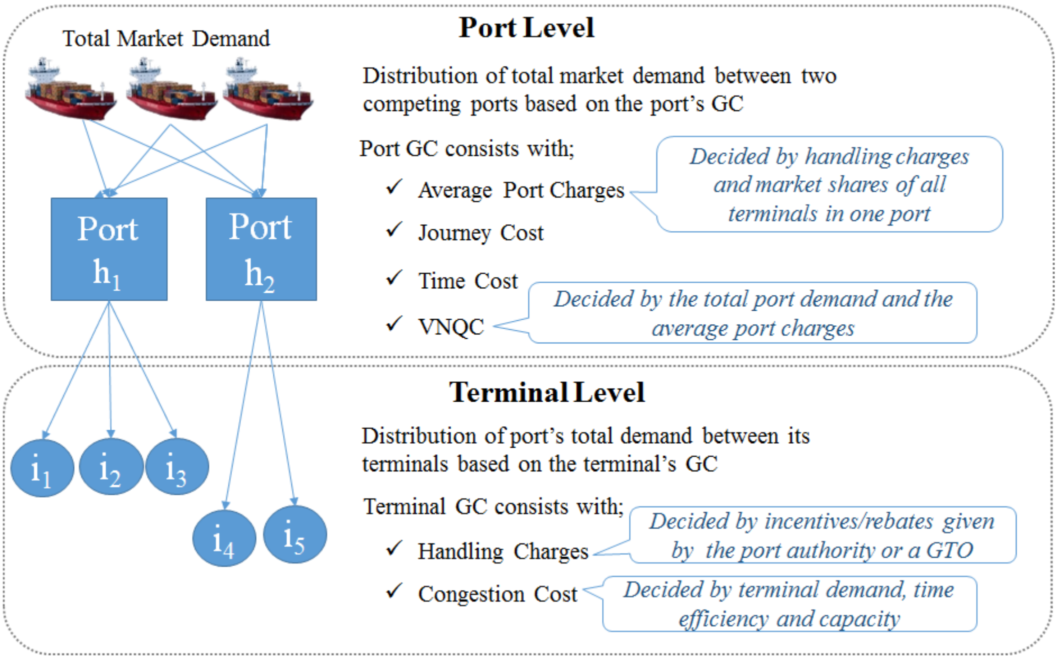

Figure 5.13. Port and Terminal Levels in Analysis

For the terminal level analysis, we consider the demand in terms of the number of vessel calls following the model used in Chapter 3, thus the average number of TEUs handled during a vessel call is assumed to be *V*. Moreover, the usage of the terminal above 80% of its capacity generates a congestion cost for the shipping lines (Bae et al., 2013; Saeed and Larsen, 2010), where T^i indicates the average handling time per vessel at terminal i. Thus, the capacity of the terminal, K^i is calculated with Equation (5.26) in terms of the number of berth hours. After calculating the GC (GC_t^i) of all terminals in one port, the market shares of individual terminals ($Share_t^i$) in period *t* are calculated with a logit function as given with Equation (5.24), which follows a similar approach used in Chapter 3. After estimating the individual terminals' market shares in each period, the Equation (5.25) calculates the demand at each terminal in the number of vessel calls, where the TS_t^h indicates the total demand of the port, which is estimated with the port level analysis. Therefore, with the terminal level analysis, the total port demand is distributed among its terminals depending on the terminal's generalized cost. Thus, depending on the pricing decisions of the port authority and the GTO, the terminal's demand and the handling charges are changed, while influencing the profit of terminal operators.

$$GC_t^i = (V * MPC_t^i) + N^h + a\left(\frac{Q_{t-1}^i * T^i}{0.8 * K^i}\right)^b \tag{5.23}$$

$$Share_t^i = \frac{e^{-\theta GC_t^i}}{\sum_{i=1}^{i=m^h} e^{-\theta GC_t^i}} \tag{5.24}$$

$$Q_t^i = Share_t^i * \left(\frac{TS_t^h}{V}\right) \tag{5.25}$$

$$K^i = no\ of\ berths^i * 24 * 365 \tag{5.26}$$

Whereas,

GC_t^i	Generalized cost (USD) of the shipping lines when using terminal *i* in *t*th decision-making period;
V	The average number of TEUs handled during a vessel call;
a, b	Parameters to estimate the additional generalized cost perceived by the shipping lines due to the congestion and delays at terminals;
T^i	Average handling time per vessel at the berth (hours) of terminal *i*;
K^i	The capacity of terminal *i* (available berth hours);
θ	Parameter of the logit function;
N^h	Navigation charges (USD) of port $h \in H$ paid by the shipping lines to the port authority.

5.3.1.3 Decision making by the port authority

As mentioned previously, the port authority, SLPA can influence the prices of three container terminals in Colombo port by offering incentives/rebates on price reduction. With that, the SLPA can maintain a competitive average price level for the entire port, which enhances the competitiveness of the Colombo port than the other competing ports in the market. However, the pricing strategies on the public terminal and private terminals are different owing to the different ownership types. As per the landlord port governance model, the port authority collects terminal fees from the private terminals depending on the number of containers handled at the private terminals. Therefore, in the case of private terminals, we assumed that the port authority offers rebates on the terminal fee, which is paid by the private terminals to the port authority. Which means, SAGT and CICT receive terminal fee rebates equal to a certain amount from the port authority, and these two private terminals are required to make a discount to the container handling charges with an equal amount as per Equation (5.28), thereby shipping lines are benefitted because they can use the terminal facilities at a lower handling charge. However, these private terminals are not negatively affected by this pricing strategy because they do not experience any revenue loss due to the fact that the amount of discount made to the container handling charge is equal to the terminal fee rebates offered by the port authority. However, these private terminals are benefitted from this pricing strategy because they can receive a high number of vessel calls after reducing their handling charges. When considering the public terminal, JCT, since the public terminal is directly operated by the port authority, the port authority decides its container handling charge as a direct discount made to the average handling charge (container handling charge in the absence of this pricing strategy) as per Equation (5.27). Thus, we use x_t^i as a decision variable to decide the price level at terminal i in period t as given with Equation (5.27), which is decided by the port authority for all three terminals in Colombo.

$$MPC_t^i = MPC_{avg}^i - \gamma * ln(x_t^i) \qquad i = \text{JCT, SAGT, CICT} \qquad (5.27)$$

$$TF_t^i = TF_{avg}^i - (MPC_{avg}^i - MPC_t^i) \qquad i = \text{SAGT, CICT} \qquad (5.28)$$

$$0 \le x_t^i \le M \qquad (5.29)$$

Whereas,

MPC_{avg}^i	Average handing charges (USD) for the shipping lines when using terminal *i* in the absence of this pricing strategy;
γ	The parameter to decide price level;
TF_t^i	Effective terminal fee (USD) paid by private terminal *i* to the port authority in the t^{th} decision-making period;
TF_{avg}^i	Average terminal fee (USD) paid by private terminal *i* to the port authority when it does not receive any rebates;
x_t^i	The decision variable, which decides the handling charges of terminal *i* in t^{th} decision-making period;
M	Large positive *M* value as the upper bound of x_t^i

In considering the pricing decisions of the SLPA, we assume seven alternative objective functions as illustrated in Figure 5.12, which are expressed by Equations (5.30) to (5.36) to understand the differences in pricing decisions depending on its objective. As per Brooks and Pallis (2012), although a port governance model identifies the operating principles and strategic objectives of the entity, whether profit or non-profit, these objectives can be varied from one country to another. Moreover, the policies related to a public sector organization may attempt to provide services at a reasonable price for making them affordable for many users (Brooks and Pallis, 2012, The World Bank, 2007). Although most public entities such as port authorities may have social surplus maximization objective or non-profit objective, the analysis of their decision-making behaviors with several possible objectives including the profit maximization objective while comparing the results from those objectives would be helpful in providing an appropriate recommendation for them. Such analysis is significant due to the existing dilemma on the objectives and operating principles of the public sector organizations.

As the first objective of SLPA, we assume that SLPA aims to maximize the total demand of the Colombo port, which is calculated as the summation of vessel calls at all three terminals in Colombo as per the Equation (5.30). Since many public port authorities aim to increase the total port demand while competing with other ports in the same market, it is reasonable to assume this as one of the objectives of SLPA. Secondly, we assume that SLPA aims to maximize the total profit of the Colombo port, as given with Equation (5.31), which is a reasonable objective due to the high significance of the port's financial performance for the port authority, as the main administrator of the port. The profit functions of three container terminals in Colombo are given by Equation (3.37) to (3.38), which are similar to the terminals' profit calculations with Chapter 3. Since the public terminal is directly operated by the port authority, the public terminal and the port authority are assumed to be the same economic entity (Brooks and Pallis, 2012; Munim et al., 2018; Saeed and Larsen, 2010). Therefore, besides the direct operating profit, the public terminal also receives a navigation revenue from all vessels called at the port as given with the last component, and the terminal fees from private terminals in the same port as given with the second and third components in Equation (3.37). The private terminal's profit is calculated with Equation (3.38) by subtracting the operation cost and the terminal fee from the terminal price (handling charges) that they receive from shipping lines.

Thirdly, the total user surplus from Colombo port is assumed as another objective of SLPA as per Equation (5.32) and the user surplus of individual terminals is calculated with Equation (5.39), following a similar approach with Chapter 3. This can be a possible objective for the SLPA because of the non-profit interests associated with public sector organizations. Moreover, the total social surplus from the Colombo port is assumed as another objective of the SLPA, which is calculated by Equation (5.33) as the summation of the profits and user surplus generated from all three terminals in Colombo port. This is one of the important objectives because the port authority can have both the profit and non-profit focus, simultaneously.

Although the SLPA has a major involvement in the Port of Colombo than in the Hambantota port, still SLPA has interests in the Hambantota port as the main public administrator of all Sri Lankan port, and also due to its limited share in Hambantota port. Therefore, as another objective, we assumed that SLPA aims to maximize the total user surplus generated from both Colombo and Hambantota ports, which is given by Equation (5.34). Despite the nature of the SLPA as a public sector organization, its decision-making with the objective of maximizing SLPA's own profit can be analyzed to understand the related implications. Therefore, the profit of SLPA is calculated with Equation (5.35). However, the decision-making related to this objective is even complicated because, in addition to the public terminal, JCT's profit, the SLPA also has limited share from Hambantota port as well, which are included as a 15% share from two container terminals' profits and a 50.7% share from navigation services at Hambantota port as expressed by the second and third components of Equation (5.35). The last objective considers the Colombo port's total profit and the SLPA's share of profit from the Hambantota port as per Equation (5.36). This is an important objective for the SLPA because it has a strategic role in the Colombo port as the direct operator of the public terminal, the landlord of two private terminals and also as the provider of navigation services, which all increase the SLPA's interest on Colombo port's total profit together with its share of profit from Hambantota.

$$Max; Q_t^{CMB} = \sum_{i=1}^{i=3} Q_t^i \qquad i = \text{JCT, SAGT, CICT} \tag{5.30}$$

$$Max;\ \pi_t^{CMB} = \sum_{i=1}^{i=3} \pi_t^i \qquad i = \text{JCT, SAGT, CICT} \tag{5.31}$$

$$Max; US_t^{CMB} = \sum_{i=1}^{i=3} US_t^i \qquad i = \text{JCT, SAGT, CICT} \tag{5.32}$$

$$Max; SS_t^{CMB} = \sum_{i=1}^{i=3} \left[US_t^i + \pi_t^i\right] \qquad i = \text{JCT, SAGT, CICT} \tag{5.33}$$

$$Max; US_t^{CMB+HBT} = \sum_{h=1}^{h=2} \sum_{i=1}^{i=n} US_t^i \qquad i = \text{JCT, SAGT, CICT, HBT}_1\text{, HBT}_2 \quad h = \text{CMB, HBT} \tag{5.34}$$

$$Max;\ \pi_t^{SLPA} = \pi_t^{JCT} + 0.15\ \sum_{i=1}^{i=2} \pi_t^i + 0.507 \sum_{i=1}^{i=2} Q_t^i * (N^{HBT} - N_{cost}^{HBT}) \quad i = \text{HBT}_1\text{, HBT}_2 \tag{5.35}$$

$$Max;\ \pi_t^{CMB+SLPA} = \sum_{i=1}^{i=3} \pi_t^i + 0.15\ \sum_{i=1}^{i=2} \pi_t^i + 0.507 \sum_{i=1}^{i=2} Q_t^i * (N^{HBT} - N_{cost}^{HBT}) \quad \forall i \tag{5.36}$$

$$\pi_t^{JCT} = V * \left[Q_t^{JCT} * \left(MPC_t^{JCT} - C^{JCT}\right) + \left(Q_t^{SAGT} * TF_t^{SAGT}\right) + \left(Q_t^{CICT} * TF_t^{CICT}\right)\right] + \sum_{i=1}^{i=m^h} Q_t^i * (N^{CMB} - N_{cost}^{CMB}) \tag{5.37}$$

$$\pi_t^i = V * \left[Q_t^i * (MPC_t^i - TF_t^i - C^i)\right] \qquad i = \text{SAGT, CICT} \tag{5.38}$$

$$US_t^i = 0.5\left[(GC_{t-1}^i - GC_t^i)(Q_{t-1}^i + Q_t^i)\right] \qquad \forall i \tag{5.39}$$

Where;

π_t^i Profit (USD) of terminal i in t^{th} decision-making period ($i =$ JCT, SAGT, CICT, HBT_1, HBT_2). However, π_t^{CMB} and π_t^{SLPA} represent the total profit of Colombo port and the profit of SLPA, respectively;

Q_t^i The demand for terminal *i* in t^{th} decision-making period;

US_t^i User surplus (USD) from terminal *i* in t^{th} decision-making period; However, US_t^{CMB} indicates the user surplus of Colombo port and $US_t^{CMB+HBT}$ indicates the combined user surplus of Colombo and Hambantota ports, respectively;

SS_t^i Social surplus (USD) from terminal *i* in t^{th} decision-making period; However, SS_t^{CMB} indicates the total social surplus of the Colombo port;

N^h Navigation charges (USD) of port *h* paid by the shipping lines to the port authority;

N_{cost}^{h} Cost of the port authority in providing navigation services;

C^{i} Operating cost of terminal *i* (USD/TEU).

5.3.1.4 Decision making by the GTO

Since the previous section discusses the objectives of the port authority, this section discusses the objectives for the decision-making of the GTO, which is the CMPH. As discussed earlier, CMPH operates three container terminals; HBT_1, HBT_2 and CICT and with the majority of stake in Hambantota port, it can influence the handling charges at HBT_1 and HBT_2 as well. Therefore, when considering the pricing decisions of CMPH, the handling charges of HBT_1 and HBT_2 terminals in Hambantota port and that of CICT in Colombo port are decided by CMPH in each of its decision-making period as a discount made to the average container handling charges (handling charges in the absence of this pricing strategy), as given with Equation (5.40). Thus, we use x_t^i as a decision variable to decide the price level at terminal i in period *t*, which is decided by the CMPH for its all three terminals. Therefore, the handling charge of CICT is influenced by the decisions of both the SLPA and CMPH. Since the administrative structure of the Hambantota port is different from a landlord port with concession terminals owing to the 99 years leasing agreement, we assume that HBT_1 and HBT_2 are not required to pay terminals fees to the port authority, as per the terms of the agreement between them.

$$MPC_t^i = MPC_{avg}^i - \gamma * ln(x_t^i) \qquad i = \text{HBT}_1, \text{HBT}_2, \text{CICT} \qquad (5.40)$$

$$0 \le x_t^i \le M \qquad i = \text{HBT}_1, \text{HBT}_2, \text{CICT} \qquad (5.41)$$

The terminal pricing decisions of the CMPH are analyzed with two different objectives namely, maximizing total profit and maximizing total demand of the company (CMPH) from the focused market, as given by Equation (5.42) and (5.43), respectively. When calculating the total profit and the demand of the CMPH, we consider all three terminals, HBT_1, HBT_2 and CICT operated under this company. As a GTO, it is reasonable to assume a profit maximization objective with CMPH and the profit is calculated with Equation (5.42) considering its shares from both container terminals and the navigation services at the Hambantota port together with the profit of CICT in Colombo port. However, when considering the transshipment market in South Asia, as a new market player who competes with the established hub port status of the Colombo port, the CMPH would consider the maximizing the total demand of the company from this market, which is analyzed as an alternative objective for CMPH with Equation (5.43). Moreover, since GTOs have strong interests in expanding their market share after entering a new market, it is reasonable to assume the total demand maximization as an alternative objective of the CMPH.

$$Max;\ \pi_t^{CMPH} = \Big[V * \Big[0.85\Big[\big[Q_t^{HBT_1} * \big(MPC_t^{HBT_1} - C^{HBT_1}\big)\big] + \big[Q_t^{HBT_2} * \big(MPC_t^{HBT_2} - C^{HBT_2}\big)\big]\Big] + \big[Q_t^{CICT} * (MPC_t^{CICT} - TF_t^{CICT} - C^{CICT})\big]\Big]\Big] + 0.493\big[(Q_t^{HBT_1} + Q_t^{HBT_2}) * (N^{HBT} - N_{cost}^{HBT})\big] \quad (5.42)$$

$$Max;\ Q_t^{CMPH} = \big[Q_t^{HBT_1} + Q_t^{HBT_2} + Q_t^{CICT}\big] \quad (5.43)$$

Where;

π_t^{CMPG}	Profit (USD) of the CMPH in t^{th} decision-making period;
Q_t^{CMPG}	The total demand of terminals operated under CMPH in t^{th} decision-making period.

5.3.1.5 Calculation Process for the Pricing Decisions with Multiple Periods

Since we focus on the theoretical contribution by analyzing behaviors of the port authority and a GTO, a unilateral decision-making process is assumed. Therefore, only one decision-maker either port authority or GTO makes the decisions on terminal prices in one period and the other decision-maker makes the decisions in the following period. As an example, if we assume four decision-making periods for the pricing strategy, starting from $t = 0 < 1 < 2 < 3 < 4$, where $t = 0$ represents the initial stage, the first mover makes the pricing decisions in periods 1 and 3, and the follower decides in periods 2 and 4 (Ishii et al., 2013). The yearly decision-making periods are assumed because the port of calls in liner services are planned on a yearly basis. For the model development, we assumed the port authority as the first decision-maker due to its strong interest in creating benefits on all port users and the GTO as the follower of this pricing strategy. As illustrated in Figure 5.14, with the given market condition at the initial period *n* (initial period *n* = 0), the port authority, SLPA makes the pricing decisions for terminals in Colombo in period *n+1* based on its one of the focused objective functions out of seven possible objectives given in Figure 5.12. Due to the pricing decisions of SLPA, the handling charges (prices) of three terminals operated in Colombo port are changed, which eventually changes the market shares and profits of all terminals and both ports in the focused study area. The results from the SLPA's decisions in period *n+1* are used as exogenous for updating the market condition for the period *n+2.*

Subsequently, the CMPH makes the terminal pricing decisions for HBT_1, HBT_2, and CICT in period *n+2* considering the updated market condition given from the SLPA's decisions made in the previous period. Repeating the same process, the decisions of CMPH change the prices of HBT_1, HBT_2, and CICT, while influencing the market shares and profits of all terminals and both ports and these results are used to update the market condition. Thereafter, the SLPA modifies its previous decisions in period *n+3* considering the reaction from the CMPH made in the previous period. However, in the case of CICT, its handling charge is influenced by the decisions of both SLPA and CMPH because CICT is a private terminal in Colombo port, although it is operated by the CMPH. Thus, when deciding the handling charge of CICT, both SLPA and CMPH consider the updated discounted handling charge of CICT derived from the decisions made by the other decision-maker in the previous period. Except for the CICT, since the prices of all other terminals are influenced by only one decision-maker either SLPA or CMPH, their prices are decided in each period as a discount made to the initial price, which is the average price in the absence of this pricing strategy (MPC_{avg}^{i}). Only in the case of CICT, the MPC_{avg}^{CICT} is changed when setting the updated market condition for decision-making while taking the amount of discounts made by the other decision-maker to the initial terminal price (MPC_0^i) into consideration. Both the SLPA and CMPH unilaterally modify their previous decision in the respective decision-making period considering the updated market condition. This decision-making process continues for several periods until both decision-makers, SLPA and CMPH do not change their pricing decisions unilaterally. Thus, the terminal prices are considered as stable if the changes in pricing decisions of each decision-maker between its two consecutive decision-making periods $\left|\frac{(x_{n+2}^i - x_n^i)}{x_n^i}\right|$ are less than 0.001% for all terminals under its consideration (Lin et al., 2017). This is reasonable because, at this condition, a decision-maker does not have to modify its previous pricing decision as the pricing decision of the other decision-maker remains unchanged.

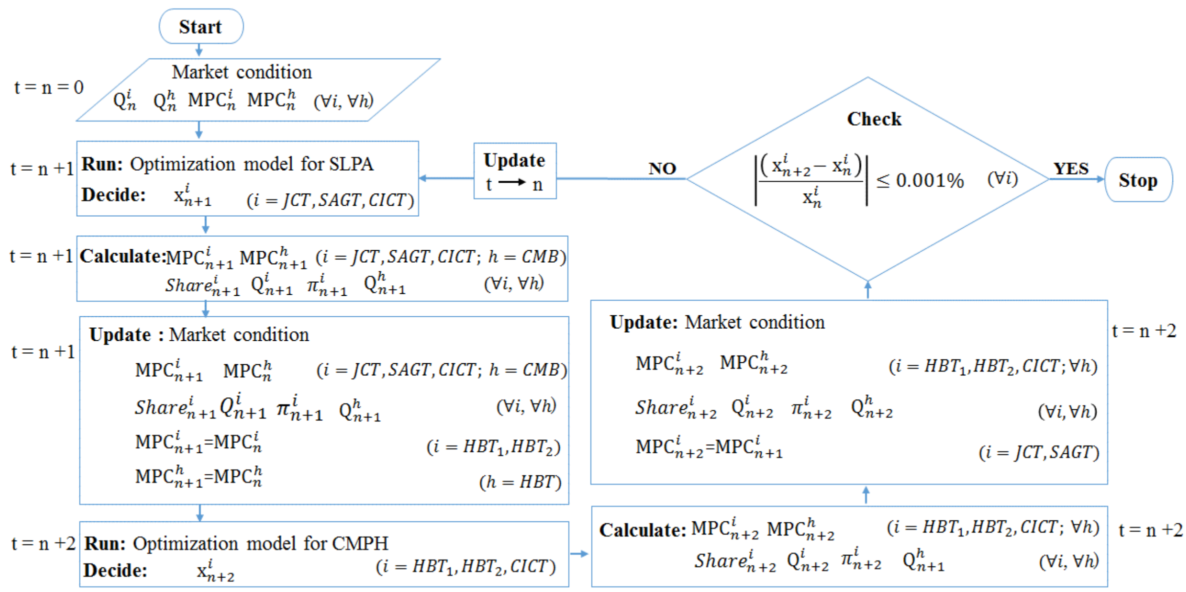

Figure 5.14. Calculation Process for the Pricing Decisions with Multiple Periods

Thus, the repeated decision-making of SLPA and CMPH can be expressed more clearly with Figure

5.15 considering strategy matrixes related to them with a unilateral decision-making process similar to Chapter 3. Accordingly, the strategy options of SLPA and CMPH are represented in columns and rows respectively. When considering strategy options, the very first row ($x_{n+1}^{JCT} = 0,\ x_{n+1}^{SAGT} = m, x_{n+1}^{CICT} = M - m$) and very first column ($x_{n}^{CICT} = M,\ x_{n}^{HBT_1} = 0, x_{n}^{HBT_2} = 0$) can be considered as pure cooperation approaches because SLPA offers the highest rebates on two private terminals despite its direct operation with the public terminal and CMPH offers the highest discount on CICT instead of two terminals in Hambantota. These pricing decisions would significantly reduce the average price of the Colombo port and enhance its competitiveness than the Hambantota port. However, on the contrary, the last row ($x_{n+1}^{JCT} = M,\ x_{n+1}^{SAGT} = 0, x_{n+1}^{CICT} = 0$) and the last column ($x_{n}^{CICT} = 0, x_{n}^{HBT_1} = m, x_{n}^{HBT_2} = M - m$) represent the extreme levels of competitive approaches because SLPA offers discounts only with the public terminal and CMPH does not support to reduce the average price level of Colombo because it does not reduce the price of CICT at all. Thus, when making pricing decisions (discounts and rebates), SLPA and CMPH choose different combinations of discounts and rebates for individual terminals under their consideration focusing on given alternative objectives in Figure 5.12. Depending on the unilateral decisions made by one decision-maker, the market condition is updated. When SLPA makes the pricing decisions, it can choose the alternative strategies given within a particular column as specified by the decisions made by CMPH in the previous period. Similarly, the alternative strategies of CMPH are limited within a given row as specified by the decisions made by SLPA in the previous period. This process continuous between SLPA and CMPH for multiple decision-making periods to understand the effectiveness of their coopetition.

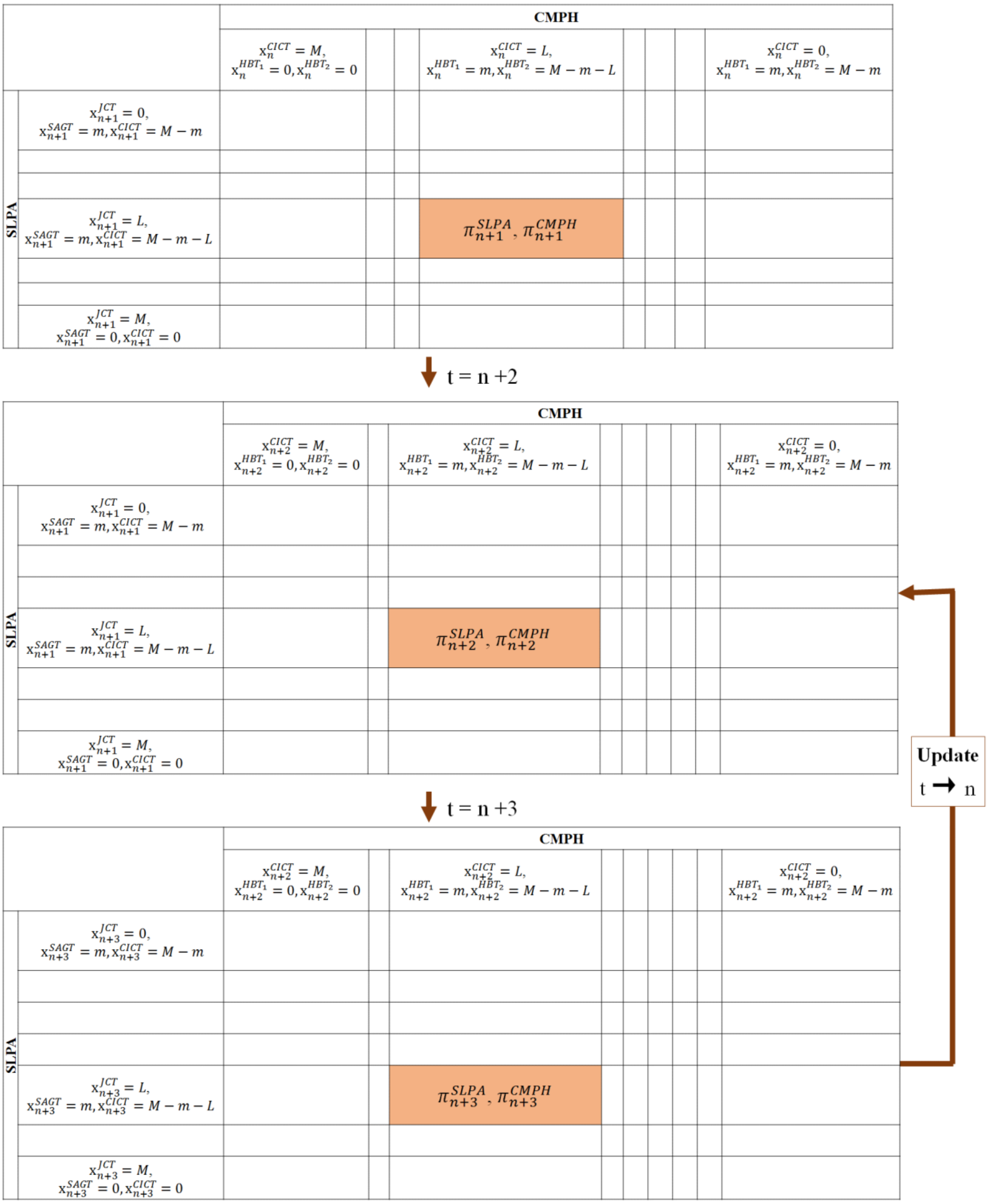

Figure 5.15. Unilateral Decision-Making for the Coopetition Strategy

Since the pricing decisions are made considering the updated market condition given by the previous period, the system can be considered as a dynamic system with multiple stages in decision-making. Therefore, the objective function of a decision-maker is given in Equation (5.44) as an example in the case of maximizing total port demand. Details formulations on the objective functions are given in Appendix G. Accordingly, we can observe that total demand of a port is influenced by the handling charges at individual terminals, their market share from the total port demand, total ports' demand from the previous period, and some other fixed components that are not varied with the time. As per Equation (4.46), the individual terminal's market share is affected by its handling charges, terminal demand in the previous period and some other fixed components. Accordingly, the total port demand is ultimately affected by the individual terminals' handling charges and the updated market condition given from the previous period. However, similar to Chapter 3, this updated market condition is affected by the pricing decisions made by the other player in the previous period. Therefore, in each period, the objective function of a decision-maker is affected by its decisions made in the current period and the decisions made by the other player in the previous period, which implies the relationship between decision-making periods. Similarly, when we consider the total profit of a port as an example for the objective function, the total profit of Colombo port can be given as Equation (5.47) as a function of handling charges at three terminals in Colombo, their demand and terminal fees which are varied with the time. The demand at individual terminals can be given in Equation (5.48) as a function of terminals' market share from the total port, handling charges and ports' demand from the previous period. Following Equation (5.46), since individual terminals' market shares are affected by their handling charges and the updated market conditions, the terminal demand is ultimately affected by their handling charges in the current period, and pricing decisions made by the other player (CMPH) in the previous period. Therefore, the total profit of the Colombo port can be given as a function of terminals' pricing decisions made by SLPA in the current period and the pricing decisions made by CMPH in the previous period.

Thus, as per the system of equations given for each objective function, the optimization model can be expressed a function of decision-variables related to the current period, and those related to the previous period. For instance, when SLPA has the total demand maximization objective of Colombo port in period t, the objective function of this optimization model is affected by the x_t^{JCT}, x_t^{SAGT}, x_t^{CICT} made by SLPA in period t and x_{t-1}^{JCT}, $x_{t-1}^{HBT_1}$, $x_{t-1}^{HBT_2}$ made by CMPH in period $t-1$. Similarly, when we consider the pricing decisions of CMPH in period $t-1$, the optimization model is affected by the x_{t-1}^{JCT}, $x_{t-1}^{HBT_1}$, $x_{t-1}^{HBT_2}$ made by CMPH in period $t-1$ and the x_{t-2}^{JCT}, x_{t-2}^{SAGT}, x_{t-2}^{CICT} made by SLPA in period $t-2$. Since the demands and profits of ports and terminals can be expressed as functions of pricing decisions made for terminals in the current period and the updated market condition given from previous period, the remaining objectives mentioned in Figure 5.12 such as user surplus, social surplus of ports and terminals also can be expressed as functions of terminals' pricing decisions and the updated market condition. However, to maintain the brevity, those objective functions are expressed only in abstract form in Equations (5.32) - (5.36) and Equations (5.42) - (5.43).

$$TS_t^h = \sum_{f=1}^{f=12} TS^f * \frac{e^{\left[\frac{\sum_{i=1}^{i=m^{(f.least)}}(Share_t^i * MPC_t^i) * \left[1+\frac{\left[L^{(j,f,least)}+e*Q_{t-1}^{(f,least)}\right]}{SS_{(Port\ Charges)}}\right]}{\sum_{i=1}^{i=m^{(f.h)}}(Share_t^i * MPC_t^i) * \left[1+\frac{L^{(j,f,h)}+e*Q_{t-1}^{(f,h)}}{SS_{(Port\ Charges)}}\right]}\right]}}{\sum_{h=1}^{h=2} e^{\left[\frac{\sum_{i=1}^{i=m^{(f.least)}}(Share_t^i * MPC_t^i) * \left[1+\frac{\left[L^{(j,f,least)}+e*Q_{t-1}^{(f,least)}\right]}{SS_{(Port\ Charges)}}\right]}{\sum_{i=1}^{i=m^{(f.h)}}(Share_t^i * MPC_t^i) * \left[1+\frac{L^{(j,f,h)}+e*Q_{t-1}^{(f,h)}}{SS_{(Port\ Charges)}}\right]}\right]}} \tag{5.44}$$

$$L^{(j,f,h)} = \sum_{j=1}^{j=2}\left[D^{(j,f,h)} * \frac{SS_{(j)}}{(\sum_{h=1}^{h=2} D^{(j,f,h)}/2)}\right] +* \sum_{w=1}^{w=4}\left[T^{(w,f,h)} * \frac{SS_{(w)}}{(\sum_{h=1}^{h=2} T^{(w,f,h)}/2)}\right] - \left[PPI_0^{(f,h)} - e * Q_0^{(f,h)}\right] \tag{5.45}$$

$$Share_t^i = \frac{e^{-\theta\left[\left(V*MPC_t^i\right)+N^h+a\left(\frac{Q_{t-1}^i * T^i}{0.8*K^i}\right)^b\right]_t^i}}{\sum_{i=1}^{i=m^h} e^{-\theta\left[\left(V*MPC_t^i\right)+N^h+a\left(\frac{Q_{t-1}^i * T^i}{0.8*K^i}\right)^b\right]_t^i}} \tag{5.46}$$

$$\begin{aligned} Max;\ \pi_t^{CMB} = \Big[V & * \left[Q_t^{JCT} * \left(MPC_t^{JCT} - C^{JCT}\right) + \left(Q_t^{SAGT} * TF_t^{SAGT}\right) + \left(Q_t^{CICT} * TF_t^{CICT}\right)\right] \\ & + \sum_{i=1}^{i=m^h} Q_t^i * (N^{CMB} - N_{cost}^{CMB})\Big] + V \\ & * \left[Q_t^{SAGT} * (MPC_t^{SAGT} - TF_t^{SAGT} - C^{SAGT})\right] + V \\ & * \left[Q_t^{CICT} * (MPC_t^{CICT} - TF_t^{CICT} - C^{CICT})\right] \end{aligned} \tag{5.47}$$

$$Max; Q_t^i$$

$$= Share_t^i * \left[\sum_{f=1}^{f=12} TS^f * \frac{e^{\left[\frac{\sum_{i=1}^{i=m^{(f.least)}}(Share_t^i * MPC_t^i) * \left[1+\frac{\left[L^{(j,f,least)}+e*Q_{t-1}^{(f,least)}\right]}{SS_{(Port\ Charges)}}\right]}{\sum_{i=1}^{i=m^{(f.h)}}(Share_t^i * MPC_t^i) * \left[1+\frac{L^{(j,f,h)}+e*Q_{t-1}^{(f,h)}}{SS_{(Port\ Charges)}}\right]}\right]}}{\sum_{h=1}^{h=2} e^{\left[\frac{\sum_{i=1}^{i=m^{(f.least)}}(Share_t^i * MPC_t^i) * \left[1+\frac{\left[L^{(j,f,least)}+e*Q_{t-1}^{(f,least)}\right]}{SS_{(Port\ Charges)}}\right]}{\sum_{i=1}^{i=m^{(f.h)}}(Share_t^i * MPC_t^i) * \left[1+\frac{L^{(j,f,h)}+e*Q_{t-1}^{(f,h)}}{SS_{(Port\ Charges)}}\right]}\right]}}\right] \Big/ V \tag{5.48}$$

Since we update the market condition in each period to analyze the pricing decisions with multiple periods, the results of the current period will influence future decisions as well. The consideration of multiple decision-making periods is significant for understanding this pricing behavior of each player made in response to each other until they reached the stable price levels. Although we analyze multiple periods considering only two local ports due to our main focus on analyzing their pricing decisions made in response to each other, there is a possibility of market share shift to/from external completive ports located outside the country. Therefore, the implications of these pricing decisions would be varied depending on the related market condition given by external competitors. Since our main focus is on analyzing their behavior with different objectives to clarify the coopetition at both the intra-port and inter-port level, we will discuss the implications and conclusions only by considering the pattern of variations of significant variables.

5.3.2 Results and Discussion for Objective [5.2]

This section discusses the results derived from the Objective [5.2] considering profit and demand maximization objectives of CMPH and multiple objectives of SLPA. The analysis of Objective [5.2] requires certain input data and assumptions. First, we assume the average handling TEUs per vessel call (V) as 1200 TEUs based on statistics from Colombo, owing to the consideration of aggregate market demand in terms of the number of vessel calls. This is reasonable because our main focus is on the theoretical contribution from Objective [5.2]. Besides, a small value equals to 0.05 is assumed as γ since we consider a hypothetical scenario as a terminal pricing strategy. Therefore, we focus on the variations of significant results among cases rather than interpreting exact numerical values because we treat all cases with similar parameters and similar calculation process. Besides, when deciding a parameter for the logit function, θ, we incorporate the actual vessel handling statistics of three terminals in Colombo port and sensitivity analysis. Then, the value of θ is assumed as 0.003. Since we aim to analyze the decision-making behaviors of the port authority and a GTO, all terminals are assumed to have equal charges; USD 42 at the initial period, which is taken from the official port tariff published by the Colombo port. The initial demand for each port is taken from the results of Objective [5.1] and all terminals operated within a given port are assumed to have equal handling volumes at the initial period. Since we analyze the interactions between the port authority and a GTO, it is important to make such assumptions for the initial market condition, thus the impacts of their pricing decisions can be understood more precisely because those decisions are not greatly affected by the initial market condition, rather affected by the updated market condition given from the decisions made by each other.

5.3.2.1 Decision-making when CMPH maximizes total company demand

This section discusses the pricing decisions made by the SLPA and CMPH when considering the total demand maximization objective of CMPH and all different objectives of SLPA. Table 5.3 summarizes the pricing decisions made by the SLPA on three terminals in Colombo where the terminals received with highest to least amounts of rebates/incentives are listed from top to bottom, considering each objective of SLPA. Moreover, terminals highlighted in gray color do not receive any rebates/incentives on price reduction. Accordingly, besides the SLPA's total profit maximization objective, for all other objectives, CICT receives the highest amount of rebates on terminal fee, which allows CICT to reduce its price than the other terminals in Colombo. This is reasonable because, with the SLPA's objectives such as maximizing profit, demand and user surplus of Colombo port, the SLPA is motivated to offer more rebates on CICT since it has the least operating cost and the highest time efficiency when compared to other terminals in Colombo port. Owing to a similar reason, when SLPA focuses on maximizing Colombo port's total profit, it does not reduce the price of JCT and SAGT. However, when SLPA focuses on maximizing only SLPA's own profit, it reduces only the price of the public terminal, JCT to enhance its competitiveness because JCT is directly operated by the SLPA, thereby it generates a major portion of the SLPA's profit. Thus, SLPA does not reduce the prices of other two private terminals in Colombo port with its profit maximization objective, because the offerings of rebates on the terminal fee for private terminals would directly reduce the profit of SLPA. Besides, SLPA may try to balance its interests on both ports with its profit maximization objectives rather than focusing only on Colombo port's competitiveness by reducing Colombo's average handling charge because SLPA also receives a portion of the profit from Hambantota port's operation as well.

Table 5.3. Rebates/ Incentives Given by SLPA when CMPH Maximizes Total Demand

Rebates/ Incentives	Both Ports US	CMB Total Demand	CMB Total Profit	CMB Total Profit and SLPA's HBT Profit	CMB Total SS	SLPA Total Profit	CMB Total US
Highest	CICT	CICT	CICT	CICT	CICT	JCT	CICT
↓	SAGT	SAGT	JCT/SAGT	JCT/ SAGT	SAGT	CICT/SAGT	SAGT
Least	JCT	JCT			JCT		JCT

Next, the pricing decisions of CMPH are summarized in Table 5.4 with its total demand maximization objective together with various objectives of SLPA. Accordingly, the CMPH reduces the handling charges of HBT_1, HBT_2, and CICT when the SLPA focuses on maximizing both ports' user surplus, Colombo's total profit, Colombo's total social surplus, and the SLPA's total profit. However, with the remaining objectives of SLPA, the CMPH reduces the prices of only HBT_1 and HBT_2. This is reasonable because the SLPA offers the highest amount of rebates to the CICT with these objectives as per Table 5.3, which may discourage CMPH in reducing the price of CICT by own incentives since CMPH can receive the benefits from the already discounted price at CICT made by SLPA while behaving as a free rider.

Table 5.4. Rebates/ Incentives Given by CMPH when CMPH Maximizes Total Demand

Rebates	Both Ports US	CMB Total Demand	CMB Total Profit	CMB Total Profit and SLPA's HBT Profit	CMB Total SS	SLPA Total Profit	CMB Total US
Highest	HBT_1	HBT_2	HBT_1	HBT_1	HBT_1	HBT_2	HBT_2
↓	HBT_2	HBT_1	HBT_2	HBT_2	HBT_2	HBT_1	HBT_1
Least	CICT	CICT	CICT	CICT	CICT	CICT	CICT

Although we compare the SLPA's and CMPH's decisions on terminal pricing considering the highest and least amounts of rebates/incentives given by them, it is also important to identify the objectives associated with the least and highest prices of individual terminals. Therefore Table 5.5 summarizes the SLPA's objectives which give the least to highest prices associated with each terminal after reaching the stability in pricing decisions when CMPH aims to maximize its total demand. Accordingly, both JCT and SAGT have the highest handling charges with multiple objectives of SLPA in where the SLPA does not offer any incentives/rebates on price reduction of these two terminals. The least handling charges of JCT and SAGT are derived when SLPA maximizes SLPA's own profit and Colombo total user surplus, respectively. Since the handling charge of CICT is influenced by the decisions of both SLPA and CMPH, its least and highest handling charges are derived when SLPA focuses on maximizing "total profit of Colombo and SLPA's portion of profit from Hambantota port" and SLPA focuses on maximizing SLPA's own profit, respectively. When considering the average handling charges at the Colombo port, the least and highest handling charges are derived when SLPA focuses on maximizing Colombo port's total user surplus and maximizing Colombo port's total profit, respectively. Such results are reasonable because the user surplus maximization objective may encourage port service providers to offer services at a low and affordable price while the profit maximization objective may discourage them to reduce the handling charges. Thus, the SLPA reluctant to reduce prices especially at SAGT and CICT when it has profit maximization objectives.

Next, when considering the handling charges of terminals operated in Hambantota port, HBT_1 and HBT_2 have the least handling charges when SLPA focuses on maximizing Colombo port's total social surplus and Colombo port's total user surplus, respectively. However, HBT_1 and HBT_2 have the highest handling charges when SLPA focuses on maximizing Colombo port's total user surplus and Colombo port's total social surplus, respectively. This implies that CMPH maintains a trade-off relationship between the handling charges of two terminals in the Hambantota port to maintain a competitive average charge for the entire port. However, when considering the handling charges at Hambantota port in average, the least handling charge is derived when the SLPA focuses on maximizing "Colombo's total profit and SLPA's profit from Hambantota port", which is reasonable because the comparatively high handling charges of JCT and SAGT with this objective of SLPA may encourage CMPH to maintain comparatively lower average handling charges at Hambantota port to obtain large market share when competing with Colombo. Owing to similar reasons, CMPH maintains comparatively high handling charges at the Hambantota port on average when SLPA focuses on maximizing Colombo port's total user surplus, which generates the least average handling charges at the Colombo port. Thus, rather than perfectly competing by average port charges, a CMPH tries to take advantage of the least or highest average handling charges of both Colombo and Hambantota ports while balancing interests on both ports because it has its own terminals operated in both ports. This kind of behavior would be different from a general price competition between two independent competing market players because usually, a port operator tends to reduce own price when its competitor reduces the price in a price-sensitive market because they do not have conflicting interests on both ports, unlike a GTO, who has own terminals in both competing ports, thus have to balance the interests on both ports.

Table 5.5. Summary of Pricing Decisions when CMPH Maximizes Total Demand

Price	JCT	SAGT	CICT	CMB Average	HBT_1	HBT_2	HBT Average
Least	SLPA Total Profit	CMB Total US	CMB Total Profit and SLPA's HBT Profit	CMB Total US	CMB Total SS	CMB Total US	CMB Total Profit and SLPA's HBT Profit
Highest	CMB Total Profit/ CMB Total Profit and SLPA's HBT Profit/ CMB Total SS	SLPA Total Profit/ CMB Total Profit/ CMB Total Profit and SLPA's HBT Profit	SLPA Total Profit	CMB Total Profit	CMB Total US	CMB Total SS	CMB Total US

5.3.2.2 Decision-making when CMPH maximizes total company profit

Since the results related to the total demand maximization objective of CMPH together with multiple objectives of SLPA are discussed in the previous section, this section discusses the results when CMPH focuses on maximizing its total profit. Similar to the previous case, the decisions of SLPA are summarized in Table 5.6. Accordingly, although SLPA gives the highest rebates on CICT in most cases with the total demand maximization objective of CMPH, the SLPA gives the highest rebates on SAGT in some cases such as maximizing Colombo port's total demand, and Colombo port's total user surplus, with the total profit maximization objective of CMPH. This is reasonable because the CMPH does not change the prices of HBT_1, HBT_2, and CICT with its profit maximization objective although it changes the prices of these terminals with its total demand maximization objective. Since CMPH does not reduce the price of Hambantota port's terminals, the SLPA offers least rebates on CICT when it maximizes Colombo port's total demand or user surplus because the SLPA does not have motivations to significantly reduce the Colombo port's average price.

Table 5.6. Rebates/ Incentives Given by SLPA when CMPH Maximizes Total Profit

Rebates	**Both Ports US**	**CMB Total Demand**	**CMB Total Profit**	**CMB Total Profit and SLPA's HBT Profit**	**CMB Total SS**	**SLPA Total Profit**	**CMB Total US**
Highest	CICT	SAGT	CICT	CICT	CICT	JCT	SAGT
↓	SAGT	JCT			SAGT		JCT
Least	JCT	CICT	JCT/SAGT	JCT/ SAGT	JCT	CICT/SAGT	CICT

With the total profit maximization objective of CMPH, the SLPA's objectives which generate the least and highest handling charges at each terminal are summarized in Table 5.7. Since CMPH does not change the prices of own terminals with its profit maximization objective, the handing charges of HBT_1 and HBT_2 remain unchanged. The least handling charge of JCT is received when SLPA maximizes SLPA's own profit, which is reasonable because SLPA reduces only the handling charges of JCT with this objective. However, the highest handling charge of JCT is received with multiple objectives of SLPA, in which SLPA does not reduce the handling charges of JCT. Similar to the previous case with the total demand maximization objective of CMPH, the two private terminals, SAGT and CICT have high handling charges when SLPA aims to maximize SLPA's own profit because the offering of rebates on terminal fees to reduce handling charges of these two private terminals would significantly reduce the SLPA's profit. However, the least handling charges of SAGT and CICT are received when SLPA focuses on maximizing Colombo port's total demand and Colombo port's total profit, respectively. When considering the average handling charges at the Colombo port, the least charge is received when SLPA focuses on maximizing Colombo port's total user surplus, which is reasonable because the reduction of handling charges would increase the user surplus by reducing the shipping line's generalized cost and increasing terminal's demand. The highest average handling charge at Colombo port is received when SLPA focuses on maximizing "Colombo's total profit and SLPA's profit from Hambantota port", could be due to the SLPA's interest on balancing profits from both ports, which discourages SLPA on significantly reducing handling charges of Colombo's terminals. This is reasonable because the reduction of handling charges in Colombo would reduce the SLPA's revenue, although the higher demand of Colombo port generated with lower handling charges would increase the SLPA's revenue from navigation services.

Table 5.7. Summary of Pricing Decisions when CMPH Maximizes Total Profit

Price	JCT	SAGT	CICT	CMB Average
Least	SLPA Total Profit	CMB Total Demand	CMB Total Profit	CMB Total US
Highest	CMB Total Profit/ CMB Total Profit and SLPA's HBT Profit/ CMB Total SS	SLPA Total Profit/ CMB Total Profit/ CMB Total Profit and SLPA's HBT Profit	SLPA Total Profit	CMB Total Profit and SLPA's HBT Profit

5.3.2.3 Resulting profits with terminal pricing decisions

Since the profits of individual terminals/ports and the profits of two decision-makers are significantly influenced by the pricing decisions, the variations of these profits are discussed in this section with different objectives of CMPH and SLPA. Figure 5.16 illustrates the variations of total profits of Colombo and Hambantota ports with two different objectives of CMPH together with multiple objectives of SLPA. Accordingly, the Colombo port generates a higher profit with the total profit maximization objective of CMPH than with the total demand maximization objective of CMPH. However, the variations of Colombo port's total profit with both objectives of CMPH follow nearly a similar pattern, where the lowest profit of Colombo port is received when SLPA focuses on maximizing SLPA's total profit. The highest profit of Colombo port is received when SLPA focuses on maximizing total social surplus of Colombo, which is reasonable as this objective increases the profits of all three terminals at Colombo port and reduces their generalized cost due to the user surplus component in social surplus function, which eventually generates a high demand for Colombo.

Although the variations of Colombo port's profits follow nearly a similar pattern with both objectives of CMPH, the variations of Hambantota port's profits are significantly different from the two objectives of CMPH. The least profit of the Hambantota port with the profit maximization objective of CMPH is derived when SLPA focuses on maximizing Colombo port's total user surplus. The least profit of the Hambantota port with the demand maximization objective of CMPH is derived when SLPA focuses on maximizing both ports' user surplus. It is reasonable for Hambantota port to receive comparatively higher profits when SLPA focuses on maximizing "Colombo's total profit and SLPA's profit from Hambantota port" and maximizing SLPA's total profit because the SLPA's total profit consists with a share of Hambantota port's profit as well. Moreover, except for the SLPA's objective on maximizing Colombo port's total profit, for all other objectives of SLPA, the Hambantota port's profit with the total demand maximization objective of CMPH is higher than its profit with the profit maximization objective of CMPH.

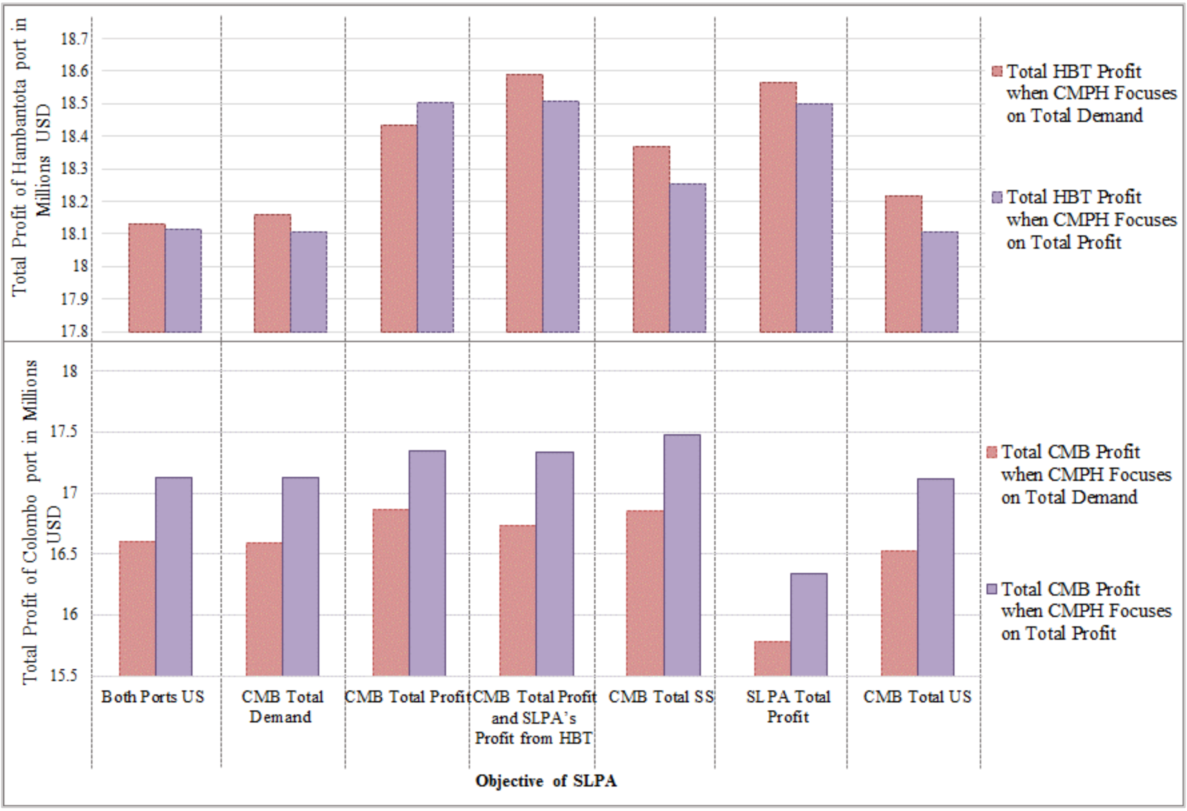

Figure 5.16. Resulting Profits of Colombo and Hambantota Ports

Next, the variations of the resulted profits of two decision-makers; SLPA and CMPH are illustrated in Figure 5.17. When comparing the results from Figure 5.16 and Figure 5.17, it is reasonable for SLPA to receive the highest profit when it focuses on maximizing its own profit, although this objective generates the least total profit for the Colombo port. This happens because the SLPA does not offer rebates on the terminal fee for two private terminals with its profit maximization objective, and only reduces the price of the public terminal. Such behavior of SLPA reduces the total profit of Colombo port by reducing its demand owing to the high average port charges because SLPA tries to balance the interests on both ports. As per the profit of CMPH, it receives higher profit when SLPA focuses on maximizing "Colombo port's total profit" and "Colombo port's total profit and SLPA's profit from Hambantota port". However, CMPH receives the least profit when SLPA maximizes SLPA's own profit, possibly because SLPA decides not to offer any rebates on price reduction at CICT.

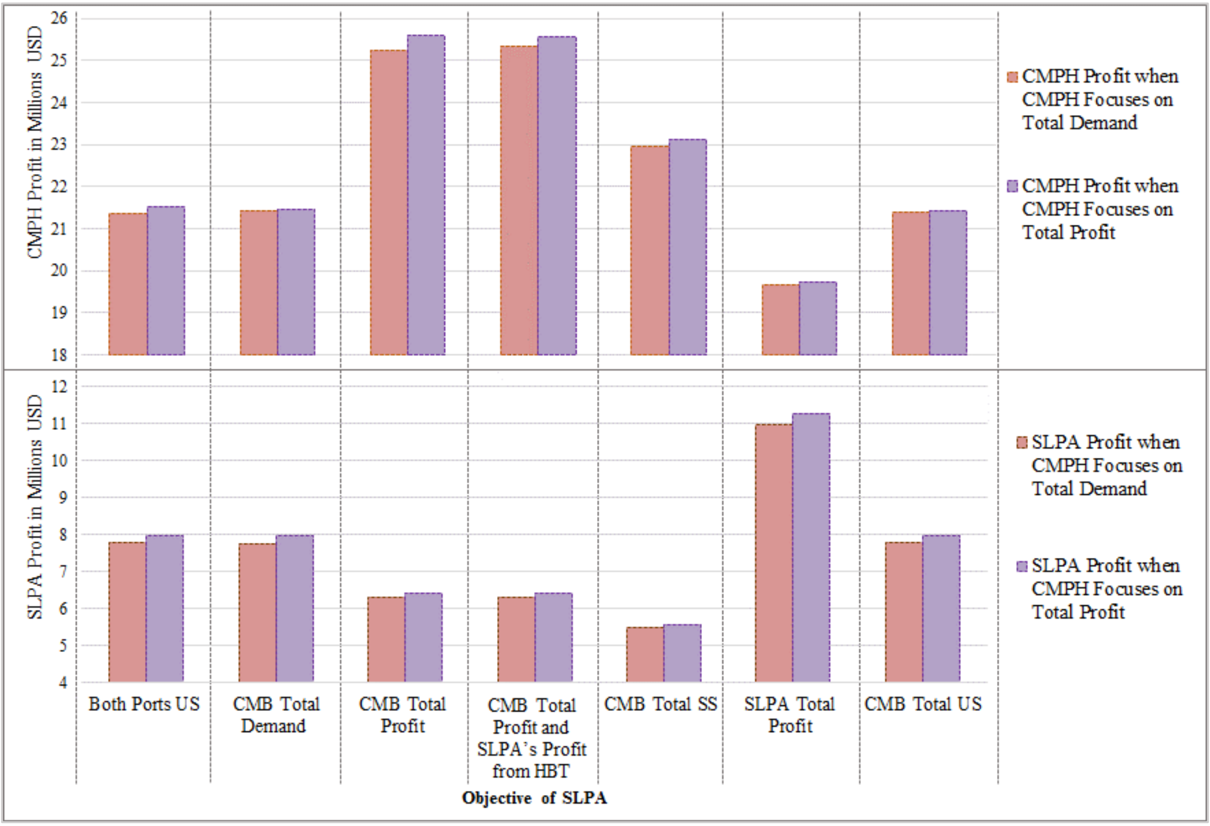

Figure 5.17. Resulting Profits of SLPA and CMPH

5.3.2.4 Resulting demands for ports and terminals with pricing decisions

Since the demands for ports and terminals are affected by the pricing decisions, resulting demands are summarized in Figure 5.18 considering a situation after reaching to the stable price levels, which imply a constant price level at each terminal because both the SLPA and CMPH do not further change their terminals' pricing decisions. Thus, results at the end of the 10th decision-making period are summarized considering each objective of the SLPA together with the total demand maximization and total profit maximization objectives of CMPH, given in the upper and lower panels of the figure. The distribution of total port demand among its three terminals is considered in the case of Colombo, together with the total demand of Hambantota port and the total demand of CMPH represented by different color codes.

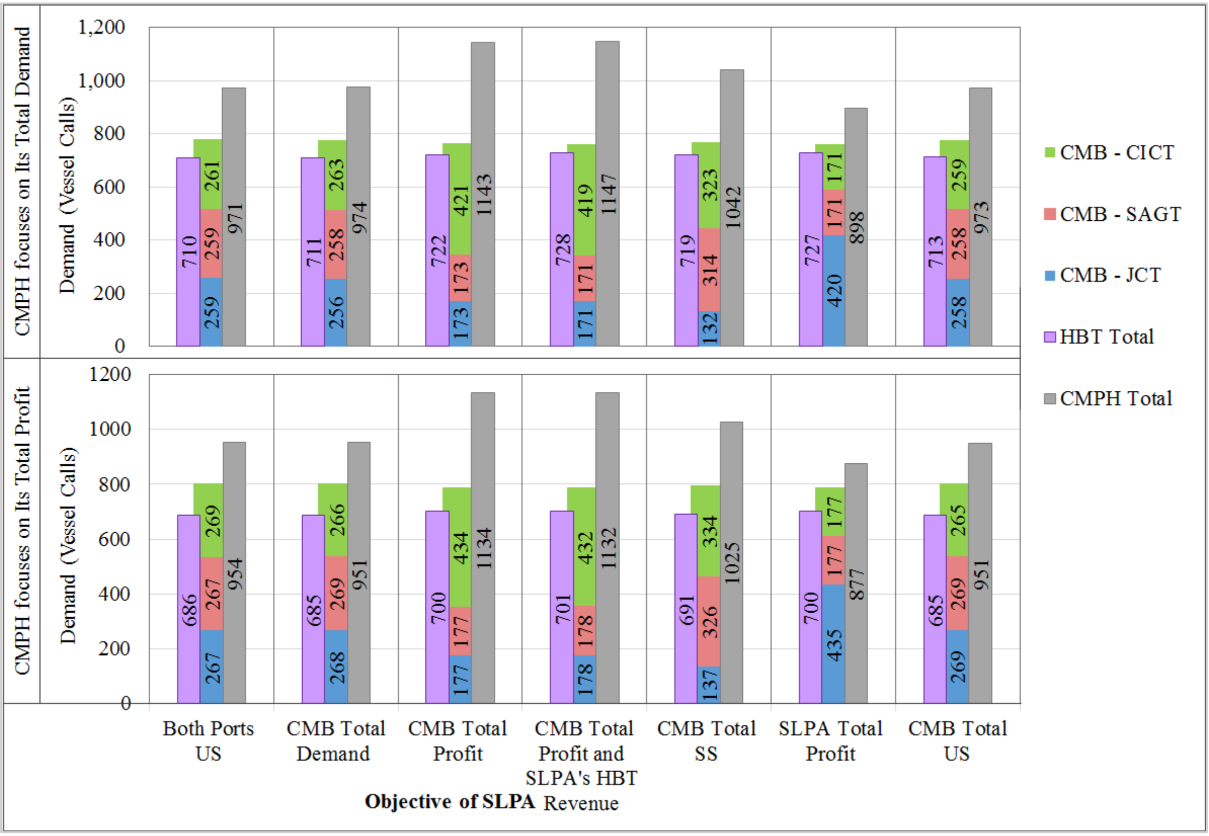

Figure 5.18. Resulting Demands for Ports and Terminals

As mentioned earlier, since we followed the calculation process with all objectives in a similar manner, we mainly compare the results from different objectives of SLPA and CMPH rather than interpreting resulted quantitative values. Accordingly, with both objectives of CMPH, the Colombo port receives the least demand when SLPA focuses on maximizing "Colombo's total profit and SLPA's profit from Hambantota port" although Colombo port receives comparatively high demand when SLPA focuses on maximizing the both ports' user surplus, Colombo port's total demand, and the Colombo port's user surplus. The highest demand of CMPH with its total demand maximization objective is received when SLPA maximizes "Colombo's total profit and SLPA's profit from Hambantota port" and the highest demand of CMPH with its total profit maximization objective is received when SLPA maximizes the Colombo port's total profit. This is reasonable because the CICT receives significantly higher demand than JCT and SAGT with those objectives of SLPA while increasing the total demand of CMPH.

5.4 Conclusions of Chapter 5

5.4.1 Conclusions and Policy Implications from Objective [5.1]

The Objective [5.1] discusses the potential competitive scenario between Colombo and Hambantota ports on both the domestic and transshipment container handling if the Hambantota port is developed as a major container port. The import/export container handling at both ports is analyzed with the domestic cargo flow analysis considering the generalized cost of local shippers and consignees and the transshipment container handling at both ports is analyzed with the transshipment cargo flow analysis considering the shipping lines' port selection decisions. The impacts on local shippers and consignees, shipping lines and the port operators are discussed with the scenario analysis. As per the results, a high attractiveness of Colombo for the domestic container handling and that of Hambantota for the transshipment container handling are revealed. Although Hambantota's market share can be slightly increased with its access road development and progressive tariff policy, the shippers and consignees still prefer Colombo as the main gateway port. Although Colombo's higher efficiency generates its 52% of market share in transshipment handling, the Hambantota port receives a 59% of market share in transshipment handling after improving its port efficiency equal to the level of Colombo and a 61% of market share after reducing its transshipment handling charges. Thus, results derive significant implications on the policymakers who engaged in Sri Lankan port development aspects to secure a substantial benefit to the country's economy.

Moreover, the shippers' and consignees' most favorable distribution of domestic container handling market shares between two ports may not be practically realized depending on the ports' transshipment market shares. Although the concentration of liner services at the Hambantota port would increase the costs for local shippers and consignees, Sri Lanka would not retain major revenue from this port. Despite the initial development plan on Hambantota port as an industrial port, the recent administrative and ownership changes with the involvement of CMPH would encourage the development of its container handling facilities, especially considering its strategic location with the China's Belt and Road initiative and the 99 years long duration of the Hambantota port's leasing agreement. The development of two large scale container ports would split the liner services between them while reducing the Colombo port's network connectivity than the other external hub ports. Although there is ongoing planning on future expansion of the Colombo port including the Colombo North port development project with additional 10 million TEUs capacity, the massive investments on both ports may not be economically viable for a country with less than 25% of captive cargo share in the total container throughput, due to the potential unhealthy competition between these two ports. Besides, the Indian container ports are being developed for accommodating large container vessels, which can significantly reduce the transshipment volume handled in Sri Lanka, while causing serious impacts due to Sri Lanka's high dependency on Indian feeder market.

Despite the negative impacts from the Hambantota port's agreement signed in 2017, this agreement released Sri Lanka's financial liability to China, which is a dominant economy in the world, while maintaining the goodwill between these two countries. As the results highlight Colombo's vulnerability, its efficiency should be strengthened to ensure the country's direct economic benefits. However, if the Hambantota port experiences a large-scale development, its inland accessibility should be improved to minimize the disutility of shippers and consignees. Besides, since two ports have distinct advantages in domestic and transshipment container handling, functional allotment between them can be done if Hambantota experiences large scale development while establishing efficient land transport or feeder services between these two ports. In transshipment container handling, since the Colombo port has advantages in the Indian West-coast and South-coast and the Hambantota port has advantages in the East-coast feeder market, instead of competing, these two ports may collaborate on a discriminant pricing strategy in their target markets. Thus, Colombo port may compete over the external competitors, Salalah and Jebel Ali ports, etc which serve the Indian West-coast and South-coast feeder markets. Further, the Hambantota port may compete with the hub ports in Singapore and Malaysia, targeting on the East-coast feeder market. With that, both ports can receive high benefits than their unhealthy competition in the transshipment market and the SLPA and the country's economy would be better off. These kinds of functional allotments between ports are introduced as possible ways of coopetition between ports by previous studies (Song, 2002; Song, 2003; Yan-Bo, 2012; Zhong et al., 2010) and such arrangement can reduce the disadvantages of extreme competition between ports while promoting Sri Lanka as a maritime hub in the region.

5.4.2 Conclusions and Policy Implications from Objective [5.2]

The Objective [5.2] analyses the behaviors of the port authority and a GTO. We developed a multi-period decision-making model aligned with a terminals' pricing scenario, such that both the port authority and a GTO offer rebates/incentives for reducing handing charges at own individual terminals, by considering the reactions from each other. The model is applied to the Colombo and Hambantota ports in Sri Lanka considering the SLPA as the port authority and CMPH as the GTO, who has its own terminals in both competing ports. The pricing decisions are analyzed considering multiple objectives associated with each decision-maker and significant implications are discussed.

As the significant findings, although CMPH changes the prices of its terminals with the total demand maximization objective, it does not change the terminal prices with its profit maximization objective. When summarizing the results with the total demand maximization objective of CMPH, the

SLPA tends to offer the highest amount of rebates on CICT with its most objectives except the SLPA's profit maximization objective, in where SLPA reduces the price of only the public terminal, JCT to increase its direct profit. When SLPA maximizes its own profit, it does not reduce the prices of two private terminals because the offerings of rebates on the terminal fee for private terminals would directly reduce the profit of SLPA. Since a portion of SLPA's profit comes from the Hambantota port as well, SLPA tries to balance the interests on both ports rather than increasing only the Colombo port's competitiveness by reducing handling charges. When the SLPA offers the highest amount of rebates on CICT, CMPH tends to behave as a free rider and does not reduce the price of CICT by its own incentives because CMPH can receive the benefits from the already discounted price at CICT made by SLPA. The least and highest average handling charges of Colombo port are derived when SLPA focuses on maximizing Colombo port's total user surplus and Colombo port's total profit, respectively. Rather than perfectly competing by average port charges, the CMPH tries to take the advantages of the least or highest average port charges of Colombo while balancing interests on both ports because it has its own terminals operated in both ports. Such behavior is different from pure price competition between two independent competing market players because generally, they do not have conflicting interests on both competing ports.

Since CMPH does not reduce the prices of own terminals with its profit maximization objective, the SLPA tends to reduce the amount of rebates given on CICT. When considering the average handling charge at the Colombo port with the profit maximization objective of CMPH, the least charge is received when the SLPA focuses on maximizing Colombo port's total user surplus, which is reasonable because the reduction of handling charges would increase the user surplus by reducing shipping line's generalized cost and increasing port's demand. The highest average handling charge at Colombo port is received when SLPA focuses on maximizing "Colombo's total profit and SLPA's profit from Hambantota port", could be due to the SLPA's interest on balancing profits from both ports, which discourages SLPA on reducing handling charges at Colombo's terminals. The Colombo port generates a higher profit with the profit maximization objective of CMPH than the demand maximization objective of CMPH. The variations in Colombo port's total profit with both objectives of CMPH follow nearly a similar pattern, where the lowest and highest profits of Colombo port are received when SLPA focuses on maximizing SLPA's total profit and maximizing total social surplus of Colombo port, respectively. Accordingly, a pure profit maximization objective is not suitable for a port authority because it generates the least profit for the Colombo port. The least profit of Hambantota port with the profit maximization and total demand maximization objectives of CMPH are derived when SLPA focuses on maximizing Colombo port's total user surplus and maximizing both ports' user surplus, respectively. Therefore, the user surplus maximization objective of the port authority of a port can significantly reduce the profit of a competing port. Except for the SLPA's objective on maximizing Colombo port's total profit, for all other objectives of SLPA, the Hambantota port's profit with the total demand maximization objective of CMPH is higher than its profit with the profit maximization objective of CMPH. The CMPH receives the least profit when SLPA focuses on maximizing SLPA's own profit, possibly due to the SLPA's decision on not offering any rebates on price reduction at CICT.

The Colombo port receives comparatively high demand when SLPA is having Colombo port's user surplus or demand maximization objectives. The least demand of Colombo port is received when the SLPA maximizes the "Colombo's total profit and SLPA's profit from Hambantota port" despite the differences in the objective of CMPH. However, CMPH receives comparatively high demand when SLPA maximizes "Colombo's total profit and SLPA's profit from Hambantota port" and Colombo port's total profit could be due to the comparatively higher demand obtained by CICT from those objectives.

5.5 Limitations of Chapter 5

As the limitations of Chapter 5, the analysis of scenarios with Objective [5.1] was done with several assumptions because we consider the potential competitive situation between Colombo and Hambantota ports in Sri Lanka as the focused case study. Although the analysis with Objective [5.1] is done for the domestic and transshipment cargo flows separately to understand the most favorable situation for the local shippers and consignees and the related impacts from transshipment cargo flow, further studies may incorporate both the domestic and transshipment cargo flows into a single model, while considering all relevant decision-makers involved in establishing cargo flows among ports. Although this chapter analyzes the competition between two local ports without considering external competing ports in the market located outside the country, such external competitors can make significant influences on this competition scenario due to the possible shifts of demand among the ports. Moreover, the analysis is done considering only short-haul hub and spoke network due to the current significant role of Colombo in this network type. However, as a GTO, there is a possibility that CMPH focuses on medium or long-haul network types to attract a strong cargo-based rather than competing with existing hub status of Colombo, thus further studies can consider the different range of network types including both medium and long-haul network types as well to understand the competitive position of Colombo and Hambantota ports in transshipment market. The analysis with Objective [5.2] mainly considers the theoretical contribution and makes several assumptions on pricing strategy, unilateral decision-making process, and initial market condition, among others. Therefore, only the variations of significant results are considered rather than interpreting their numerical values. Although we analyzed the pricing decisions with several objectives of the decision-makers, the developed equations on objective functions of the port authority and GTO could be changed when applying to a different case study due to the changes in profit components, and the ownership structures, among other. Although we developed a multi-period decision-making model, we utilized the results from a perception-based survey with shipping lines for evaluating the significance of port selection criteria and the performance of ports, thus the results of the model can be changed if these perceptions are changed with the time. Besides, the scope of the study is limited to the liner shipping market and does not consider the growth of other industries in Sri Lanka related to bulk and industrial cargo which can influence the competition between Colombo and Hambantota ports in Sri Lanka.

Note: Related Journal Publications from Chapter 5

- ✓ Kavirathna, C.A., Kawasaki, T. and Hanaoka, S. (2018) Transshipment hub port competitiveness of the port of Colombo against the major Southeast Asian hub ports. The Asian Journal of Shipping and Logistics, 34 (2): 71–82. https://doi.org/10.1016/j.ajsl.2018.06.004
- ✓ Kavirathna, C.A., Kawasaki, T., Hanaoka, S. and Matsuda, T. (2018) Transshipment hub port selection criteria by shipping lines: the case of hub ports around the Bay of Bengal. Journal of Shipping and Trade, 3 (4). https://doi.org/10.1186/s41072-018-0030-5

CHAPTER 6: CONCLUSIONS

The burgeoning rise of port-based trade and the engagements of ports and terminals in major sea routes have increased the demand for time, efficiency and the scale of operation in container vessel handling facilities at ports. Considering the significance of maintaining effective interactions among ports and terminals with the challengers given by the contemporary nature of the liner-shipping industry, this study discusses the coopetition for both the intra-port and inter-port levels. The decision-making behaviors of the terminal operators, port authority, and GTOs with different ownership types and objectives, and the interests of shipping lines and shippers and consignees are discussed considering numerical analysis and case studies as well.

6.1 Summary of Chapters and Significant Findings

After understanding the background of this study, its objectives and motivations with Chapter 1, the literature review in Chapter 2 clarifies the current research gap and the positioning of this study. Therefore, this dissertation consists of three main analysis chapters, given from Chapter 3 to Chapter 5 with different objectives related to the specific case under consideration. Hence, the interpretation of the coopetition strategy and its value creation and value appropriation are different in each chapter. Table 6.1 summarizes the main focus, analysis method, type of problem and the decision-makers associated with each chapter. As discussed by Ritala et al. (2014), there is no defined basic model for the coopetition and the coopetition-based business models are naturally depended on the goals and motivation on coopetition. Since several previous studies discuss the coopetition with its two main components namely; value creation and value appropriation, we consider different strategies on value creation and value appropriation in each chapter to represent the cooperative and competitive approaches, respectively, as summarized in Table 6.2.

In Chapter 3, we analyzed the coopetition among terminal operators in a single port while considering its impacts on the external competitors. Owing to the lack of previous studies, this chapter mainly focuses on the theoretical contribution by introducing the intra-port coopetition and numerical analysis was carried out with eleven different cases that are varied based on the different extents of profit and social surplus maximization objectives of the private and public terminal operators in a single port. This chapter employs a budget allocation problem, where each terminal allocates its available budget on competitive and cooperative efforts depending on its objective. Therefore, the value creation by terminals in one port is done with their cooperative budget allocation on enhancing the entire port competitiveness with different strategies such as combined marketing effort, and single window system, among others. In terms of individual value appropriation, a terminal makes a budget allocation on enhancing the own terminal performance with three alternative approaches; price adjustment, operation cost reduction, and time efficiency improvement at own terminal.

Table 6.1. Summary of Chapters

	CHAPTER 3	CHAPTER 4	CHAPTER 5
Focus	Impacts of intra-port coopetition on external competitors	Impacts of intra-port coopetition on the port competitiveness	Impacts of coopetition considering the inter-port level
Analysis	Numerical analysis	Case study on the Port of Colombo	Case study on the Colombo and Hambantota ports
Problem	Budget allocation problem	Vessel transfers between terminals and revenue sharing	Terminal pricing scenario
Decision-makers	Terminal operators	Terminal operators and the port authority (policy making)	Port authority and a GTO

As the significant findings from Chapter 3, a difference between coopetition decisions of a private terminal with a profit maximization objective and a public terminal with a user surplus maximization objective could be observed because the private terminal does not allocate all available budget on the coopetition especially when increasing the available budget limit and increasing the returns from cooperative efforts, although the public terminal with user surplus maximization objective allocates all available budget on the coopetition strategy. Terminals reduce the price down to a certain minimum level and tend to maintain a constant price level thereafter. Besides, terminals do not have interests in coopetition strategy at a very large market size owing to their capacity constraints. When the coopetition strategy is executed between two private terminals, they focus on value creation with cooperative budget allocation at the beginning but after increasing the entire port market size, subsequently, they focus more on the value appropriation with budget allocation on enhancing own terminal's performance. When there is a public-private terminal combination in a port, the private terminal behaves as a free-rider if the public terminal focuses highly on common value creation especially with its user surplus maximization objective. Besides, the port authority can receive high incentives from terminals on enhancing the port competitiveness if both terminals are public terminals with user surplus maximization objectives. When the coopetition strategy is executed between public and private terminals with their user surplus and profit maximization objectives, respectively, the external competing port experiences the lowest profit. The market shares and profits of ports and terminals with coopetition strategy are varied depending on the ownership types and objectives of terminal operators.

Table 6.2. Value Creation and Value Appropriation Focused by Individual Chapters

Chapter	Value Creation by Cooperation	Value Appropriation by Competition
CHAPTER 3	Cooperation among terminals in one port with budget allocation on reducing the cost of all port users with different strategies; ✓ Combined marketing effort ✓ Inter-terminal transfer system ✓ Single window system	Competition among terminals with budget allocation on enhancing the performance of own terminals with different strategies; ✓ Price Adjustment: discounts, rebates ✓ Operation Cost Reduction ✓ Time efficiency improvement
CHAPTER 4	Cooperation among terminals in one port on enhancing the competitiveness of the entire port by reducing average waiting time, berthing delays and congestion at terminals	Competition among terminals in one port to obtain a greater number of vessel calls from shipping lines towards the individual terminals
CHAPTER 5	Incentives/rebates given by the port authority on terminals in one port to, ✓ Maintain a competitive average price for the entire port ✓ Enhance the total user surplus, social surplus, profit of the port Pricing decisions made by a GTO on own terminals located in two competing ports, ✓ When acting as a part of the entire port	Incentives/rebates given by the port authority on terminals in one port to, ✓ To maximize individual profit Pricing decisions made by a GTO on own terminals located in two competing ports; ✓ To maximize the total profit or demand of a GTO

Chapter 4 considers the effectiveness of the coopetition strategy with a vessel transfer policy among terminals in one port to enhance the port competitiveness, which is analyzed as a case study on the Port of Colombo. The coopetition strategy is defined as the presence of competitive interactions during the contract stage, to obtain a high number of vessel calls towards the individual terminals although terminals have cooperative interactions during the operation stage when handling container vessels to reduce delays and congestion at terminals. The value creation is defined in terms of enhancing the overall port competitiveness by reducing delays and congestion at the terminals, which is important when competing with other external ports in the market while the value appropriation is defined with competitive interactions during the contract stage. After discussing the effectiveness of the vessel transfer policy with a game theoretical decision-making approach with the first objective, the second objective analyzes the vessel transfer decisions of terminals and policy scenarios with a mixed-integer programming model for minimizing total penalty cost related to berthing delays and maximizing combined profit of all terminals.

As the significant findings from Chapter 4, it is observed that the coopetition strategy among all three terminals generates the highest benefits for all terminals and the public terminal, JCT receives the highest number of transfer vessels from other two private terminals. However, the coopetition strategy only between two private terminals is found to be unstable. A longer duration of maximum tolerable waiting time and a very low value of penalty charge are not effective because they generate a higher number of penalty calls than the number of vessel transfers while significantly increasing the total delay hours with the total profit maximization objective of terminals. However, the penalty cost minimization objective always generates a higher number of vessel transfers than the penalty calls. Moreover, the policies related to the exception of terminal fees for the vessels transferred from private terminals to the public terminal generate a high number of vessel transfers especially when the public terminal has less number of handling containers from own desired vessels. The coopetition strategy enhances the port competitiveness not only in operational aspects but also in environmental aspects while lowering the vessel emissions at the anchorage area by reducing the total number of delay hours of vessels. Besides, the proposed vessel transfer policy does not create serious equity issues among terminals in terms of profit distribution.

In Chapter 5, we discussed the coopetition situation considering both intra-port and inter-port levels due to the involvement of a GTO, CMPH in two competing ports, Colombo and Hambantota in Sri Lanka, and with the conflicts of interests of the port authority; SLPA and CMPH on both ports. First, the potential competitive scenario between Colombo and Hambantota ports in Sri Lanka is analyzed considering both the domestic and transshipment cargo flows that consider shippers' and consignees' gateway port choices and shipping lines' transshipment port choices, respectively. As its significant contribution, the impacts from transshipment cargo flow on the local shippers and consignees are discussed in a country where the majority of port throughput is represented by transshipment containers. Next, the terminals' pricing decisions of the port authority and a GTO are analyzed considering the impacts on both the port and terminal levels. The common value creation among the terminals in one port and among the terminals owned by the same GTO and the value appropriation due to the different ownership types and objectives are discussed.

As the significant findings from Chapter 5, the first objective highlights the attractiveness of Colombo port as a gateway port for local shippers and consignees although shipping lines prefer Hambantota port for transshipment handling. Besides, the negative impacts on local shippers and consignees were highlighted if the majority of liner services concentrate at the Hambantota port. With the second objective, significant differences in terminals' pricing decisions made by the port authority and GTO are observed when changing their objectives. When the SLPA offers a high amount of rebates on the terminal fee to the CICT, which is operated by CMPH, the CMPH tends to behave as a free rider.

Moreover, the behavior of both the SLPA and CMPH on balancing interests on both ports could be observed especially with their profit maximization objectives, which generate lower profits for both the Colombo and Hambantota ports. Although the demand maximization objective of CMPH reduces the handling charges of its own terminals, its profit maximization objective does not reduce the handling charges. The higher market share of Colombo port could be observed with the user surplus maximization objectives of SLPA.

6.2 Coopetition as a General Framework

After introducing the coopetition with Chapter 1, and studying about previous literature related coopetition with Chapter 2, next Chapters 3, 4 and 5 focused on modeling and application of coopetition to the intra-port and inter-port levels in the liner shipping industry. Therefore, summarizing the entire dissertation, a general framework of coopetition is developed in Chapter 6 incorporating findings from all previous Chapters. Accordingly, we clarify the motivations, market conditions, nature of decision-making, conditions for continuing coopetition strategy, drawbacks and applications of coopetition as summarized in Table 6.3.

Table 6.3. Coopetition as a General Framework

Factors	**Descriptions**
Motivations for coopetition	✓ Possibility to create a common value by a group of competing market players for achieving a win-win situation ✓ Mutual benefits for all players
Number of players and market environment	✓ Two or more competing players ✓ Lower level of individual demand than their available capacities ✓ Market players offer somewhat homogenous services and have similarities in business processors
Nature of decision-making and dynamics	✓ Coopetition relationship changes with the time, so the optimal strategy can be decided upon the current market, rather than long-term planning ✓ Dynamics in early decision-making periods due to the changes in reactions
Condition for continuing coopetition strategy	✓ Ability to erode demand from external competitors ✓ Satisfy the individual rationality of all players participated in coopetition ✓ Advantages by retaining the benefits received from coopetition ✓ Positive externalities generated with induced demand
Drawbacks of coopetition	✓ Opportunities for free-riders when the objectives and ownership types are different

	✓ Risk in transparency and information sharing among competing players
Applications of coopetition in ports and terminals	✓ Port infrastructure and operational improvement ✓ Resource-based argumentation by the usage of supplementary and complementary resources in an integrated approach ✓ Port pricing, discount strategies, and concession charging

6.3 Policy Implications and Recommendations

The findings from each of the main analysis chapter of this dissertation derive significant policy implications and recommendations as follows.

Although the results of Chapter 3 are derived based on numerical analysis, significant implications and recommendations can be discussed as follows. Since terminals tend to reduce the price down to a certain minimum level, the port authority may enforce minimum price level or price ceilings to maintain a competitive average price for the entire port while simultaneously encouraging the price discounts or rebates made by individual terminals. Since the private terminal does not spend all available budget on the coopetition in some situations, the port authority may use some policy instruments with an effective framework on utilizing cooperative budget allocated by terminals to promote the coopetition. When a port faces high competition from external competitors, its terminal operators can focus on a win-win solution by having cooperative interactions on common value creation on the entire port that enables eroding some market share from external competitors, while simultaneously having competitive interactions on individual value appropriation. Besides, when a port has a market-leading public terminal, the coopetition strategy can support the growth of the private terminals in the same port considering long-term positive externalities.

The results from Chapter 4 derive significant policy implications especially due to the issues with long vessel waiting at ports, causing waste of time and cost of shipping lines. Thus, by channeling both competition and cooperation, this chapter speaks to the very pertinent challenges in the domain today. Thus, the port authority can encourage vessel transfers between terminals with appropriate policy instruments such as terminal fee exception for transfer vessels, especially when the public terminal has idle container berths available. To perceive additional benefits such as emissions reduction of vessels at anchorage, the port authority should decide a short duration of maximum tolerable waiting time and sufficiently penalty charge when deciding policies related to the penalty charge. However, a very high value of penalty charge is not economical because it drastically reduces the terminals' profit and creates conflicts between the port authority and terminal operators although it cannot further reduce berthing delays beyond an optimal level. Since the proposed vessel transfer policy significantly reduces the berthing delays and enhances the terminal utilization, the additional supportive services such as effective inter-terminal transport systems, and compatibility of terminal information systems, among others can be facilitated with the involvement of the port authority.

As the policy implications derived from Chapter 5, although the negative impacts on local shippers and consignees could be observed when shipping lines concentrate more liner services at Hambantota port than the Colombo port, the majority of revenue from Hambantota port would not be retained in Sri Lanka due to its 99 years lease owned by CMPH. Although it is significant to maintain the competitiveness of Colombo port to ensure direct economic benefits to the country, the massive developments on two container ports may not be feasible for Sri Lanka especially due to its role as a transshipment hub that requires high network connectivity. Since CMPH tries to take advantage of high and low average prices at Colombo port while balancing interests on both ports rather than encouraging extreme price competition between Colombo and Hambantota ports, it may not be economical for SLPA to perceive pure user surplus maximization objectives focusing only on Colombo. However, since the Colombo port receives a considerable low market share when SLPA aims to maximize own profit, such extreme profit maximization objectives may not be appropriate for the port authority. Although the private terminals in Colombo port are not directly operated by the SLPA, the rebates given on terminal fee can significantly increase the market share of entire Colombo port due to the reduction of the average port charges, thus the port authority may consider different incentives/ rebates on private terminals to enhance the entire port performance. Since the offering of rebates can significantly reduce the SLPA's own revenue, the SLPA should balance the amount of rebates given on private terminals and the benefits received by enhancing entire port demand considering both profit and non-profit objectives.

Considering the entire dissertation, since we focus on interactions and decision-making behaviors of players related to container ports and terminals, several recommendations can be discussed as follows. Similar to many other industries and organizations, there is a gap between the idealistic situation in decision-making and the practical situations when considering ports and terminals as well. For instance, although we highlighted potential benefits from a vessel transfer policy among terminals in one port considering the maximum possible number of vessel transfers, the decision-making behaviors in a practical situation would not able to generate these maximum benefits due to the conflicts of interests of terminals, port authority and shipping lines as well. To receive high benefits from these proposed coopetition strategies in each chapter, there should be a high level of transparency in decision-making which minimizes the gap between the idealistic situation and practical situation. Besides, in case of the extreme level of intra-port competition, terminal operators may not fully adhere to the published tariffs and charges by the port authority and private terminals may have higher flexibility in deciding charges. Since these handling charges are decided based on the negotiations with shipping lines, sharing such revenue information may be hindered, which may act as a constraint for the coopetition strategy. Therefore, it is important to receive support from the competition policy directives related to port industry behavior to ensure that behaviors of port service providers and their charges are subjected to monitoring by a regulatory tribunal. Apart from handling charges, the quality of services and operation principles must be declared clearly with an agreement between terminal operators and port authority to ensure that the competitiveness of the port is not negatively affected by their individual operations. Considering the advantages of coopetition, provisions related to coopetition can be included in the future concession agreements in container ports to encourage container terminals on such coopetition interactions.

6.4 Future Research Directions

The directions for future research can be discussed by addressing the several limitations of this study and the existing research gap on the coopetition in the liner-shipping industry, which were not discussed in this study, but have potential to be focused by future studies.

✓ ***Decision-makers and inter-organizational relationships***

Although the model development of the current study considers various market players such as terminal operators, port authority, GTO, shipping lines, and shippers and consignees, depending on the selected cases under consideration, the decision-making process in a practical situation could be more complicated due to the various inter-organizational relationships. Especially the strategic changes recently observed from the liner shipping industry such as the formation of shipping lines alliances, liner-own terminals, dedicated terminals, and dedicated feeder operators, among others can be discussed in future studies when analyzing coopetition among ports and terminals. Besides, in Chapter 3 with the multi-period model, we assumed fixed decisions of the external competitors although these external competitors would react to secure their market share in a practical scenario. Hence, further studies may analyze the reactions of external competitors as well.

✓ ***Model development***

Considering the theoretical contribution, the model development of this study assumes several hypothetical scenarios such as budget allocation problem, and incentives/rebates strategies of the port authority and a GTO, among others, which may not fully represent the current industrial practices. Therefore, the analysis with alternative scenarios that have a high representation of the industrial practices can be a possible extension for future research. Besides, the decision-making frameworks of individual chapters are subject to the unilateral decision-making process, thus, further studies may consider the simultaneous decision-making by market players. Since we discussed the variations of significant results by comparing among multiple cases, those were treated in an equal manner rather than interpreting their exact numerical values, the parameters were estimated with sensitivity analysis or referring to the related previous studies. However, further studies may focus on parameter estimation methods as well. With the focus on variations in results among multiple cases, the optimization models are solved with exact methods such as GRE, and Evolutionary algorithm in individual chapters. Therefore, developing an improved heuristic solution algorithm can be possible in future research. Further, currently in Chapter 3 and Chapter 5, the optimization models consider the profits, social surplus or user surplus in a given period as the objective functions for decision-making without considering aggregate benefits from multiple periods. Thus, further studies can consider the decision-making with an objective function associated with multiple periods utilizing a dynamic programming approach. Despite the main contribution of Chapter 3 is to introduce the coopetition to the intra-port level, there can be many aspects for enhancing model development in the future. For instance, the model structure in Chapter 3 can obtain a stochastic user equilibrium situation in the cargo flow allocation assuming a bi-level optimization problem with the terminal operator (upper level) and shipping lines (lower level). Although this study considers a simplified market setting such as two ports in the market with two terminals in each port in Chapter 3 as an example, further studies may consider a more complex market setting that involves multiple players.

✓ ***Dynamics nature of the market, risk, and uncertainties***

The dynamic nature of the market and uncertainties associated with market players' approaches to competition and cooperation can be discussed in future studies especially focusing on potential risk reduction related to the coopetition strategy. Although Chapter 3 and Chapter 5 consider the stable size of the total market, the coopetition behavior can be analyzed considering the variations in total market size as well. Besides, the characteristics of vessels such as the number of TEUs handled, and vessel handling times, among others, are assumed as the average values due to the consideration of aggregate demand rather than considering each individual vessel call in Chapter 3 and Chapter 5. However, incorporating the dynamic nature of the industry propelled by the enlargement of container vessel sizes, further studies may analyze the impacts of coopetition when changing these vessel-specific characteristics as well.

✓ ***Applications with different case studies with updated data***

Although we discussed the policy implications with each chapter, they can be changed if the market condition and data are significantly changed when applying to another case. Therefore, further studies may consider the application of developed models or their improved versions to other cases with different input data. Chapter 5 incorporates the results of a questionnaire survey carried out with shipping lines as the input data. However, these perception-based data can be changed with time due to the changes in market condition and further studies may expand the questionnaire survey with more respondents and criteria. Besides, some policy scenarios are analyzed based on the interviews conducted with port authorities and terminal operators, thus further studies may consider detail interviews including more stakeholders.

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APPENDIX

Appendix A. Verifying the Optimization Solver for Chapter 3

We used the generalized reduced gradient method with the analytical solver platform 2016-C version for solving the coopetition decision of a single terminal operator in Chapter 3. Thus, it is important to verify the appropriateness of the selected method for the mentioned optimization problem. Since the coopetition decision of a terminal operator in Chapter 3 consists of two main decision variables x_t^i and y_t^i, we convert the set of equations from Equation (3.1) to (3.14) as a non-near function, $\pi = f(x, y)$, by assuming the price adjustment scenario as an example. By considering the decision-making of one terminal in a single period, we use x and y to simply represent x_t^i and y_t^i. Moreover, to minimize the complications associated with multiple y values in the objective function, the cooperative effort level (y_t^i) decided by the other terminal in the same port (TO2 as an example) in the previous period is represented as ρ because it is not a variable for the decision-making of the first terminal (TO1). Thus, Equation (A.2) is the objective function of a coopetition decision assuming the profit maximization objective of a terminal operator. The remaining equations represent the different components of Equation (A.2) for convenience.

$$\pi = f(x, y) \tag{A.1}$$

$$\pi = \frac{V \times S \times [W - \gamma \times \ln(x)] \times [e^{-\theta \times (N_1 - V \times \gamma \times \ln(x) - \tau(y+\rho)}]}{\left[e^{-\theta\left(N_1 - V \times \gamma \times \ln(x) - \tau(y+\rho)\right)}\right] + \left[e^{-\theta \times \left(N_2 - \tau(y+\rho)\right)}\right] + L + M} - (x + y) \tag{A.2}$$

$$W = P_{avg} - TF^1 - C^1 \tag{A.3}$$

$$N_1 = V \times P_{avg}^1 + N^{h1} + a\left(\frac{Q_{t-1}^1 \times \beta^1}{0.8 \times K^1}\right)^b \tag{A.4}$$

$$N_2 = V \times P_{t-1}^2 + N^{h1} + a\left(\frac{Q_{t-1}^2 \times \beta^2}{0.8 \times K^2}\right)^b \tag{A.5}$$

$$L = e^{-\theta \times (V \times P_3 + N^{h2} + a\left(\frac{Q_{t-1}^3 \times \beta^3}{0.8 \times K^3}\right)^b} \tag{A.6}$$

$$M = e^{-\theta \times (V \times P_4 + N^{h2} + a\left(\frac{Q_{t-1}^4 \times \beta^4}{0.8 \times K^4}\right)^b} \tag{A.7}$$

$$x + y \leq I_{max}^i \tag{A.8}$$

$$0 \leq x, y \tag{A.9}$$

To verify the appropriateness of the generalized reduced gradient method for the above non-linear optimization problem, we calculate the profit by manually changing the values of x and y within their constraint of maximum available budget ($I_{\max}^i$). To perform the verification with multiple conditions, we repeat the calculations for four different available investment levels as summarized in Table A.1. However, to minimize the calculation time, first, we consider intervals of x and y values within the whole range defined by the maximum available budget. Table A.1 summarizes the results derived from the optimization solver with the generalized reduced gradient method and the results derived by manually changing the x and y without using an optimization solver. As mentioned, first we consider the entire range defined by the maximum available budget to find the intervals of x and y associated with the highest profit. Figure A.1 illustrates an example of the variation of profits with different values of x and y considering USD 15000 as the maximum available budget. Accordingly, the highest range of profit is derived when the values of x and y vary between 4146.45-4297.20 and 10703.80-10854.55, respectively. After finding the intervals of x and y associated with the highest profit range, we repeat the calculation considering this close interval to find a more improved solution. Accordingly, we derived an improved solution with the highest profit when x and y equal to 4185.84 and 5961.87, respectively. A similar process is done considering all four different values of $I_{\max}^{i}$ to obtain the optimal x and y values that associate with the highest profit. When comparing the solutions derived from this manual calculation process and the solutions derived from the optimization solver, we can observe their similarities in all four cases, which confirm the appropriateness of the generalized reduced gradient method with the analytical solver platform 2016-C for solving the above optimization problem.

Table A.1. Verifying the Optimization Solver for Chapter 3

Maximum available investment			**10000**	**15000**	**20000**	**25000**
Frontline Solver-generalized reduced gradient method	x		4038.40	4185.84	4347.85	4525.71
	y		5961.60	10814.16	15652.15	20474.29
	Profit		20509434.21	21340619.71	22154211.61	22947061.88
Calculation by manually changing x and y without using an optimization solver	**Considering the whole range defined by the maximum available investment**					
	Interval x	Lower	3970.45	4146.45	4221.89	4397.81
		Higher	4070.94	4297.20	4422.89	4649.06
	Interval y	Lower	5930.06	10703.80	15578.11	20351.94
		Higher	6030.55	10854.55	15779.11	20603.19
	Reducing the range of x and x defined by the above close interval					
	x		4038.12	4185.84	4348.15	4525.33
	y		5961.87	10813.64	15651.84	20474.41
	Profit		20509432.54	21340534.94	22154209.99	22947020.84

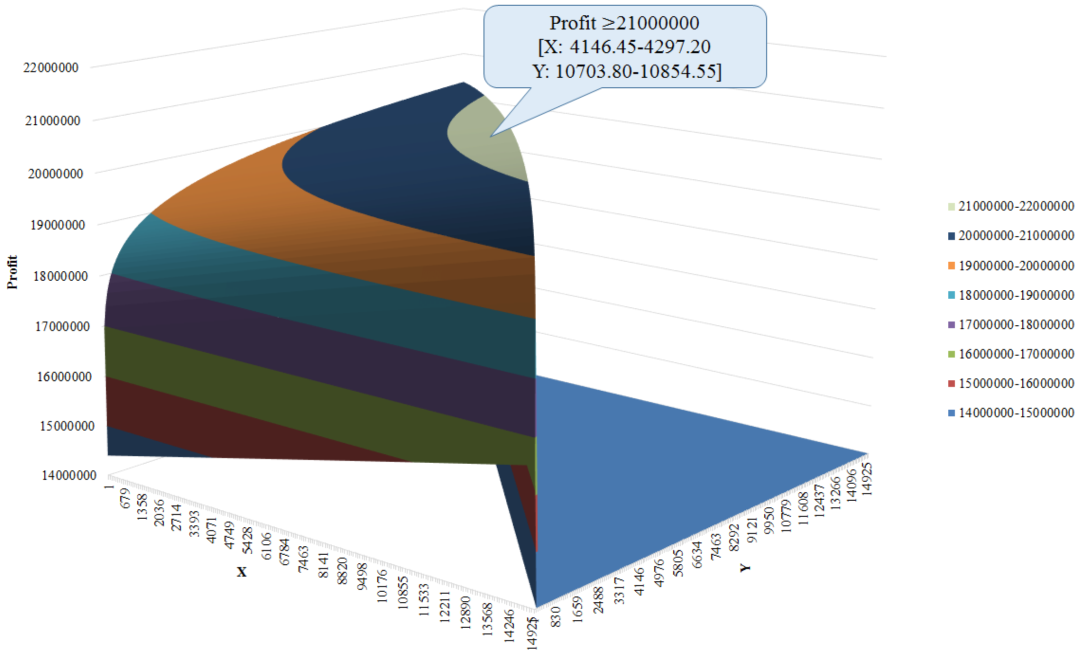

Figure A.1. Profit as a Function of Competitive and Cooperative Effort Levels

Appendix B: Properties of the Objective Function in Chapter 3

$$\pi = \frac{V \times S \times [W - \gamma \times \ln(x)] \times [e^{-\theta \times (N - V \times \gamma \times \ln(x) - \tau(y+\alpha)}]}{[e^{-\theta(N - V \times \gamma \times \ln(x) - \tau(y+\alpha))}] + [e^{-\theta \times (D - \tau(y+\alpha))}] + L + M} - (x + y)$$

$$\frac{\partial \pi}{\partial x} = \frac{\frac{(\gamma . S . V(-\theta . V . W + \gamma . V . \theta . \ln(x) + 1) . e^{-\theta(N - V.\gamma.\ln(x) - h(y+\alpha))})}{x}}{([e^{-\theta(N - V.\gamma.\ln(x) - h(y+\alpha))}] + [e^{-\theta(D - h(y+\alpha))}] + L + M)} - \frac{-(V . S . [W - \gamma . \ln(x)] . [e^{-\theta \times (N - V.\gamma.\ln(x) - h(y+\alpha))}]) \times \frac{[\gamma . V . \theta . e^{-\theta \times (N - V \times \gamma \times \ln(x) - h(y+\alpha))}]}{x}}{([e^{-\theta(N - V.\gamma.\ln(x) - h(y+\alpha))}] + [e^{-\theta(D - h(y+\alpha))}] + L + M)^2} - 1$$

$$\frac{\partial^2 \pi}{\partial^2 x} = \frac{\left[\frac{\theta . \gamma^2 . S . V^2 . (-\theta . V . W + \gamma . V . \theta . \ln(x) + 1) . e^{-\theta(N - V.\gamma.\ln(x) - \tau(y+\alpha)}}{x^2} + \frac{\theta . \gamma^2 . S . V^2 . e^{-\theta(N - V.\gamma.\ln(x) - \tau(y+\alpha)}}{x^2} - \frac{\gamma . S . V . (-\theta . V . W + \gamma . V . \theta . \ln(x) + 1) . e^{-\theta(N - V.\gamma.\ln(x) - \tau(y+\alpha)}}{x^2}\right]}{([e^{-\theta(N - V \times \gamma \times \ln(x) - \tau(y+\alpha))}] + [e^{-\theta \times (D - \tau(y+\alpha))}] + L + M)}$$

$$- \frac{\left(\frac{(\gamma . S . V(-\theta . V . W + \gamma . V . \theta . \ln(x) + 1) . e^{-\theta(N - V.\gamma.\ln(x) - \tau(y+\alpha)})}{x}\right) \times \left[\frac{\gamma . \theta . V . e^{-\theta(N - V.\gamma.\ln(x) - \tau(y+\alpha)}}{x}\right]}{([e^{-\theta(N - V \times \gamma \times \ln(x) - \tau(y+\alpha))}] + [e^{-\theta \times (D - \tau(y+\alpha))}] + L + M)^2}$$

$$- \frac{([e^{-\theta(N - V \times \gamma \times \ln(x) - \tau(y+\alpha))}] + [e^{-\theta \times (D - \tau(y+\alpha))}] + L + M)^2 \times \left[\frac{2 . \gamma^2 . \theta^2 . V^3 . S . (N - V . \gamma . \ln(x) - \tau(y + \alpha) . e^{-\theta \times (N - V \times \gamma \times \ln(x) - \tau(y+\alpha)^2}}{x^2} - \frac{\gamma . \theta . S . V^2 . S . e^{-\theta \times (N - V \times \gamma \times \ln(x) - \tau(y+\alpha)^2}}{x^2}\right]}{([e^{-\theta(N - V.\gamma.\ln(x) - \tau(y+\alpha))}] + [e^{-\theta(D - \tau(y+\alpha))}] + L + M)^4}$$

$$- \frac{\left((V . S . [W - \gamma . \ln(x)] . [e^{-\theta \times (N - V.\gamma.\ln(x) - \tau(y+\alpha)}]) \times \frac{[\gamma . V . \theta . e^{-\theta \times (N - V \times \gamma \times \ln(x) - \tau(y+\alpha)}]}{x}]\right) \times \left[\frac{2 . \gamma . \theta . V . e^{-\theta(N - V.\gamma.\ln(x) - \tau(y+\alpha)} . ([e^{-\theta(N - V \times \gamma \times \ln(x) - \tau(y+\alpha))}] + [e^{-\theta \times (D - \tau(y+\alpha))}] + L + M)}{x}\right]}{([e^{-\theta(N - V.\gamma.\ln(x) - \tau(y+\alpha))}] + [e^{-\theta(D - \tau(y+\alpha))}] + L + M)^4}$$

$$\frac{\partial^2\pi}{\partial^2 x}=\frac{\gamma^2.S.V^2.\ \theta\ .e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha)}}{x^2.\left(\left[e^{-\theta\left(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+L+M\right)}-\frac{\gamma^2.S.\ \theta\ .V^2.\left(-\ \theta\ .V.W+\ \gamma.V.\ \theta\ .\ln(x)+1\right)\times\left[e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha)}\right]^2}{x^2.\left(\left[e^{-\theta\left(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+L+M\right)^2}$$

$$-\frac{\gamma.S.V^2.\ \theta\ .e^{-\theta\times((N-V\times\gamma\times\ln(x)-\tau(y+\alpha))^2}\left[2.\gamma.S.V.\ \theta\ .(N-V.\gamma.\ln(x)-\tau(y+\alpha)-1\right]}{x^2.\left(\left[e^{-\theta\left(N-V.\gamma.\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\left(D-\tau(y+\alpha)\right)}\right]+L+M\right)^2}$$

$$-\frac{2.V^3.\theta^2.\gamma^2.S.\left[e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha)}\right]^3.[W-\gamma\times\ln(x)]}{x^2.\left(\left[e^{-\theta\left(N-V.\gamma.\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\left(D-\tau(y+\alpha)\right)}\right]+L+M\right)^3}$$

$$\frac{\partial\pi}{\partial y}=\frac{(\tau.V.S.\theta.[W-\gamma\times\ln(x)].[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}])}{\left[e^{-\theta\left(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+L+M}-\frac{\left(V\times S\times[W-\gamma\times\ln(x)]\times[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]\right)\times(\tau.\theta.[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]+\tau.\theta.[e^{-\theta\times(D-\tau(y+\alpha)}])}{\left(\left[e^{-\theta\left(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+L+M\right)^2}-1$$

$$\frac{\partial^2\pi}{\partial^2 y}=\frac{h^2.\theta^2.V.S.[W-\gamma\times\ln(x)].[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]}{\left[e^{-\theta\left(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+L+M}-\frac{\left(V.S.h^2.\theta^2.[W-\gamma\times\ln(x)].[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}\right)\times\left[[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]+[e^{-\theta\times(D-\tau(y+\alpha)}]\right]}{\left(\left[e^{-\theta\left(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+L+M\right)^2}-$$

$$\frac{2.V\times S.h^2.\theta^2.e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}\left[[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]+[e^{-\theta\times(D-\tau(y+\alpha)}]\right]}{\left(\left[e^{-\theta\left(N-V.\gamma.\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\left(D-\tau(y+\alpha)\right)}\right]+L+M\right)^2}-$$

$$\frac{-\left((2.V.S.h^2.\theta^2[W-\gamma\times\ln(x)]\times[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}])\times([e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]+[e^{-\theta\times(D-\tau(y+\alpha)}]\right)\times\left[\left[[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]+[e^{-\theta\times(D-\tau(y+\alpha)}]\right]\left[\left[e^{-\theta\left(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+L+M\right]\right]}{\left(\left[e^{-\theta\left(N-V.\gamma.\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\left(D-\tau(y+\alpha)\right)}\right]+L+M\right)^4}$$

$$\frac{\partial^2\pi}{\partial^2 y}=\frac{h^2.\theta^2.V.S.[W-\gamma\times\ln(x)].[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]}{\left[e^{-\theta\left(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+L+M}-\frac{\left(V.S.h^2.\theta^2.[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}\right)\times\left[[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]+[e^{-\theta\times(D-\tau(y+\alpha)}]\right][W-\gamma\times\ln(x)-1]}{\left(\left[e^{-\theta\left(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+L+M\right)^2}$$

$$-\frac{\left(2.V.S.h^2.\theta^2\left[W-\gamma\times\ln(x)\right]\times[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]\right)\times\left[[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]+[e^{-\theta\times(D-\tau(y+\alpha)}]^2\right]}{\left(\left[e^{-\theta\left(N-V.\gamma.\ln(x)-\tau(y+\alpha)\right)}\right]+\left[e^{-\theta\left(D-\tau(y+\alpha)\right)}\right]+L+M\right)^3}$$

$$\frac{\partial^2\pi}{\partial y.\partial x}$$

$$= \frac{\frac{(\gamma.S.V.\ \theta.\tau.(-\theta.V.W+\ \gamma.V.\ \theta.\ln(x)+1).e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha)})}{x}}{([e^{-\theta(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}]+[e^{-\theta\times(D-\tau(y+\alpha))}]+L+M)} - \frac{\left(\frac{(\gamma.S.V(-\theta.V.W+\ \gamma.V.\ \theta.\ln(x)+1).e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha)})}{x}\right)\times\tau.\theta.[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]+\tau.\theta.[e^{-\theta\times(D-\tau(y+\alpha)}]}{([e^{-\theta(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}]+[e^{-\theta\times(D-\tau(y+\alpha))}]+L+M)^2}$$

$$-\frac{([e^{-\theta(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}]+[e^{-\theta\times(D-\tau(y+\alpha))}]+L+M)^2\times(2.\gamma.V^2.\theta^2.\tau.S.[W-\gamma.\ln(x)]).\frac{e^{-2\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}}{x}}{([e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha))}]+[e^{-\theta(D-\tau(y+\alpha))}]+L+M)^4}$$

$$-\frac{\left((V.S.[W-\gamma.\ln(x)].[e^{-\theta\times(N-V.\gamma.\ln(x)-\tau(y+\alpha)}])\times\frac{[\gamma.V.\ \theta.e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]}{x}]\right)\times 2.\tau.\theta.[[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]+[e^{-\theta\times(D-\tau(y+\alpha)}]][[e^{-\theta(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}]+[e^{-\theta\times(D-\tau(y+\alpha))}]+L+M]}{([e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha))}]+[e^{-\theta(D-\tau(y+\alpha))}]+L+M)^4}$$

$$\frac{\partial^2\pi}{\partial y.\partial x} = \frac{[\gamma.S.V.\ \theta.\tau.(-\theta.V.W+\ \gamma.V.\ \theta.\ln(x)+1).e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha)}]}{x.([e^{-\theta(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}]+[e^{-\theta\times(D-\tau(y+\alpha))}]+L+M)}$$

$$-\frac{(\tau.\theta.\gamma.S.V(-\theta.V.W+\ \gamma.V.\ \theta.\ln(x)+1).e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha)})\times[[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]+[e^{-\theta\times(D-\tau(y+\alpha)}]]}{x.([e^{-\theta(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}]+[e^{-\theta\times(D-\tau(y+\alpha))}]+L+M)^2}$$

$$-\frac{(2.\gamma.V^2.\theta^2.\tau.S.[W-\gamma.\ln(x)]).e^{-2\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}}{x.([e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha))}]+[e^{-\theta(D-\tau(y+\alpha))}]+L+M)^2}$$

$$-\frac{((2.\tau.\gamma.V^2.\theta^2.S.[W-\gamma.\ln(x)].[e^{-\theta\times(N-V.\gamma.\ln(x)-\tau(y+\alpha)}])\times[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]])\times[[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]+[e^{-\theta\times(D-\tau(y+\alpha)}]]}{x.([e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha))}]+[e^{-\theta(D-\tau(y+\alpha))}]+L+M)^3}$$

To confirm the concave property of the objective function;

$\gamma.e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha)}$

$$\leq\frac{[e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha)}]^2[\gamma.(-\theta.V.W+\ \gamma.V.\ \theta.\ln(x)+1)-[2.\gamma.S.V.\ \theta.(N-V.\gamma.\ln(x)-\tau(y+\alpha)-1]]}{([e^{-\theta(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}]+[e^{-\theta\times(D-\tau(y+\alpha))}]+L+M)}$$

$$-\frac{2.V.\ \theta.[e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha)}]^3.[W-\gamma\times\ln(x)]}{([e^{-\theta(N-V.\gamma.\ln(x)-\tau(y+\alpha))}]+[e^{-\theta(D-\tau(y+\alpha))}]+L+M)^2}$$

$$\mathrm{W}-\gamma\times\ln(\mathrm{x})\leq-\frac{\left[\left[\mathrm{e}^{-\theta\times(\mathrm{N}-\mathrm{V}\times\gamma\times\ln(x)-\tau(\mathrm{y}+\alpha)}\right]+\left[\mathrm{e}^{-\theta\times(\mathrm{D}-\tau(\mathrm{y}+\alpha)}\right]\right][\mathrm{W}-\gamma\times\ln(\mathrm{x})-1]}{\left(\left[\mathrm{e}^{-\theta\left(N-\mathrm{V}\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[\mathrm{e}^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+\mathrm{L}+\mathrm{M}\right)}-\frac{(2[\mathrm{W}-\gamma\times\ln(\mathrm{x})])\times\left[\left[\mathrm{e}^{-\theta\times(\mathrm{N}-\mathrm{V}\times\gamma\times\ln(x)-\tau(\mathrm{y}+\alpha)}\right]+\left[\mathrm{e}^{-\theta\times(\mathrm{D}-\tau(\mathrm{y}+\alpha)}\right]^{2}\right]}{\left(\left[\mathrm{e}^{-\theta\left(N-\mathrm{V}.\gamma.\ln(x)-\tau(y+\alpha)\right)}\right]+\left[\mathrm{e}^{-\theta\left(D-\tau(y+\alpha)\right)}\right]+\mathrm{L}+\mathrm{M}\right)^{2}}$$

$$\Bigg[\gamma^{2}-\frac{\gamma^{2}.\left(-\theta.\mathrm{V}.\mathrm{W}+\gamma.\mathrm{V}.\ \theta.\ln(x)+1\right)\times\mathrm{e}^{-\theta(\mathrm{N}-\mathrm{V}.\gamma.\ln(x)-\tau(\mathrm{y}+\alpha)}}{\left(\left[\mathrm{e}^{-\theta\left(N-\mathrm{V}\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[\mathrm{e}^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+\mathrm{L}+\mathrm{M}\right)}-\frac{\gamma.\mathrm{e}^{-\theta(\mathrm{N}-\mathrm{V}.\gamma.\ln(x)-\tau(\mathrm{y}+\alpha)}\left[2.\gamma.\mathrm{S}.V.\ \theta.(\mathrm{N}-\mathrm{V}.\gamma.\ln(x)-\tau(\mathrm{y}+\alpha)-1\right]}{\left(\left[\mathrm{e}^{-\theta\left(N-\mathrm{V}\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[\mathrm{e}^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+\mathrm{L}+\mathrm{M}\right)}$$

$$-\frac{2.V.\gamma^{2}.\left[\mathrm{e}^{-\theta(\mathrm{N}-\mathrm{V}.\gamma.\ln(x)-\tau(\mathrm{y}+\alpha)}\right]^{3}.[\mathrm{W}-\gamma\times\ln(\mathrm{x})]}{\left(\left[\mathrm{e}^{-\theta\left(N-\mathrm{V}.\gamma.\ln(x)-\tau(y+\alpha)\right)}\right]+\left[\mathrm{e}^{-\theta\left(D-\tau(y+\alpha)\right)}\right]+\mathrm{L}+\mathrm{M}\right)^{2}}\Bigg]\Bigg[h^{2}.[\mathrm{W}-\gamma\times\ln(\mathrm{x})]-\frac{(h^{2})\times\left[\left[\mathrm{e}^{-\theta\times(\mathrm{N}-\mathrm{V}\times\gamma\times\ln(x)-\tau(\mathrm{y}+\alpha)}\right]+\left[\mathrm{e}^{-\theta\times(\mathrm{D}-\tau(\mathrm{y}+\alpha)}\right]\right][\mathrm{W}-\gamma\times\ln(\mathrm{x})-1]}{\left(\left[\mathrm{e}^{-\theta\left(N-\mathrm{V}\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[\mathrm{e}^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+\mathrm{L}+\mathrm{M}\right)}$$

$$-\frac{(2.h^{2}.[\mathrm{W}-\gamma\times\ln(\mathrm{x})]])\times\left[\left[\mathrm{e}^{-\theta\times(\mathrm{N}-\mathrm{V}\times\gamma\times\ln(x)-\tau(\mathrm{y}+\alpha)}\right]+\left[\mathrm{e}^{-\theta\times(\mathrm{D}-\tau(\mathrm{y}+\alpha)}\right]^{2}\right]}{\left(\left[\mathrm{e}^{-\theta\left(N-\mathrm{V}.\gamma.\ln(x)-\tau(y+\alpha)\right)}\right]+\left[\mathrm{e}^{-\theta\left(D-\tau(y+\alpha)\right)}\right]+\mathrm{L}+\mathrm{M}\right)^{2}}\Bigg]$$

$$\leq\Bigg[\left[\tau.\left(-\theta.\mathrm{V}.\mathrm{W}+\gamma.\mathrm{V}.\ \theta.\ln(x)+1\right).\mathrm{e}^{-\theta(\mathrm{N}-\mathrm{V}.\gamma.\ln(x)-\tau(\mathrm{y}+\alpha)}\right]-\frac{\left(\tau.\theta.\left(-\theta.\mathrm{V}.\mathrm{W}+\gamma.\mathrm{V}.\ \theta.\ln(x)+1\right)\right)\times\left[\left[\mathrm{e}^{-\theta\times(\mathrm{N}-\mathrm{V}\times\gamma\times\ln(x)-\tau(\mathrm{y}+\alpha)}\right]+\left[\mathrm{e}^{-\theta\times(\mathrm{D}-\tau(\mathrm{y}+\alpha)}\right]\right]}{\left(\left[\mathrm{e}^{-\theta\left(N-\mathrm{V}\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[\mathrm{e}^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+\mathrm{L}+\mathrm{M}\right)}$$

$$-\frac{(2.V.\theta.\tau.[\mathrm{W}-\gamma.\ln(\mathrm{x})])}{\left(\left[\mathrm{e}^{-\theta\left(N-\mathrm{V}\times\gamma\times\ln(x)-\tau(y+\alpha)\right)}\right]+\left[\mathrm{e}^{-\theta\times\left(D-\tau(y+\alpha)\right)}\right]+\mathrm{L}+\mathrm{M}\right)}$$

$$-\frac{\left(\left(2.\tau.V.\theta.[\mathrm{W}-\gamma.\ln(\mathrm{x})].[\mathrm{e}^{-\theta\times(\mathrm{N}-\mathrm{V}.\gamma.\ln(x)-\tau(\mathrm{y}+\alpha)}])]\right)\right)\times\left[\left[\mathrm{e}^{-\theta\times(\mathrm{N}-\mathrm{V}\times\gamma\times\ln(x)-\tau(\mathrm{y}+\alpha)}\right]+\left[\mathrm{e}^{-\theta\times(\mathrm{D}-\tau(\mathrm{y}+\alpha)}\right]\right]}{\left(\left[\mathrm{e}^{-\theta\left(N-\mathrm{V}.\gamma.\ln(x)-\tau(y+\alpha)\right)}\right]+\left[\mathrm{e}^{-\theta\left(D-\tau(y+\alpha)\right)}\right]+\mathrm{L}+\mathrm{M}\right)^{2}}\Bigg]^{2}$$

Appendix C: Comparative Statistics Analysis in Chapter 3

In terms of γ; (Assuming an effective range of γ in terms of a positive relationship with profit)

$$V.\ \theta\ .[\mathrm{W}-\gamma\ .\ln(\mathrm{x})] \geq \frac{[V.\ \theta\ .[\mathrm{W}-\gamma\ .\ln(\mathrm{x})].]}{[e^{-\theta(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}]+[e^{-\theta\times(D-\tau(y+\alpha))}]+L+M}+1$$

In terms of τ; (Assuming an effective range of τ in terms of a positive relationship with profit, because the terminal's profit increases when increasing benefit factor)

$$\frac{[(y+\alpha).[\mathrm{W}-\gamma\times\ln(\mathrm{x})].[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]]}{[[e^{-\theta(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}]+[e^{-\theta\times(D-\tau(y+\alpha))}]+L+M]} \geq \frac{[(y+\alpha).[\mathrm{W}-\gamma\times\ln(\mathrm{x})].[e^{-\theta\times(N-V\times\gamma\times\ln(x)-\tau(y+\alpha)}]][[[e^{-\theta(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}]+[e^{-\theta\times(D-\tau(y+\alpha))}]]]}{[[e^{-\theta(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}]+[e^{-\theta\times(D-\tau(y+\alpha))}]+L+M]^2}$$

In terms of V; (Assuming an effective range of V in terms of a positive relationship with profit, because the terminal's profit increases when increasing handling TEUs per vessel)

$$[V.\gamma.\theta.\ln(\mathrm{x})] \geq \frac{[V.\gamma.\theta.\ln(\mathrm{x})\ .]}{[e^{-\theta(N-V\times\gamma\times\ln(x)-\tau(y+\alpha))}]+[e^{-\theta\times(D-\tau(y+\alpha))}]+L+M}+1$$

Appendix D: Coopetition with Changing Total Market Demand (Number of Vessel Calls)

Table D.1. Price and Market Shares in Growing and Shrinking Market Scenarios

Market Scenarios	Price		Market Share		
	TO1	**TO2**	**TO1**	**TO2**	**Port h2**
Least ↓ Highest	Decrease by 50	Decrease by 100	Increase by 100	Increase by 100	Decrease by 100
	Decrease by 100	Decrease by 50	Increase by 50	Increase by 50	Decrease by 50
	Increase by 50	Increase by 50	Decrease by 50	Decrease by 50	Increase by 50
	Increase by 100	Increase by 100	Decrease by 100	Decrease by 100	Increase by 100

Note: Decrease by 50 means total market demand is decreased by 50 vessel calls per year indicating a market shrinking scenario. Similarly, Decrease by 100, Increase by 50, Increase by 100 indicate changes in total market demand by the respective number of vessel calls.

Table D.2. Competitive and Cooperative Effort Levels in Growing and Shrinking Market Scenarios

Market Scenarios	X		Y	
	TO1	**TO2**	**TO1**	**TO2**
Least ↓ Highest	Increase by 100	Increase by 100	Decrease by 50	Decrease by 100
	Increase by 50	Increase by 50	Decrease by 100	Decrease by 50
	Decrease by 100	Decrease by 50	Increase by 50	Increase by 50
	Decrease by 50	Decrease by 100	Increase by 100	Increase by 100

Appendix E. Duties and Powers of the SLPA (Source: Summarized from https://www.slpa.lk/port-colombo/act)

Main objects and duties of SLPA

- ✓ Provides efficient and regular services for stevedoring, lighterage, shipping and transhipping, landing and warehousing of dry and wet cargo and cargo in bulk;
- ✓ Supply of water, fuel, and electricity to vessels, handling petroleum, petroleum products and lubricating oils to and from vessels and between bunkers and depots; for pilotage and mooring of vessels; for diving and under-water ship repairs, etc;
- ✓ Efficient and regular tally and protective services; regulate and control navigation related to ports; maintain port installations and promote the use, improvement, and development of ports;
- ✓ Co-ordinate and regulate all activities within port; to establish and maintain on and off the coast of Sri Lanka such lights and other means for the guidance and protection of vessels as are necessary for navigation in and out of the ports;
- ✓ Conduct business in such manner and such charges for services rendered by the Authority as will secure that the revenue of the Authority is not less than sufficient for meeting the charges which are proper to be made to revenue of the Authority,
- ✓ Replace assets, make new investments and to establish and maintain an adequate general reserve; etc

Powers of the SLPA

- ✓ Acquire, take on lease, give on lease, hire, pledge and sell or otherwise dispose of any movable or immovable property;
- ✓ Employ officers and servants; to do anything for the purpose of improving the efficiency of port operations and advancing skill of persons employed or efficiency of equipment or the manner in which equipment is operated, facilities for training persons required to carry out the work; establish insurance scheme, provident fund, welfare fund, fines fund and provide welfare, health, and recreational facilities, houses, hostels and accommodation for persons employed;
- ✓ Make rules for officers and servants, including their appointment, promotion, discipline, leave, working times, and grant of loans, etc; make rules and prescribe procedures in respect of the administration of affairs;

- ✓ Establish, maintain and operate within the limits of the port, a security service for protecting port installations, equipment, cargo and vessels within port;
- ✓ Acquire undertaking affording facilities for loading and discharging, warehousing of goods or bunkering of vessels; to carry on functions of builders and repairers of vessels and machinery, removers or salvagers of wrecks, shipbreakers, carriers of passengers, vehicles, and goods by land or sea, stevedores, etc
- ✓ Operate and maintain a rail transport system within the port limit;
- ✓ Control the berthing and movement of all vessels whether in the harbor or in the approaches within the port limit and to divert vessels to any specified port;
- ✓ Enter into, and perform, directly or through any officer or agent authorized in that behalf by the Authority, all such contracts as may be necessary for the performance of the functions, to levy such port dues, fees and other charges upon vessels, goods, vehicles and in respect of services within the port limit and upon cargo loaded, discharged or kept in such port as it may deem necessary;
- ✓ Construct, maintain and operate all means and appliances for berthing, loading and dishonoring within port; to provide and use, within the territorial waters of Sri Lanka or otherwise, vessels and appliances for the purpose of protecting, guiding and communicating with vessels or towing and rendering assistance to any vessel or for recovering any property lost, sunk or stranded;
- ✓ Provide such fire services both within any specified port and on the high seas, as may be deemed necessary for the purpose of extinguishing fires on land, on sea or afloat and of preserving life and property;
- ✓ Borrow money from any person, organization or institution within or outside Sri Lanka or from the Government; to guarantee, with the consent of the Minister given with the concurrence of the Minister in charge of the subject of Finance, the repayment of any loan, or performance of obligations of any person, firm, corporate body, organization in which the Ports Authority has an interest;
- ✓ Control the use of, and to issue licenses in respect of all craft, equipment, vehicles, and services that are operated within port limits; to survey, plan and execute maritime engineering works for Government departments, public corporations and for other bodies approved by the Minister; to clean, deepen or improve any portion of port and, for any of such purposes to construct, maintain and operate dredgers and other appliances and to make hydrographic surveys; to reclaim, enclose, raise, drain and excavate any area falling within port limits or belonging to the Authority; to maintain, repair, erect and to control erection and use of piers, breakwaters, bridges, wharfs, docks, warehouses, stores, offices, and any other buildings or works within the limits of, or the approaches to, port and to install and maintain coast lights and other means of protecting and guiding vessels;
- ✓ Provide following services within the limits of, and the approaches to, any specified port (berthing, towing, mooring, moving, slipping or docking of any vessel including pilot age; loading or discharging of any vessel including all ancillary services; the sorting, weighing, measuring, storing, warehousing or otherwise handling of any goods; radio communication between ports and between ships and such ports; transport services and other facilities for port users and for employees; supply of electricity and telephone services to vessels; disposal of garbage from ships; etc);
- ✓ Construct, manufacture, purchase, operate, maintain and repair anything required for purposes of the business; to co-ordinate and execute any Government project relating to the establishment of free trade zone in port and to enter into any agreement with port users for the utilization of such facilities;
- ✓ Control entry of vehicles, persons, goods, and animals within the port limits and to regulate their movements within such limits;

Appendix F. Forecasting Container Throughputs for Chapter 5

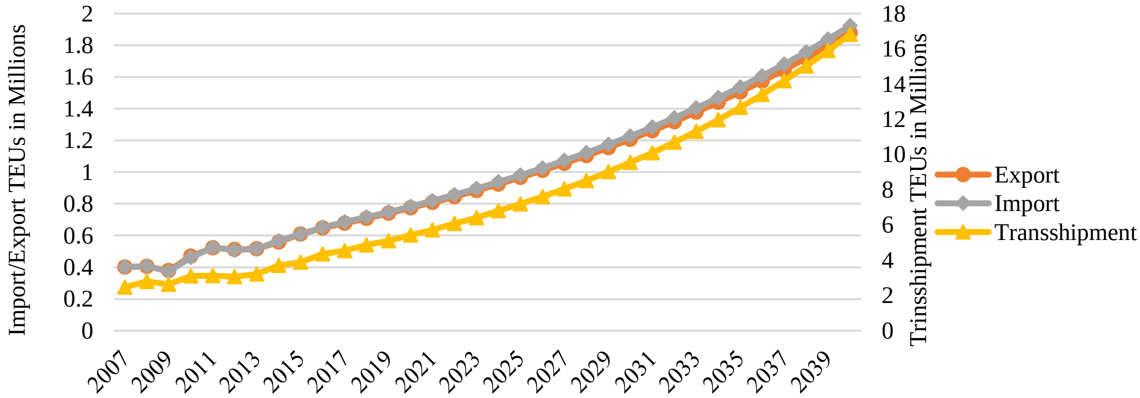

Figure F.1. Forecasting Container Throughputs

Appendix G: Derivation Related to Objective [5.2]

Step 1. Port Level Generalized cost function

$$\mathrm{GC}_t^{f,h} = \mathrm{MPC}_t^h + \mathrm{JC}_t^{f,h} + \mathrm{TC}_t^{f,h} - \mathrm{VNQC}_t^h$$

Step 2. Journey cost Calculation

$$\mathrm{JC}_t^{f,h} = \sum_{j=1}^{j=2}\left[\mathrm{D}^{(j,f,h)} * \frac{\left(\frac{\mathrm{MPC}_t^h}{\mathrm{SS}_{(\text{Port Charges})}}\right) * \mathrm{SS}_{(j)}}{\left(\sum_{h=1}^{h=2}\mathrm{D}^{(j,f,h)}/2\right)}\right],\ \mathrm{JC}_t^{f,h} = \mathrm{MPC}_t^h * \sum_{j=1}^{j=2}\left[\mathrm{D}^{(j,f,h)} * \frac{\mathrm{SS}_{(j)}}{\mathrm{SS}_{(\text{Port Charges})} * \left(\sum_{h=1}^{h=2}\mathrm{D}^{(j,f,h)}/2\right)}\right]$$

Step 3. Time cost Calculation

$$\mathrm{TC}_t^{f,h} = \mathrm{MPC}_t^h * \sum_{w=1}^{w=4}\left[\mathrm{T}^{(w,f,h)} * \frac{\mathrm{SS}_{(w)}}{\mathrm{SS}_{(\text{Port Charges})} * \left(\sum_{h=1}^{h=2}\mathrm{T}^{(w,f,h)}/2\right)}\right]$$

Step 4. VNQC_t^h Calculation

$$\mathrm{VNQC}_t^h = \left[\left(\frac{\mathrm{MPC}_t^h}{\mathrm{SS}_{(\text{Port Charges})}}\right) * \left(\mathrm{PPI}_0^h + e\sum_{i=1}^{i=m^h}\left(\mathrm{Q}_{t-1}^i - \mathrm{Q}_0^i\right)\right)\right],\ \mathrm{VNQC}_t^h = \mathrm{MPC}_t^h * \left[\frac{\left(\mathrm{PPI}_0^h + e\left(\mathrm{Q}_{t-1}^h - \mathrm{Q}_0^h\right)\right)}{\mathrm{SS}_{(\text{Port Charges})}}\right]$$

Step 5. Structure of generalized cost function

$$\mathrm{GC}_t^{f,h} = \mathrm{MPC}_t^h + \mathrm{MPC}_t^h * \sum_{j=1}^{j=2}\left[\mathrm{D}^{(j,f,h)} * \frac{\mathrm{SS}_{(j)}}{\mathrm{SS}_{(\text{Port Charges})} * \left(\sum_{h=1}^{h=2}\mathrm{D}^{(j,f,h)}/2\right)}\right] + \mathrm{MPC}_t^h * \sum_{w=1}^{w=4}\left[\mathrm{T}^{(w,f,h)} * \frac{\mathrm{SS}_{(w)}}{\mathrm{SS}_{(\text{Port Charges})} * \left(\sum_{h=1}^{h=2}\mathrm{T}^{(w,f,h)}/2\right)}\right] - \mathrm{MPC}_t^h * \left[\frac{\left(\mathrm{PPI}_0^h + e\left(\mathrm{Q}_{t-1}^h - \mathrm{Q}_0^h\right)\right)}{\mathrm{SS}_{(\text{Port Charges})}}\right]$$

$$\mathrm{GC}_t^{f,h} = \mathrm{MPC}_t^h\left[1 + \frac{\sum_{j=1}^{j=2}\left[\mathrm{D}^{(j,f,h)} * \frac{\mathrm{SS}_{(j)}}{\left(\sum_{h=1}^{h=2}\mathrm{D}^{(j,f,h)}/2\right)}\right] + * \sum_{w=1}^{w=4}\left[\mathrm{T}^{(w,f,h)} * \frac{\mathrm{SS}_{(w)}}{\left(\sum_{h=1}^{h=2}\mathrm{T}^{(w,f,h)}/2\right)}\right] - \left[\left(\mathrm{PPI}_0^h + e\left(\mathrm{Q}_{t-1}^h - \mathrm{Q}_0^h\right)\right)\right]}{\mathrm{SS}_{(\text{Port Charges})}}\right]$$

$$\mathrm{GC}_t^{f,h} = \sum_{i=1}^{i=m^h}\left(\mathrm{Share}_t^i * \mathrm{MPC}_t^i\right) * \left[1 + \frac{\sum_{j=1}^{j=2}\left[\mathrm{D}^{(j,f,h)} * \frac{\mathrm{SS}_{(j)}}{\left(\sum_{h=1}^{h=2}\mathrm{D}^{(j,f,h)}/2\right)}\right] + * \sum_{w=1}^{w=4}\left[\mathrm{T}^{(w,f,h)} * \frac{\mathrm{SS}_{(w)}}{\left(\sum_{h=1}^{h=2}\mathrm{T}^{(w,f,h)}/2\right)}\right] - \left[\left(\mathrm{PPI}_0^h + e\left(\mathrm{Q}_{t-1}^h - \mathrm{Q}_0^h\right)\right)\right]}{\mathrm{SS}_{(\text{Port Charges})}}\right]$$

Step 6. Converting to utility

$$\mathrm{Utility}_t^{(f.h)} = \frac{\sum_{i=1}^{i=m^{(f.least)}}\left(\mathrm{Share}_t^i * \mathrm{MPC}_t^i\right) * \left[1 + \frac{\sum_{j=1}^{j=2}\left[\mathrm{D}^{(j,f,h)} * \frac{\mathrm{SS}_{(j)}}{\left(\sum_{h=1}^{h=2}\mathrm{D}^{(j,f,h)}/2\right)}\right] + * \sum_{w=1}^{w=4}\left[\mathrm{T}^{(w,f,h)} * \frac{\mathrm{SS}_{(w)}}{\left(\sum_{h=1}^{h=2}\mathrm{T}^{(w,f,h)}/2\right)}\right] - \left[\left(\mathrm{PPI}_0^{(f.least)} + e\left(\mathrm{Q}_{t-1}^{(f.least)} - \mathrm{Q}_0^{(f.least)}\right)\right)\right]}{\mathrm{SS}_{(\text{Port Charges})}}\right]}{\sum_{i=1}^{i=m^{(f.h)}}\left(\mathrm{Share}_t^i * \mathrm{MPC}_t^i\right) * \left[1 + \frac{\sum_{j=1}^{j=2}\left[\mathrm{D}^{(j,f,h)} * \frac{\mathrm{SS}_{(j)}}{\left(\sum_{h=1}^{h=2}\mathrm{D}^{(j,f,h)}/2\right)}\right] + * \sum_{w=1}^{w=4}\left[\mathrm{T}^{(w,f,h)} * \frac{\mathrm{SS}_{(w)}}{\left(\sum_{h=1}^{h=2}\mathrm{T}^{(w,f,h)}/2\right)}\right] - \left[\left(\mathrm{PPI}_0^{(f.least)} + e\left(\mathrm{Q}_{t-1}^{(f.h)} - \mathrm{Q}_0^{(f.h)}\right)\right)\right]}{\mathrm{SS}_{(\text{Port Charges})}}\right]}$$

Fixed components: $\mathrm{L}^{(j,f,h)} = \sum_{j=1}^{j=2}\left[\mathrm{D}^{(j,f,h)} * \frac{\mathrm{SS}_{(j)}}{\left(\sum_{h=1}^{h=2}\mathrm{D}^{(j,f,h)}/2\right)}\right] + * \sum_{w=1}^{w=4}\left[\mathrm{T}^{(w,f,h)} * \frac{\mathrm{SS}_{(w)}}{\left(\sum_{h=1}^{h=2}\mathrm{T}^{(w,f,h)}/2\right)}\right] - \left[\mathrm{PPI}_0^{(f,h)} - e * \mathrm{Q}_0^{(f,h)}\right]$

$$\mathrm{Utility}_t^{(f.h)} = \frac{\sum_{i=1}^{i=m^{(f.least)}}\left(\mathrm{Share}_t^i * \mathrm{MPC}_t^i\right) * \left[1 + \frac{\left[\mathrm{L}^{(j,f,least)} + e * \mathrm{Q}_{t-1}^{(f,least)}\right]}{\mathrm{SS}_{(\text{Port Charges})}}\right]}{\sum_{i=1}^{i=m^{(f.h)}}\left(\mathrm{Share}_t^i * \mathrm{MPC}_t^i\right) * \left[1 + \frac{\mathrm{L}^{(j,f,h)} + e * \mathrm{Q}_{t-1}^{(f,h)}}{\mathrm{SS}_{(\text{Port Charges})}}\right]}$$

Step 7. Total port demand

$$TS_t^h = \sum_{f=1}^{f=12} TS^f * \frac{e^{\left[\frac{\sum_{i=1}^{i=m^{(f.least)}}(Share_t^i * MPC_t^i) * \left[1+\frac{\left[L^{(j,f,least)}+e*Q_{t-1}^{(f,least)}\right]}{SS_{(Port\ Charges)}}\right]}{\sum_{i=1}^{i=m^{(f.h)}}(Share_t^i * MPC_t^i) * \left[1+\frac{L^{(j,f,h)}+e*Q_{t-1}^{(f,h)}}{SS_{(Port\ Charges)}}\right]}\right]}}{\sum_{h=1}^{h=2} e^{\left[\frac{\sum_{i=1}^{i=m^{(f.least)}}(Share_t^i * MPC_t^i) * \left[1+\frac{\left[L^{(j,f,least)}+e*Q_{t-1}^{(f,least)}\right]}{SS_{(Port\ Charges)}}\right]}{\sum_{i=1}^{i=m^{(f.h)}}(Share_t^i * MPC_t^i) * \left[1+\frac{L^{(j,f,h)}+e*Q_{t-1}^{(f,h)}}{SS_{(Port\ Charges)}}\right]}\right]}}$$

Step 8. Terminal level generalized cost and market share

$$GC_t^i = \left(V * MPC_t^i\right) + N^h + a\left(\frac{Q_{t-1}^i * T^i}{0.8 * K^i}\right)^b$$

$$Share_t^i = \frac{e^{-\theta\left[\left(V*MPC_t^i\right)+N^h+a\left(\frac{Q_{t-1}^i*T^i}{0.8*K^i}\right)^b\right]_t^i}}{\sum_{i=1}^{i=m^h} e^{-\theta\left[\left(V*MPC_t^i\right)+N^h+a\left(\frac{Q_{t-1}^i*T^i}{0.8*K^i}\right)^b\right]_t^i}}$$

Step 9. Terminal demand

$$Max;\ Q_t^{CMB} = \sum_{i=1}^{i=3} Q_t^i,\ \ Q_t^i\ =\ Share_t^i * \left(\frac{TS_t^h}{V}\right)$$

$$Max;\ Q_t^i = Share_t^i * \left[\sum_{f=1}^{f=12} TS^f * \frac{e^{\left[\frac{\sum_{i=1}^{i=m^{(f.least)}}(Share_t^i * MPC_t^i) * \left[1+\frac{\left[L^{(j,f,least)}+e*Q_{t-1}^{(f,least)}\right]}{SS_{(Port\ Charges)}}\right]}{\sum_{i=1}^{i=m^{(f.h)}}(Share_t^i * MPC_t^i) * \left[1+\frac{L^{(j,f,h)}+e*Q_{t-1}^{(f,h)}}{SS_{(Port\ Charges)}}\right]}\right]}}{\sum_{h=1}^{h=2} e^{\left[\frac{\sum_{i=1}^{i=m^{(f.least)}}(Share_t^i * MPC_t^i) * \left[1+\frac{\left[L^{(j,f,least)}+e*Q_{t-1}^{(f,least)}\right]}{SS_{(Port\ Charges)}}\right]}{\sum_{i=1}^{i=m^{(f.h)}}(Share_t^i * MPC_t^i) * \left[1+\frac{L^{(j,f,h)}+e*Q_{t-1}^{(f,h)}}{SS_{(Port\ Charges)}}\right]}\right]}} \Big/ V\right]$$

Step 10. Total port profit (Ex: Colombo)

$$Max;\ \pi_t^{CMB} = \sum_{i=1}^{i=3} \pi_t^i$$

$$Max;\ \pi_t^{CMB} = \left[V * \left[Q_t^{JCT} * \left(MPC_t^{JCT} - C^{JCT}\right) + \left(Q_t^{SAGT} * TF_t^{SAGT}\right) + \left(Q_t^{CICT} * TF_t^{CICT}\right)\right] + \sum_{i=1}^{i=m^h} Q_t^i * \left(N^{CMB} - N_{cost}^{CMB}\right)\right] + V * \left[Q_t^{SAGT} * \left(MPC_t^{SAGT} - TF_t^{SAGT} - C^{SAGT}\right)\right] + V * \left[Q_t^{CICT} * \left(MPC_t^{CICT} - TF_t^{CICT} - C^{CICT}\right)\right]$$