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Protecting a trilateral coastal ecosystem: The Wadden Sea

[Shortened Title: Trilateral Wadden Sea protection]

Karsten Reise(*)

ABSTRACT

Coasts offer multiple advantages when topical combinations for optimal use are foreseen. The Dutch-German-Danish Wadden Sea region has been transformed on its landward half into drained arable land. This has been protected by seawalls against storm surges which frequently ravage this coast. The other half remained a dynamic seascape with the largest coherent tidal flats in the world. This had been perceived as a drenched wasteland with treacherous shallows for long but is now proudly regarded as a universally outstanding coastal wetland, listed as a World Heritage Site since 2009. Faced with accelerating sea level rise, a change in coastal adaptation is advocated. The prevailing fortress strategy should give way to living with more water and more natural areas, growing with and buffering against sea level rise. Such areas could also provide relaxation from stressful urban life, and tourism would develop into the main economy at modern coasts.

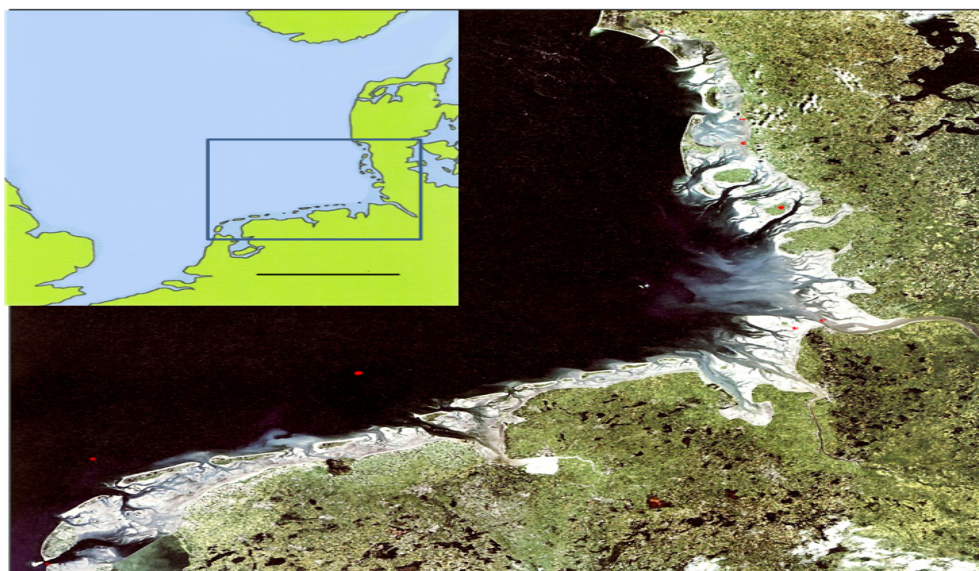
Key words: coastal transformation, living with more water, nature protection, sea level rise, tourism

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1. Introduction

Challenges at modern shallow coasts are unique in the history of our planet. Since continental drift concentrated land masses at the southern pole (Antarctica) and near the northern pole (North America and Eurasia), a net accumulation of snow resulted in extensive glaciations. These caused global sea level to fall. Due to astronomical cycles, recurrent warm intervals interrupted the glaciations, associated with sea level rising up to 120 m. We currently are near the end of such a warm interval. However, anthropogenic climate forcing over the last century has initiated renewed warming which is expected to be followed by further sea level rise (Cowie, 2007).

After an initial phase of rapid sea level rise with the beginning of the present interglacial, further rise had been slow (Vink et al., 2007). In this second phase, with a sediment supply outpacing sea level rise, wetlands have been expanding into the sea at most shallow coasts. Where sediments were supplied by rivers, large deltas have emerged over the last 8,000 years. Where sediment supply or redistribution was under the mercy of the sea and tidal range was small, coastal lagoons with extensive marshes developed. With a medium tidal range, barrier islands in front of tidal flats and marshes have formed. At very large tidal range, merely tidal flats prevailed. These coasts continue to change, and tidal range tends to increase with sea level rise (Bird, 2000).



Source: Eurimage, Common Wadden Sea Secretariat & Brockmann Consult

Figure 1. Satellite images taken of the Wadden Sea region in 2000-2002 are combined to show low tide conditions everywhere. Beaches and tidal flats appear to be white and suspended matter in the water grey. Main line of seawalls along the mainland coast is highlighted in red. Inset shows position of image in the North Sea

Presumably, already at the hunter and gatherer stage, our species took advantage of coasts where land and marine resources could complement each other. Later, coastal wetlands attracted agriculture because floods renewed nutrients. Hydraulic systems of drainage, irrigation and flood defense were developed to overcome disadvantages of irregular and excessive flooding. However, these systems entered a viscous cycle. Due to soil compaction from drainage, due to saline intrusions from irrigation, and due to diminishing nutrient and sediment supply because of flood control, the maintenance costs kept increasing relentlessly over time (Syvitski et al., 2009). More safety from flooding allowed for an increasing population density and infrastructures accumulated. These in turn demanded for more safety, and once better flood protection was achieved, more people moved to the coast and established even more infrastructures. In the absence of flooding, industrial fertilizers had to be purchased by coastal farmers similar to those not burdened by the costs of flood control. Thus, a former coastal advantage turned into a disadvantage, while maritime trade, industry and tourism still take advantage from the coast.

The Wadden Sea region is located at the southeastern shore of the North Sea in a cold temperate zone and where moderate tidal conditions prevail (Figure 1). Economy has been traditionally dominated by agriculture. Maritime trade and industrialization remained confined to inner estuaries. The latter sectors prosper, while agriculture in the coastal periphery stagnates. There tourism is now taking over as the dominant economy, but young people continue leaving for the metropolitan centers (Bazelmans et al., 2012; Kabat et al., 2012).

The Wadden Sea region belongs to The Netherlands, Germany and Denmark. Since medieval time, Dutch economy, hydraulic expertise and culture dominated in this region, until the rise of modern national states terminated this coastal coherence. However, half a century ago, an idea of a natural integrity and identity of the Wadden Sea gradually took shape. This initiated a trilateral cooperation between the three nations in protecting the largest coherent tidal flat environment in the world (Kabat et al., 2012).

These efforts have culminated in the Wadden Sea being listed as a World Heritage Site by the UNESCO based on universally outstanding values in geology, ecology and biodiversity and their proper protection (CWSS, 2008, 2009, 2013; Reise et al., 2010). The capability of the nature area to grow with sea level rise and its importance for tourism, recently prompted the question whether a revitalization and adaptation of the embanked marsh may be accomplished by giving more room to nature.

In this article, the historical development of the Wadden Sea region is reviewed with an emphasis on nature protection, and future options are discussed in the face of climate change. This case study on the Wadden Sea region may not serve as a template for other coasts but hopefully could be a source for inspirations.

2. Transformation of the coastal marsh

In the Wadden Sea, a once gradual transition between sea and land became transformed by a coherent line of earthen seawalls, separating the coast into a dynamic intertidal nature area and an embanked marsh used primarily for agriculture (Figure 2). The historical course and causes of this landscape transformation is summarized below (Bazelmans et al., 2012; Reise et al., 2010; Reise, 2013).

Initially, human use of the coastal lowlands in the Wadden Sea region as a pasture for sheep and cattle was accompanied by building dwelling mounds (Phase 1). These kept housing dry and served as a refuge for life stock when storm surges flooded the marsh. This happened frequently with low pressure systems approaching from the northern Atlantic and hampered growing crops.

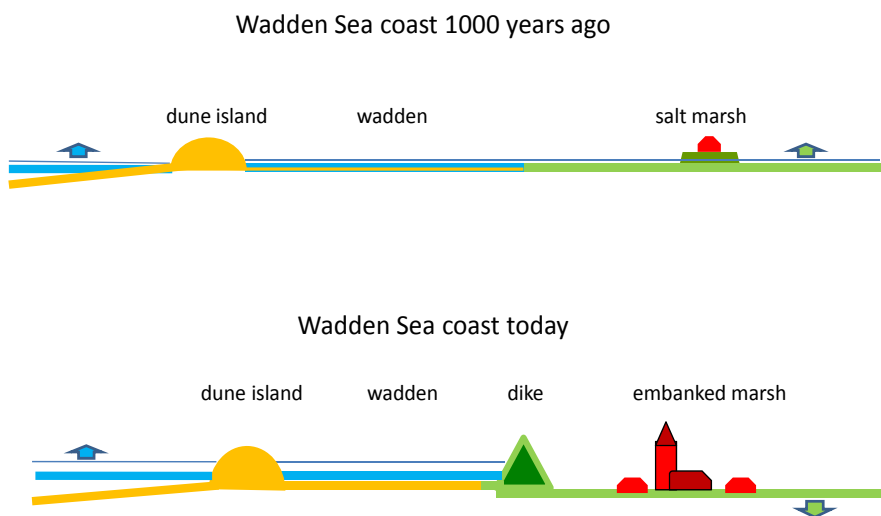


Figure 2. Schematic profiles of the Wadden Sea region 1000 years ago and today. Arrows indicate direction of sea and land level changes. Thin upper blue line indicates episodic storm surge flooding, bold blue line the tidal range. Dark green indicates artificial earth works

Nevertheless, attempts of culturing land commenced in the wet hinterland (Phase 2). Drainage resulted in soil compaction, and this required building earthen walls, named dikes, around such low terrain to prevent flood water intrusion. While the shrinking of soils aggravated behind dikes with ongoing drainage, the storm surges in front of the dikes rose higher the more of the land became embanked and less area remained to accommodate the flood waters. Farmers on unprotected areas were disadvantaged by this development.

Therefore, dike building quickly proceeded and by 1300 AD almost all of the marshland was protected against flooding by the sea with a coherent line of earthen seawalls (Figure 1; Phase 3). This wall separated land and sea, and the floods no longer provided the land with nutrients and new sediment. Rainwater had to be pumped upwards through sluices into the sea. This hydraulic system came under pressure. (1) As the sinking of the land continued, so did the rising level of the sea, creating a coastal gap which gradually became wider over the centuries, increasing the risk of irreversible seawater intrusions when dikes broke. (2) In some regions freshwater swamps and bogs became submerged by the sea and then were buried under marine sediments. The organic material (peat) was later mined, dried, burned, and from the ash salt could be extracted and exported as a precious commodity. This mining lowered the surface of the land. (3) From 1300 AD onwards, climate deteriorated (the so-called 'Little Ice Age'). Weather became colder and wetter, and extreme weather conditions occurred more frequent (Marcott et al., 2013).

These adverse developments entailed disastrous intrusions of the sea during storm surges far into the agricultural land (Phase 4). With technological improvements in dike building and capital investments from outside, part of the lost land was subsequently reclaimed but some areas reverted permanently into tidal flats. However, in spite of some fundamental criticism on the transformation of the coastal landscape by dike building and drainage, the hydraulic strategy did not change until today. Instead, the progressive embankment of tidal flats continued on a larger scale, particularly after 1900 AD (Phase 5).

The transformation of the coastal marsh affected the Wadden Sea region as a whole. Three bays created by former sea intrusions remained and there muddy tidal flats abound. In front of dikes, only a narrow belt of artificially created salt marshes exist. Most of the tidal flats there are sandy. Progressive embankments have narrowed the distance between the mainland and the barrier islands or sand bars. The latter slowly shifted landward with the rising of the sea. These and the slow and gradual rising of the sea accompanied by an increasing tidal range, caused hydrodynamics to become stronger in the Wadden Sea. Waves and currents stir up fine mud particles and sand becomes to dominate the sediment of the tidal flats (Figure 3).

Technological improvements in dam and dike building finally gave rise to plans of embanking the entire tidal zone by connecting the barrier islands and these with the mainland. The rational proposed was not only to gain agricultural land but also more safety against storm surges breaking the dikes. The southwest coast of The Netherlands was struck by an unusual flood in 1953, breaking dikes and more than 3000 people died. The German port city of Hamburg, located far upstream in the Elbe estuary, was unexpectedly flooded in its lower parts by a storm surge in 1962. About 300 people died. Presumably, this flood could rush into the city so fast because the bed of the estuary had been dredged deeper to ease passage for larger vessels. Both disastrous events alerted governments to the high

risk of living at the sea. Coastal protection programs were carried out all along the shores of the Wadden Sea by building new dikes and enforcing existing ones, building storm surge barriers at rivers, and stopping shore erosion by stone revetments.

3. The rise of coastal nature protection

Hunting and fishing pressure increased with human population growth over the centuries (Lotze, 2007; Reise, 2013). Marine mammals and coastal breeding birds became rare, large fish vanished, and the regional oyster population went extinct because of overexploitation (Figure 3). This development is reminiscent of the concept of fishing down the food web (Pauly et al., 1998), because the present fishery is confined to shrimp and mussels. Excessive use of fertilizers and pesticides on arable land, industrial wastes and insufficient sewage treatment by the cities first killed fish in the rivers and subsequently negative effects became also apparent at the coast in the form of diseased seals and fish, dead birds and algal blooms. Along the estuaries, power plants and industries sprawled. Shipping and aquaculture have entailed a tide of nonnative species invasions which irreversibly altered living communities (Buschbaum et al., 2012).

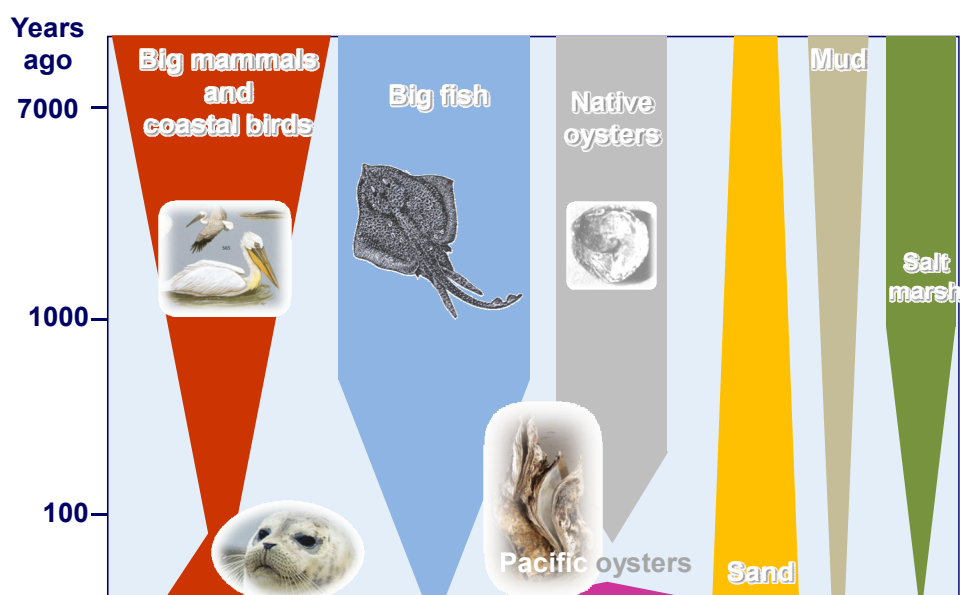


Figure 3. Schematic kite diagrams to indicate rough temporal trends (note logarithmic time scale) affected by human forcing in the Wadden Sea. For explanation see text

These adverse developments gave rise to a strong environmental movement. Already more than one hundred years ago, concern about birds prompted non-governmental organizations to buy small uninhabited islands in order to operate bird sanctuaries. However, the Wadden Sea was not yet perceived as a natural entity. This vision came to be generally known not before the 1960s. Then the Wadden Sea was recognized an essential staging area for most birds of the East-Atlantic Flyway. Also a dramatic decline in the seal population became public. Embankments which further reduced the area for salt marshes and tidal flats were met by fierce opposition.

In 1974, the Dutch government decided to stop plans of further large-scale embankments in the Wadden Sea. Urged by scientists, it also started to cooperate with Germany and Denmark to improve nature protection and environmental conditions. The idea of a common protection area was born in 1982. Regular meetings of the three environmental ministers were held and stepwise the protection regime became more comprehensive. In 1997 a common management plan with environmental targets was adopted (CWSS, 1998 and updated in 2010). Also a detailed trilateral monitoring program commenced. Many dedicated volunteers contributed to bird counts throughout the Wadden Sea. Results of monitoring and research are presented every five years in Quality Status Reports. Ongoing research played a significant role from the beginning. With popular books (Abrahamse, Joenje and van Leeuwen Seelt, 1976) and the book series *The Ecology of the Wadden Sea* (Wolff 1983) a comprehensive scientific assessment of natural processes, biodiversity and threats was achieved. Regular International Scientific Wadden Sea Symposia served to exchange insights and concerns between scientists and environmental managers.

In the national sub-regions of the Wadden Sea, protection regimes took various forms but attempts were made to harmonize the measures. Coordination is achieved through a Common Wadden Sea Secretariat since 1987 which also initiated the nomination of the Wadden Sea as a World Heritage Site. Since the early 1990s all parts of the Wadden Sea were declared Biosphere Reserves. These are confined to the protected area and therefore merely consist of core zones and lack development zones in the adjoining marsh or on the inhabited islands. The only exception is a group of small islands, the so-called Halligen, which are adapted to flooding during storm surges when only the houses set on dwelling mounds stay above the waves. These islets constitute the 'Biosphere Halligen'. By 2002, trilateral cooperation also commenced on the landscape and the cultural heritage of the Wadden Sea region by establishing a stakeholder forum in 2002 (Frederiksen, Enemark and Nuttall, 2013).

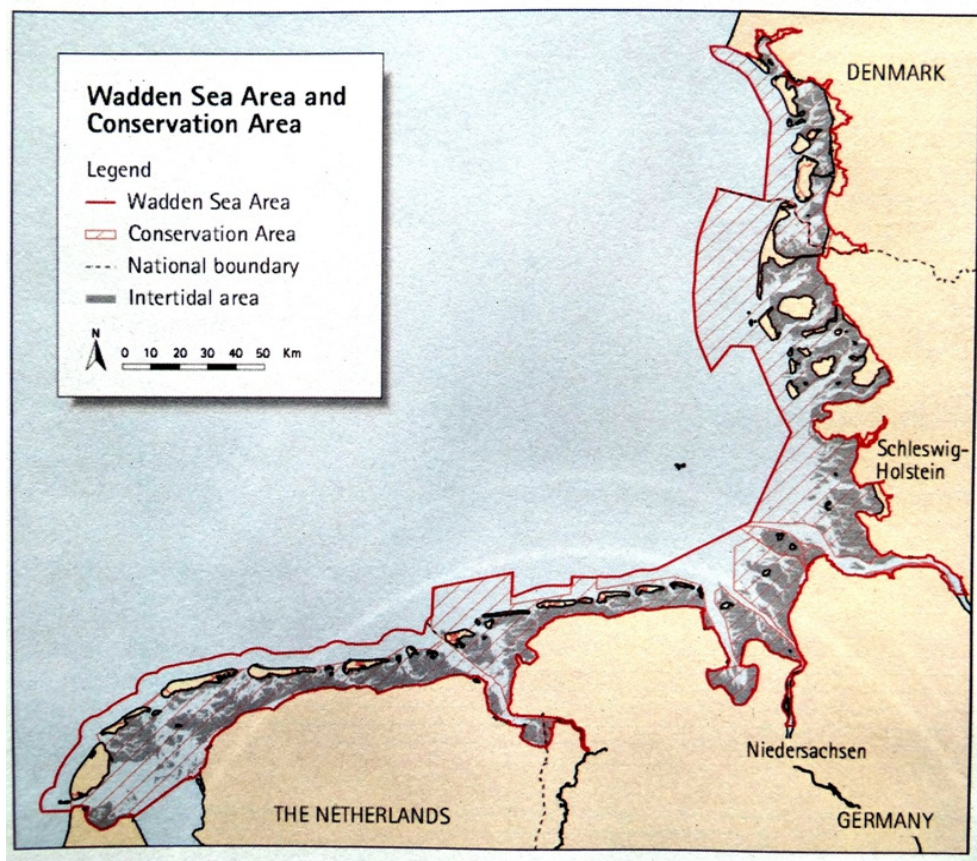
The success of the nature protection measures has been impressive. Breeding bird and seal populations have increased about ten-fold. Flight distance considerably decreased in species of birds and marine mammals because hunting has been phased out completely. Commercial shellfish exploitation has been restricted to certain zones. Seagrass beds affected

by eutrophication have begun to recover since the 1990s. Grazing by domestic animals on salt marshes has been reduced or even phased out. This increased vegetation height and the number of flowering plants considerably.

Non-governmental organizations and also National Park rangers conduct guided nature wet walks which are highly popular among tourists. Visitor centers have been set up on almost all islands and along the mainland coast. A trilateral school brings together young people from the three Wadden Sea nations in summer camps. Special events are celebrated like Brent Goose Days or Bird Migration Days. Fierce initial opposition by residents to nature protection gradually faded away, and since the 2000s the protection status is generally well appreciated by residents and visitors alike. In particular, the World Heritage Status has catalyzed a mind shift in favor of nature protection.

In the 1960s, most people perceived tidal flats as a wasteland. Often tidal flats were seen as a once flourishing farmland lost to a merciless sea. Salt marshes were looked at as potential arable land to be embanked with dikes. Awareness of the natural values grew slowly in the coastal population. On the other hand, with new agricultural policies by the European Community, incentives to gain more land for more agriculture came to an end. Nevertheless, embankments continued for the sake of improving water management or for more safety into the 1980s. These were finally stopped by an overwhelming opposition regretting the loss of salt marshes and tidal flats. No more embankments have been planned since then.

However, nature protection has to grant priority to coastal defense, and traditional use of natural resources such as artisanal fishery is also granted, although hunting has been banned. With a few exceptions, the protection area does not include inhabited islands, and stops at dikes and in estuaries (Figure 4). Particularly the latter have been exempted from the Wadden Sea protection regime because there the interests of maritime trade and industry left little chance for nature protection.



Source: Common Wadden Sea Secretariat, Wilhelmshaven, Germany

Figure 4. Map of the Wadden Sea Area and Conservation Area (hatched).

4. Adaptations to climate change

The transformation of the marsh has created a coastal gap which is inevitably widening as the land keeps on sinking and the sea is rising. Particularly towards the end of the last century, safety has been improved by reinforcing coastal defense. This in turn was perceived as an invitation for an expansion of infrastructures which may entail even stronger defense measures to compensate for the coastal gap.

Within the last 50 years, nature protection on a trilateral level has profoundly transformed the perception of the Wadden Sea from useless shallows to a touristic attraction. This may not have been achieved entirely by the strength of the environmental movement. Previous tensions relaxed with new European policies on agricultural development and with

an appreciation of the high level of safety against flooding.

However, with growing concern about global warming and expected regional effects, the coastal situation is changing again. The coastal gap may become unbearable when sea level rise starts accelerating, and the morphodynamics in the protected Wadden Sea may threaten its natural values. An obvious response to sea level rise, increasing storminess and other weather extremes, would be a managed coastal retreat. Not surprisingly, this option has found little support but met strong objections so far. Instead, two alternatives are on the agenda, the technological fortress strategy and the water strategy of adapting lifestyle to live with more water.

The fortress strategy is a continuation of traditional coastal defense measures which have successfully protected human life and property over the last 50 years. New dikes are already under construction which are wider and with a broad top onto which a 'climate cap' could be added when necessary. These measures are based on projections on sea level rise until the end of this century, as issued by the IPCC in 2007 and 2013. In addition, eroding shores are either more strongly armored with stones or concrete than before or sand nourishments to the beaches of the islands use larger volumes to compensate losses. The fortress strategy relies on technical solutions alone. However, a combination with spatial planning which divides the coastal lowland into categories of differential risks is also envisioned (Ahlhorn, 2009). In this concept, risk is defined as the likelihood of coastal defense structures to fail, which is multiplied by the potential number of people being affected and the value of infrastructures likely to be damaged.

The water strategy seeks to combine new technical approaches with a change in lifestyle towards living with more water. This is not yet part of any official policy. However, a growing number of innovative people are pushing this idea (i.e., Geuze, 2009; Helmer et al., 1996; Metz and van den Heuvel, 2012; Stokman, von Seggern and Rabe, 2009). In the paragraphs below these efforts are linked to nature protection as developed over the last decades. Other than the fortress strategy, a time scale also beyond the end of this century is taken into account and an attempt is made to close the coastal gap.

For the Wadden Sea with its very shallow waters and an adjoining land at or below the level of the sea, the rate of sea level rise is seen as a key variable. However, it seems unlikely that this rate can be predicted in the near future. The time lag between atmospheric warming and sea level rise as well as the dynamics of melting polar ice caps are insufficiently known. IPCC projections are based on those processes which are reasonably understood. Semi-empirical approaches incorporate more of the 'unknowns' and generally come up with higher estimates (Rahmstorf, 2007). A Dutch commission has suggested to coastal planners in the North Sea region a magnitude of 1 m until the end of this century, and a continued rise throughout subsequent centuries (Deltacommissie, 2008). For the last interglacial 115,000 to 127,000 years ago, a sea level of about 4-8 m above the present has been reconstructed with mean temperature being only slightly

warmer than now (O'Leary et al., 2013; Rohling et al., 2008).

Such figures may be sufficient to start with instead of postponing the issue of sea level rise. It is clear that an early start will become cheaper in the long run, and that in case of a disaster it would be good to have an elaborated strategy at hand for the period thereafter. The basic idea is to grow with the sea as salt marshes and tidal flats have done in the past for thousands of years. This natural process has been intercepted by the building of dikes and prompted the subsidence of land. The question is how the concept of growing land with the sea can be combined with the continued presence of people and a thriving economy.

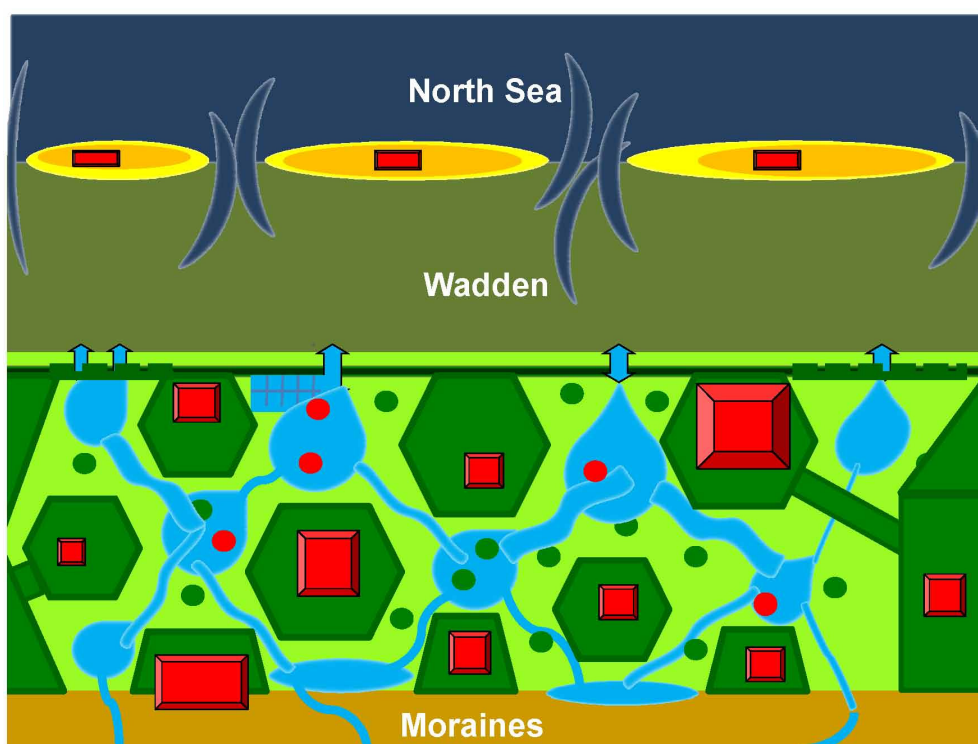


Figure 5. Scheme for adaptations to sea level rise for a sector of the Wadden Sea region with a chain of barrier islands between the North Sea and the tidal flat area (wadden), an embanked marsh area bounded by higher elevations of moraines of glacial origin. To keep dune islands in position, sand extracted from offshore bottoms of the North Sea is supplied (yellow). The main dike is supplied with overwash sections (toothed dark green) and sluices (arrows) connecting the marsh with the sea. Residential areas (dark green and red) protected by auxiliary dikes are interspersed into nature areas (blue and light green) subject to seasonal flooding. For touristic use, traditional dwelling mounds (green dots) and floating homes (red dots) are made available. For further explanation see text

A suggested solution for the Wadden Sea is schematically shown in Figure 5. For the sandy barrier islands continued nourishments with sand dredged from offshore areas in North Sea is seen as sufficient to keep the islands in position and to save the touristic infrastructures which have arisen there over the last 150 years. Presumably, large amounts of sand nourished at a time would be more efficient than a piecemeal strategy at short intervals. Most tidal flat areas and the adjacent belt of salt marshes are expected to grow with the sea. Larger volumes of water swinging in and out of the Wadden Sea may also transport larger amounts of sediments. However, there is a time lag, and it is discussed at what rate of sea level rise the sediment accretion will lag behind (CPSL, 2010; Oost et al. 2012; Wang et al., 2012). In any case, where the sediment balance becomes negative, this could also be mitigated by sand nourishments with sand taken from offshore areas.

While the adaptive capacity of the natural system is assumed to be high, the embanked marsh has already demonstrated its negative capacity with respect to sea level rise over the past centuries. Measures are needed which stop soil compaction by keeping rain water in the land. Then the next step is reversing the trend of a sinking land by allowing tides with suspended sediment to enter the marsh, without precluding the potential to live and work safely in the area. This can only be accomplished by diversification of the landscape.

For safety, the present line of defense should be reinforced as in the fortress strategy. However, the defense structure could also be used for additional purposes. This could distribute costs or even allow for an income. For example, dikes could be widened to incorporate roads, housing and promenades. Sectors of the dike could also be built of concrete and be hollow, for use as restaurants or similar facilities with access from land and a view to the sea (Metz and van den Heuvel, 2012).

Residential areas may be surrounded by auxiliary dikes. The lowest level of houses should not be used anymore for permanent living. Also other infrastructures should be reshaped to withstand flooding if all precautions fail. Between such residential areas, the land should be no longer drained. This would stop the process of subsidence. Arising lakes should be linked by canals to prevent stagnant water.

The main dike could include sectors which allow seawater to overflow the structure during storm surges. The height of the overflow structures could be adjusted to limit the amount that enters the marsh behind. During storms, seawater is particularly rich in suspended sediments. These could be trapped behind the dike and there contribute to a growing level of the land. In addition, the wetland vegetation will accumulate organic material, also raising the level of the land.

To compensate the loss of agricultural land, a touristic use is envisioned. Where still preserved from former times, farmhouses on dwelling mounds could be converted into tourist accommodations. In addition, new dwelling mounds could be built. In particularly deep lying areas which presumably would stay permanently under water, floating homes

or homes on pilings could seasonally accommodate tourists. In such a watery landscape, living and travelling would be an adventure. More water would partly restore former living conditions. Thus, this water-rich landscape also provides room for time. It is assumed that touristic use could more than compensate for a loss of arable land although these areas could still be used as pastures or for aquaculture.

Episodically flooded areas could also serve as carbon sinks through strong vegetative growth as other wetlands do. Together with wind energy turbines and panels for solar energy, this coast could be developed into a climate-friendly region. This would improve the image of the area which depends on subsistence for coastal defense. The gradual restructuring of the coastal lowland with more water would increase the contrast with the interior land and make it more attractive. This attraction will depend on life style, the willingness to live with more water and nature. This may be a great challenge in a region where getting rid of excess water has a tradition of almost one thousand years (Blackbourn, 2006).

The new water management may even need more expertise than the former drainage system. Water needs to flow in order to avoid adverse effects such as mosquito plagues. The mixing of marine water with freshwater restores lost brackish water habitats which prevailed before dikes had transformed the coastal landscape. However, the mixing regime should be kept modest. Otherwise few plants and animals would be able to adapt. The main dike also needs sluices for boats as well as for migrating fish. It is important to train personnel for water management within the coastal region to maintain the expertise and promote regional identity associated with coast and water.

A striking case of unsustainability has arisen in the estuaries. Shallow tidal rivers with ramifications and river islands have been transformed into deep shipping canals to serve major ports in upstream locations. Tidal range has increased and marine waters flow further upstream than before, causing irrigation problems for agriculture alongside the estuary, and requiring higher seawalls. Storm surges push water masses quickly into these waterways with a high risk for people in the adjacent lowlands in the countryside as well as in urbanized areas. To avoid disaster, it may become necessary to establish a swimming terminal for the transfer of cargo from large to small vessels in an offshore position. Then the estuaries may return to their former shallowness with high biodiversity and opportunities for recreation.

5. Conclusions

The Wadden Sea region comprises a dynamic tidal nature area with interspersed islands, separated by a coherent line of earthen seawalls from a transformed coastal marsh.

Draining the water out of the embanked marsh caused soil compaction and a sinking land while on the other side of the seawall the sea keeps on rising. When sea level rise begins accelerating in the wake of climate change, the resulting coastal gap constitutes an increasing risk.

The tidal nature area, on the other hand, has been upgraded from treacherous shallow waters to a World Heritage Site by trilateral efforts in nature protection. This area seems to be capable of adapting to an accelerating sea level rise without much support.

Therefore, it is suggested to smooth the strict separation and interlink the nature area with the transformed marsh. The latter could be diversified into high residential sites surrounded by episodically flooded marshes capable of growing with the sea.

This restructuring of the marsh would be feasible when former arable land is used for touristic purposes in an amphibious, seasonally flooded landscape which also serves as an effective carbon sink rich in wildlife.

Even if sea level rise will not accelerate as presently expected, the advocated water strategy would offset the coastal gap and increase the economic potential of the coast, while the traditional fortress strategy is heading in the long run towards coastal collapse.

This coastal case study demonstrates how dedicated nature protection could lead the way in coastal development rather than remaining confined to the conservation of endangered habitats and species.

The advocated water strategy is aiming for multifunctional and a multiple use of coastal structures and landscape elements. While in the past the coasts offered complementing land and marine resources, modern coasts mainly may offer recreation next to maritime trade.

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Examining the Impact of Korea's Free Trade Agreement (FTA) on Seaborne Trade Cargo Volumes¹⁾

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Abstract

This paper aims to estimate the net effect on port cargo volume generated by free trade agreement (FTA) through empirical analysis of port cargo, employing various econometric models. To estimate the change in trade volume, we adopted various models such as gravity model, network model, and modified gravity model. Our test results show that the net effects of the FTA on port throughput estimated by the network model account for 2~6% annual increase in terms of performance in 2012. In contrast, the net effects by the modified gravity model are four to six times higher than those by the network model. Therefore, it implies that there is a large gap in the estimated FTA effect among the applied estimation models. However, this gap can be explained so far as the diversion effect caused by the FTA in trade between countries is taken into consideration. We conclude that the modified network model is the most appropriate for estimating the effect of the FTA in terms of how easily the explanatory variables can be estimated, how exactly the diversion effect of trade can be excluded, and how simple the estimation is.

Key words: gravity model, network model, FTA, port throughput, substitution effect

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1. Introduction

The main purpose of the Free Trade Agreement (FTA) is to foster international trade between countries concerned enabling resource allocation improvement. The influx of foreign direct investment (FDI) is also expected to be encouraged because of the improvement of business circumstances resulting from FTA. With the productivity enhancement and capital accumulation in this process, it will lead to long-term economic growth.

The Korean government has made efforts to conclude the FTA with her key trading partners in the world, responding to the megatrends in the wave of FTA in the world. As a result, as of May 2014 The FTA affects 47 countries and regions including, among others, Chile, Singapore, EFTA (European Free Trade Association), India, European Union, Peru, United States, Australia, and Canada. Furthermore, the FTAs with Columbia, Australia and Canada are scheduled for implementation in near future as the relevant negotiations have been settled through 2013 and early 2014. In 2013, the Korea's share of trade volume with the FTA countries accounted for approximately 25% of the total import and export. If the FTA agreement with China, which is under negotiation is successful, the share of Korea's trade volume with the FTA countries is expected to exceed 50%.

Most previous researches on estimation of FTA's impact on the Korea's trade focused on the trade value rather than the trade volume. The latter is considered more significant in the field of port development and maritime transportation than the former because the trade volume is crucial information for extending the port facilities and determining the shipping schedule for each sea route in maritime transport. Although FTA's net promotion effect on trade volume is an important issue, particularly for those who has interest in the FTA, no research has been done to estimate the net effect directly until now. Estimating the net effect is not an easy task since numerous factors can affect the trade between the countries at the same time. The objective of this paper is twofold. First, through the empirical analysis of seaborne trade cargo, applying network model, gravity model, and modified gravity model, we estimate the net effect on port cargo volume caused by the FTA. Second, we investigate which model is the most reasonable to estimate it based on trade volumes, considering how easy it is to predict the explanatory variables, and each model's ability to take into account the diversion effect on trade from non-member countries to member countries of FTA.

2. Literature Review

Previous research results provided a comprehensive analysis of the FTA's impact on Korean economy (e.g., Bae et al. 2012; Joe and Song, MOFAT-KIEP, 2003, 2005a, 2005b, 2007; MLTMA, 2009; Song, 2011; Jung, 2005; Lee et al, 2013; Kim et al., 2009). Based on the trade data among the FTA partners, various analysis models were developed to estimate the impacts on production, added value, and employment. The impact (benefit) of tariff removal tariffs was introduced item by item through qualitative analysis of the FTA countries. The Ministry of Land, Transport and Maritime Affairs (2009) comprehensively analyzes the Korean domestic port throughput that is affected by changes in the global port volume due to the Korea-EU FTA. Kim et al. (2009) showed the FTA effect between Korea and each country in BRIC (Brazil, Russia, India, and China) through the CGE model. They computed the volatility of the GDP caused by the FTA and analyzed the increasing impacts on imports and exports in 12 industries. They also converted the estimated trade value into trade volume by using conversion coefficients.

Lee *et al.* (2013) estimated the changes in cargo throughput caused by the FTA between Korea and ASEAN using the global computable general equilibrium (CGE) model, namely, Global Trade Analysis Project (GTAP). They selected 13 countries¹⁾ and eight items²⁾ related to Korea's recent FTA and classified the tariff rates into eight categories based on three tariff scenarios.³⁾ Bae *et al.* (2012) performed the empirical analysis on the economic effects of the FTAs in terms of trade value between Korea-Chile, Korea-Singapore, Korea-EFTA, and Korea-ASEAN, using the gravity model. They added dummy variables (representing the FTA) to the generalized gravity model to estimate the effect on Korea's economy and examined how the FTA affected Korea's trade and analyzed which factors were responsible for these changes. Primo *et al.* (1994), Frankel (1997), Baier and Bergstrand (2007), and Magee (2008) added a dummy variable representing whether the FTA was undergoing a general type of gravity model. They classified the total Korean trade into two categories: one with member countries and the other with non-member countries of FTA according to the methodology from Cernat (2001), Magee (2008), and Plummer *et al.* (2010).

Joe *et al.* (2009) assumed different scenarios to analyze the economic impacts of the Korea-EU FTA using a self-established model. His research was designed to solve the weak points of the GTAP model by developing a new and highly reliable CGE model.

1) Korea, ASEAN, China, Japan, Taiwan, India, other Asian Countries, USA, other American countries, EU, other European countries, Oceania, etc.

2) Containerized general commodities, containerized agriculture commodities, major bulk, break bulk, liquid, crude oil, automobiles, and others.

3) Scenario 1: ASEAN+1 (China) FTA. Scenario 2: Korea-EU, Korea-USA FTA. Scenario 3: Korea-ASEAN FTA.

In particular, this model considered whether there was the constraint of capital flow. It showed that the estimated values under the two scenarios were different from each other. Lee et al. (2005) estimated the macroeconomic effect of the FTA among Korea-China-Japan using the CGE model through simulation analysis on the basis of the latest GTAP database. They analyzed also the FTA's ripple effect on each industry in three countries and proposed a counterstrategy for each industry. The Korea Trade-Investment Promotion Agency (2012) analyzes the FTA effect and shows the most beneficial industries in each country. It presents the top ten items that have the highest import growth rate in Korea. Lee et al. (2011) used the CGE model to estimate the port throughput after the Economic Cooperation Framework Agreement (ECFA) between China and Taiwan. They estimated the port throughput by multiplying the result of the post-simulation trade value by the conversion coefficient (ton/dollar) because their GTAP database was built based on the amount of money.

Lee and Lee (2011) applied the similar method to quantify the impacts of India, Brazil, and South Africa (IBSA) trade liberalization on seaborne cargo volumes. The major advantage of the GTAP model is that it can capture the effects of economy wide adaptation and asymmetric structure change in exports and imports caused by trade liberalization for the IBSA. In the literature, the CGE models were most widely used to estimate the FTAs' impacts on trade value. Cheong and Cho (2013) examined the impact of Korea's FTA and predicted the port throughput (including container throughput) referring to Lee and Lee's model to convert trade value to trade volume with GTAP in association with conversion coefficient (Lee and Lee, 2011; Lee et al., 2012). They claimed that the conversion coefficient has improved Lee and Lee's one and then analyzed the trade impact of FTAs, in particular, for 17 items with four main FTA partners (USA, EU, ASEAN, and India) in the short term and long term. They used the GTAP CGE model for estimating the effect of the FTA on each item in each country, and they converted the estimated trade value to trade volume using a containerized coefficient in each item.

However, the CGE model cannot be used to estimate the trade volume effect because the social accounting data that underlie the CGE model are in currency units. Therefore, the result of the CGE model analysis is expressed also in currency. Basically, a social accounting matrix cannot be created in units of volume, which makes it impossible to estimate the direct FTA trade volume effect through the CGE model. Therefore, when using the CGE model to estimate the fluctuations of import and export volume caused by an FTA, the indirect method is commonly used, which converts the trade value into the quantity of traffic by using the conversion coefficients. Moreover, when applying this indirect method, it is impossible to convert value into volume precisely because discrepancies occur when matching trade volume classified by HS (Harmonized Commodity Description and Coding System) codes to port throughput classified by SP-IDC (Shipping & Port – Internet Data Center)⁴. A more critical problem is that the estimated effects

of the FTA, based on trade value and trade volume, appear to be different on the imports and exports of each country. This means that the conversion coefficient may be different not only among commodity types but also among trading routes. Therefore, an error may be made in applying the indirect method that uses the conversion coefficient. In summary, to improve the reliability of estimated effect of the FTA, we need the econometric model, which focuses mainly on the trade volume from the beginning rather than trade value. In addition, few of the previous researchers analyzed econometrically the relationship between the implementation of FTAs and trade volume. Having said that, this paper applies gravity model, network model, and modified gravity model to estimate the net effect on port cargo volume generated by FTA through empirical analysis of port cargo, applying and to investigate which model is the most appropriate to estimate the impact of FTA on the trade volumes.

3. Impact of FTA on Seaborne Trade Volume

3.1 Data Set for the Analysis

To achieve a meaningful statistical analysis, we limited the targeted countries with Korea to those of which the FTA came into effect quite long before. Accordingly, Chile (April, 2004), Singapore (March, 2006), and ASEAN (June, 2007) were chosen for the analysis. To confirm whether the FTA with these selected countries made a significant impact on Korea's' trade, we examined if there were meaningful differences in the actual trade volume between the periods before and after the FTA. Additionally, we select the most appropriate model for estimating the effect of the FTA, not only on the trade value but also on the trade volume. We obtained the records for the import and export throughputs from SP-IDC and trade value data from the Korea International Trade Association. The differences between trade volume (import and export throughput) and trade value resulted from that air cargo is included or not. Here, the import and export trade volumes were only the maritime traffic cargo.

Since Korea's imports and exports have steadily increased over the last decades, examining only the absolute trade numbers could not determine the true significant difference in trade volume or trade value before and after the FTA. Rather, we examined the share of each country's imports and exports for Korea. That is, if the share variation of a certain country before and after the FTA was statistically significant, it could be said that there was an additional increase in imports and exports caused by the FTA with that

4) Shipping & Port - Internet Data Center (www.spidc.go.kr).

country. When calculating the share variation between two periods, the length before the FTA should be considered. It might be long enough to secure statistical reliability of any statistics during the periods examined.

We used observed data since 2000, in consideration of recording history of SP-IDC and reliability of significance test for calculated statistics. We conducted a t-test to determine the significance of the variation between the two periods and set up the confidence interval at 5%. However, if the t-statistics is not much different from a 5% error bound, it is regarded as significant also. We assumed that the variances in the two periods were equal. If the result of the t-test for one nation was significant, it was determined that an obvious effect of the FTA existed.

From the result of the t-test of trade volume for the three countries, the exports between Korea and Chile, imports and exports between Korea and Singapore, and imports and exports between Korea and ASEAN proved to be significant. On the other hand, based on trade value, it could be judged that the following trades were significant: imports and exports between Korea and Chile, exports between Korea and Singapore, and exports between Korea and ASEAN. From the t-test, it can be inferred that the result based on trade value was quite different from the one based on trade volume. The discrepancies resulted from the difference of the FTA effect on goods among each country. It is natural that the large deviation between the two different units occurs when the FTA effect happens to be noticeable in luxury goods that are small in volume or liquid bulk goods of great size. Therefore, a severe error may happen in estimating the trade volume by applying the indirect method that uses the conversion coefficient which converts value into volume. For this reason, we need the econometric model focusing mainly on the trade volume from the beginning rather than trade value.

Table 1. The results of the significance in the three FTA groupsa

(a) Korea-Chile

Item	Based on volume (share)				Based on value (share)			
	Import		Export		Import		Export	
	2000–2004	2005–2012	2000–2004	2005–2012	2000–2004	2005–2012	2000–2004	2005–2012
Average	0.5063	0.4395	0.4384	0.9802	0.6008	1.0006	0.3100	0.5709
Variance	0.0004	0.0136	0.0029	0.0853	0.0230	0.0171	0.0024	0.0242
Number of observations	5	8	5	8	5	8	5	8
Pooled variance	0.0104		0.0553		0.0192		0.0162	
Degree of freedom	11		11		11		11	
T-statistics	1.1480		-4.0402		-5.0507		-3.5854	
P-value	0.1376		0.0009		0.0001		0.0021	

(b) Korea-Singapore

Item	Based on volume (share)				Based on value (share)			
	Import		Export		Import		Export	
	2000– 2006	2007– 2012	2000– 2006	2007– 2012	2000– 2006	2007– 2012	2000– 2006	2007– 2012
Average	0.908	1.2193	3.006	3.5417	2.1316	1.9497	2.6754	3.6704
Variance	0.0462	0.0022	0.332	0.5086	0.0261	0.0628	0.1191	0.1347
Number of observations	7	6	7	6	7	6	7	6
Pooled variance	0.0353		0.4123		0.0428		0.1262	
Degree of freedom	11		11		11		11	
T-statistics	-2.975		-1.668		1.5795		-5.0335	
P-value	0.0126		0.086		0.1425		0.0003	

(c) Korea-ASEAN

Item	Based on volume (share)				Based on value (share)			
	Import		Export		Import		Export	
	2000– 2007	2008– 2012	2000– 2007	2008– 2012	2000– 2007	2008– 2012	2000– 2007	2008– 2012
Average	11.3453	13.6783	10.3126	12.2571	10.3477	10.0889	10.4743	12.3469
Variance	0.6358	1.0622	1.7311	1.0411	0.6042	0.1916	0.6444	1.8089
Number of observations	8	5	8	5	8	5	8	5
Pooled variance	0.7909		1.4802		0.4541		1.0679	
Degree of freedom	11		11		11		11	
T-statistics	-4.6015		-2.8034		0.6738		-3.1785	
P-value	0.0007		0.0171		0.5143		0.0087	

^aUsing data since 2002.

3.2 Applied Models for Impact Estimation of Korea's FTA on Seaborne Cargo

In this section network model, gravity model, and modified gravity model are applied for the estimation of net effect on port cargo volume generated by FTA. Through these empirical analyses we also are to investigate which model is the most appropriate to estimate the impact of FTA on the trade volumes.

3.2.1 Network Model Estimation

In international trade theory, Linder (1961) considers the GDP of trade-participating countries and changes in non-participating third nation's economic conditions in trade networks to be important factors in making an impact on trade volume. In the globalized

world in tandem with FTA, Asian countries have come to form complex trade networks. Therefore, the persuasive power of Linder's logic has become stronger. A network theory considers the synergistic effect caused by the interactions among network members and the network externality, as described in Linder's theory. The network externality is defined as positive in the case of an increase in activities between two particular members influenced by an increasing number of activities among the network members. In an international trade network where Korea has played an important role, this positive network externality has been generally observed recently. In other words, as the number of Korea's trade partners and global trade volume increases, the amount of trade volume between Korea and other countries also rises. This means that Korea's trade receives positive external effects from international trade networks.⁵⁾

We constructed a network model to forecast the port throughput using traffic and other economic-related data between Korea and the 17 other groups (a total of 51 countries including nine ASEAN countries and 27 EU countries). To achieve this, an international network was formed of the 17 groups with Korea. With the exception of Singapore and Croatia, ASEAN and EU were each considered a single group. We estimated the impact of the FTA on Korea port throughput based on economic-related variables like the tariffs and GDP of the network countries.

- The throughput function is defined as $Q_{it} = F(G_{it}, K_{it}, I, t)$ based on the theory of international trade.
- Q_{it} , G_{it} , K_{it} are the nations' yearly port throughput, trade potential index, and tariff index, respectively, according to nations ($i = 1, 2, 3, \dots, N$) and years ($t = 1, 2, 3, \dots, T$).
- In addition, K_{it} represents the trends of the tariff rates between Korea and other countries and is calculated by multiplying the Korean tariff rates by the other countries' yearly tariff rates.
- A regression analysis is applied using the trade potential indexes and port traffic data between Korean and other countries. Q_{it} is the trade volume and can be calculated by the following equation:

$$\log Q = \alpha + \lambda_t + \beta_G \log G + \beta_T \log K + \nu_i + \epsilon \quad (5.1)$$

λ_t is the year dummy variable calculated by using the time effect.

ν_i is the country-specific effect invariant over time.

ϵ is a random error term.

5) The Ministry of Land, Transport and Maritime Affairs (2009) predicted the trade volume between Korea and the EU after the FTA by using these features of network theory. T is the increased trade volume between Korea and other particular nations caused by the externality, and S is the size of the international trade network. Therefore, T is equal to f(S), and we can assume that f(0) = 0 and f'(s) ≥ 0.

In the case of the fixed effects model, such as Eq. (5.1), U_i , which is the country specific effect, is generally calculated by using dummy variables for each country. However, it is difficult to obtain statistically significant results if there are too many dummy variables because there are as many variables to be estimated. Therefore, this paper transformed Eq. (5.1) to solve this problem by removing U_i and introduced the following within-countries regression Eq. (5.2):

$$\log Q - \log Q_i = \beta_G(\log G - \log G_i) + \beta_T(\log K - \log K_i) + \epsilon - \epsilon_i \quad (5.2)$$

$$\log X_i = 1/T \cdot \sum_{t=1}^T \log X$$

In Eq. (5.2), the results obtained by the method of ordinary least squares were technically the same as those derived from the method of least squares dummy variable. We estimated the effect of the FTA using the fixed effects model (5.2).

3.2.2 Trade Potential Index

Seventeen groups (51 countries all belonging to ASEAN and EU) were included in the trade network with Korea. To estimate the trade potentials among all the included countries, we named this network “K-Network.” The K-Network consists of the 17 groups that showed the most active trade movement with Korea including nine ASEAN countries and 27 EU countries. The K-Network intersects each 18 point mutually. The trade potential index is represented by the weight of each line connecting two countries. This paper adopted the same procedure used by the Ministry of Land, Transport and Maritime Affairs (2009) to calculate the index.

Table 2. The trade potential index between Korea and other main trading partners

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Taiwan	288.5	278.9	290.3	317.7	362.2	405.3	446.2	504.0	560.8	531.1	605.1	680.9	709.7
Russia	274.8	281.3	299.8	343.3	411.8	485.3	566.0	665.6	703.2	623.4	733.4	834.7	856.3
Mexico	331.4	330.1	353.5	390.8	439.4	499.4	560.0	626.8	650.3	592.1	687.3	769.3	798.1
Brazil	340.5	320.8	329.9	366.2	424.1	504.7	581.4	674.8	702.5	655.1	789.5	882.8	904.2
Saudi Arabia	258.0	255.4	262.3	293.2	340.2	392.8	441.1	501.9	573.2	531.0	608.6	698.1	731.1
United Arab Emirates	233.4	233.6	237.3	264.6	309.5	352.7	401.9	467.0	545.4	513.4	580.2	662.3	693.6
Iran	232.4	237.3	239.7	268.5	314.7	356.5	402.2	475.3	549.8	523.8	591.6	664.2	690.5
Japan	660.0	597.9	656.4	725.4	794.8	871.9	919.8	972.2	905.2	840.9	994.5	1,078.9	1,081.5
China	406.8	406.1	453.5	508.8	580.3	674.9	775.3	900.6	888.2	839.0	1,016.4	1,144.5	1,175.5
Australia	305.2	294.4	310.3	350.8	416.0	473.5	525.3	597.8	646.9	596.2	697.8	791.1	819.2
Hong Kong	252.9	251.4	255.1	276.4	315.5	351.7	390.9	450.5	524.6	501.8	564.0	638.4	668.7

Country	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
ASEAN	320.9	312.6	339.7	380.1	431.1	489.5	559.9	642.2	673.9	632.4	748.9	829.8	860.0
EU	841.4	799.2	944.0	1,100.8	1,228.3	1,384.9	1,521.9	1,672.6	1,387.0	1,200.4	1,403.3	1,505.1	1,497.4
USA	899.5	861.0	996.8	1,085.2	1,167.9	1,328.0	1,455.2	1,534.5	1,265.9	1,134.8	1,347.8	1,428.9	1,435.7
Singapore	230.5	229.6	229.9	252.5	295.3	331.2	371.5	436.6	512.6	494.7	561.3	637.5	667.7
India	314.9	312.0	333.1	377.4	433.4	497.0	559.5	657.0	663.4	634.9	751.4	833.9	863.1
Chile	222.6	221.4	219.9	243.8	289.7	331.0	377.8	438.4	515.9	493.9	562.0	639.5	672.0

Notes: 1. ASEAN excludes Singapore.

2. EU includes 27 countries except Cyprus.

3. Estimated by using 2012's GDP growth rate from Global Insight

source: the present writer.

4. Estimation Results by Model and Discussions

4.1 Network model estimation

We estimated the regression equation based on the network model by adopting the respective trade potential indices and tariff rates of 51 countries as the main independent variables with 13 years of data (2000 to 2012). By that established model, we calculated the effect of the FTAs of three selected countries. All of the results for the model estimation proved to be significant, showing high correlation coefficients and F-values. Additionally, there was not any multi-collinearity or autocorrelation when checked by Durbin-Watson test statistics. Judging the significance of the coefficients of two explanatory variables, the tariff rates, and the trade potential indexes by p-values, the latter showed to be more significant. In other words, the trade potential index provided a better explanation of the FTA effect than the tariff rate in the network model. This model showed that the potential trade index made positive impacts on Korean trade throughput; however, the tariff rate was negative.

Table 3. The estimation results of the network model between Korea and Chile

Items	(i) between Korea and Chile	(i) between Korea and ASEAN	(i) between Korea and Singapore
β_G	0.6037 (5.293)	0.722 (9.988)	0.695 (4.424)
β_T	-0.0277 (-1.164)	-0.017 (-1.509)	-0.018 (-0.432)
F	30.366	94.710	21.710
$Adj. R^2$	0.741	0.849	0.689

Note: () is T-statistics.

Table 4 shows the empirical results of the estimated port throughput by using the network model. In case of Chile, the annual average effect of the FTA after implementation was 345,000 tons. Its increasing rate of trade volume compared to 2012's was 6.1%. For the ASEAN, the annual average increased traffic volume affected by the FTA was 489 million tons, which was a 3.4% increase compared to 2012. The effect of the FTA with ASEAN showed very sharp upward trends due to tariff reductions. The smallest effect among the three countries was in the FTA between Korea-Singapore, showing an annual average of 482,000 tons. After implementing the FTA, Singapore's trade volume increased only 2.1% annually on average due to Singapore's duty-free tariff system. It is difficult to determine the common features of the network model by considering only these three results. However, it shows that the FTA effect tends to be more sensitive to changes in the tariff variables of which the statistical significance was rather low because the trade potential index does not change rapidly.

Table 4. The analysis on the FTAs' effects on port throughput between FTA-participating countries

Country	Year	Port throughput in 2012 (thousand tons)	Annual average changes in throughput (thousand tons)	Annual growth rate of empirical result compared to 2012 (%)
Chile	2005~2012	5,699	345	6.1
ASEAN	2008~2012	145,589	4,889	3.4
Singapore	2007~2012	23,308	482	2.1

Source: Compiled by the authors.

4.2 Gravity Model Estimation

The gravity model is one of the most widely applied methodologies for the empirical estimation of the FTA's effect on trade value. We applied gravity model to this study using the following equation and calculated the effect of FTA using dummy variables of 0 or 1.

$$\ln Y_{jt} = \beta_0 + \beta_1 \ln gdp_{jt} + \beta_2 \ln dist_{jt} + \beta_3 inland_{jt} + \beta_4 FTA_{jt} + \sum_{k=1}^6 \gamma_k region_k + \sum_{t=2000}^{2012} \delta_t year_t + e_j \quad (5.3)$$

Y : The total port throughput of Korea between Korea and a trading partner j in year t , as the dependent variable.

j : a trading partner.

t : year.

ln: natural logarithm.

gdp: the log value of GDP (nominal) at the trading partner.

dist: distance between Korea and a trading partner (calculating the distance between, especially, Seoul and the capital of a trading partner).

inland: dummy variable indicating whether the trading partner is an inland country (inland = 1, not inland = 0).

region: dummy variable indicating the continent that a trading partner with Korea belongs to (divided into six continents).

year: dummy variable for controlling the changes in macroeconomic factors by year.

FTA: FTA dummy variable. If Korea and a trading partner's FTA already came into effect in year t , this variable is presented as 1, if not, it is presented as 0.

In Eq. (5.4), the FTA variable is replaced with other variables, Chile, Singapore, and ASEAN, which indicate the FTA countries with Korea. The explanatory variable “region,” which was set for finding the feature of each continent, was divided into six areas: North America, South America, Europe (including Russia), Middle East-Africa, Asia, and Oceania. The variable Chile identifies the FTA between Korea and Chile. Singapore and ASEAN have the same meaning as Chile; therefore, each coefficient of each dummy variable representing the country's FTA can be interpreted as the increase in the trade volume by the FTA,

$$\ln Y_{jt} = \beta_0 + \beta_1 \ln gdp_{jt} + \beta_2 \ln dist + \beta_3 inland_{jt} + \beta_4 Chile_{jt} + \beta_5 Singap_{jt} + \beta_6 ASEAN_{jt} + \sum_{k=1}^6 \gamma_k region_k + \sum_{t=2000}^{2012} \delta_t year_t + \epsilon_{jt} \quad (5.4)$$

We used the related data between Korea and the 57 other main trading partners for the 2000–2012 in the analysis. We obtained the port throughput data from SP-IDC, GDP from the National (Korea) Statistical Office's international statistics,⁶⁾ and World Bank World Development Indicators. These data were in nominal dollar units. The geographic data of the trading partners were extracted from the Centre d'Etudes Prospectives database.

Table 6 shows the results of the estimated coefficients of Eq. (5.4). The average trade volume can be calculated if the actual data for the independent variables is applied to the estimated equation. According to the estimated results in this study, the coefficient

6) National (Korea) Statistical Office (<http://kosis.kr/>).

of GDP showed a statistically significant positive sign, which means that Korean imports and exports increased as the trading partners' GDP grew. The distance variable "Indist" representing the trade-related costs, such as the distance between trading countries, was negative. This showed that the greater the distance, the less the trade volume. These results coincide well with the basic assumption of the gravity model.

We tried to include as many countries as possible unless a particular country was indifferent to Korea's trade, because the sign and the statistical significance of the estimated coefficients responded sensitively to the number of sample countries. Twenty-four countries were added to the previous 33 samples in the network model to increase the statistical significance and maintain the features of the gravity model.

From the estimated model, it was proven that the trade with non-inland countries was more active than with the inland ones. This result was similar to the generalized gravity model. In terms of continents, the tendency of an increasing trade volume was remarkable in Oceania, South America, middle east Africa (in order). On the other hand, the Asian countries (except ASEAN and Europe-Russia) that were suffering from economic recession showed relatively slow growth rates in trade volume. The slow growth rate in Asia resulted from the European economic recession that began in 2000. In this model, all of the estimated coefficients were within 1% significance level, meaning that everyone was statistically significant. Among the three countries, the effect of the FTA was highest in the ASEAN followed by Singapore and Chile.

Table 5. Gravity model analysis on the FTAs' effects on port throughput among the FTA countries.

	Including all 57 countries	
	Estimated coefficients	P-value
Y-axis intercept	57.7903 (2.2262)	0.0263
ln gdp	0.6520 (15.7799)	4.17233E-48
ln dist	-1.8251 (-10.356)	1.87082E-23
Inland	-4.6667 (-13.5863)	2.04317E-37
Chile	1.3211 (2.9443)	0.0033
Singapore	2.5205 (4.7870)	2.07377E-06
ASEAN	2.6742 (4.7223)	2.81904E-06
North America	3.6672 (6.4669)	1.8973E-10
South America	3.8462 (6.9320)	9.56837E-12
Europe-Russia	1.4539 (2.9570)	0.0032
middle east-Africa	3.8425 (7.9703)	6.58371E-15
Asia	1.3466 (3.2262)	0.001313709
Oceania	4.1393 (9.6377)	1.04971E-20
Year Dummy	-0.0198 (-1.5279)	0.1270
Observations	702	
Adjusted R^2	0.655	

* () is T-statistics

Source: Compiled by the authors.

4.3 Modified Gravity Model

Since the gravity model controls the impact of the FTA with a dummy variable, the model is suitable for carrying out empirical analysis for past performance rather than expected future effect. Comparing each country's relative FTA effect to some degree, however, is not appropriate for estimating the real future effect of the FTA. Given that the effect of the FTA is estimated by using dummy variables, all of increased trade after the FTA may be recognized as a net outcome of the FTA. Therefore, there is a risky possibility that the gravity model may overestimate the effect of the FTA. To resolve this problem, we made a modified gravity model, Eq. (5.5), which replaced the dummy variables with ones representing the effect of the tariff used in the network model

$$\begin{aligned} \ln Y_{jt} = & \beta_0 + \beta_1 \ln gdp_{jt} + \beta_2 \ln dist + \beta_3 \ln land_{jt} + \beta_4 Chile_E_t \\ & + \beta_5 Singap_E_t + \beta_6 Singap_I_t + \beta_7 ASEAN_E_t + \beta_8 ASEAN_I_t \\ & + \sum_{k=1}^6 \gamma_k region_k + \sum_{t=2000}^{2012} \delta_t year_t + \epsilon_{jt} \end{aligned} \quad (5.5)$$

$Chile_E_t$: $\log ChileE_{kt} - \log ChileE_k$

$Singp_E_t$: $\log SingapE_{kt} - \log SingapE_k$

$Singp_I_t$: $\log SingapI_{kt} - \log SingapI_k$

$ASEAN_E_t$: $\log ASEANE_{kt} - \log ASEANE_k$

$ASEAN_I_t$: $\log ASEANI_{kt} - \log ASEANI_k$

$ChileE_{kt}$: Import tariff rate to Korea in Chile on t .

$SingapE_{kt}$: Import tariff rate of Singapore for Korea on t .

$SingapI_{kt}$: Import tariff rate of Korea for Singapore on t .

$ASEANE_{kt}$: Import tariff rate of the ASEAN for Korea in on t .

$ASEANI_{kt}$: Import tariff rate of Korea for the ASEAN on t .

$$\log \bar{E}_k = 1/T \cdot \sum_{i=1}^T \log E_{ki}$$

$$\log \bar{I}_i = 1/T \cdot \sum_{i=1}^T \log I_{ki}$$

Overall, the coefficients estimated in the modified gravity model did not show any particular differences compared to the generalized gravity model. However, the substituted import-export tariff coefficients' statistical significance was lower than those of the dummy variables. Nevertheless, it was obvious that the modified model was more useful for estimating the net FTA effect since it clarified the cause-and-effect relationship between trade volume and each explanatory variable. Table 6 and 7 show the effect of the FTA on port throughput estimated by the modified gravity model. The test results show that the estimated port throughputs are four to six times higher than those of the network model. It can be said that those estimated digits are too high as the FTA net effects. Though modified gravity model complemented the reliability of estimation by introducing the tariff variables, it was still vulnerable to overestimation because it focused on the relationship of two involved FTA countries. Modified gravity model estimates the FTA effect by analyzing the functional equation between trade volume and the variables such as GDP and tariff rates. It limits the utility as estimation model for the absence of considering the substitution effect caused by the FTA. Anyhow, it draws a finding that there is a large gap in the estimated FTA effect among the applied estimation models

Table 6. Modified gravity model analysis on the FTAs' effect on port throughput of all 57 countries

Variables	All 57 countries	
	Estimated coefficients	P-value
Y-axis intercept	42.3067 (1.6409)	0.1012
ln gdp	0.6687 (16.4881)	5.65E-52
ln dist	-1.4690 (-9.1363)	6.62E-19
Inland	-4.6936 (-13.7092)	3.95E-38
Chile_E	-0.7526 (-1.3095)	0.1908
Singap_I	-0.4087 (-1.0799)	0.2805
Singap_E	-0.6724 (-1.3548)	0.1759
ASEAN_I	-0.4616 (-1.4097)	0.1591
ASEAN_E	-0.2974 (-0.9979)	0.3187
North America	2.8067 (5.1920)	2.72E-07
South America	2.8520 (5.4785)	5.95E-08
Europe-Russia	0.7190 (1.5322)	0.1259
Middle East-Africa	3.1347 (6.8084)	2.1E-11
Asia	1.3758 (3.3093)	0.0010
Oceania	3.3570 (8.3889)	2.63E-16
Year Dummy	-0.0134 (-1.0385)	0.2994
Observations	727	
Adjusted	0.655	

※ () is T-statistics.

source: the present writer

Table 7. Modified gravity analysis on port throughput between the FTA three groups

FTA's trading Group	Year	Port throughput in 2012 (thousand tons)	Annual average changes in throughput (thousand tons)	Annual growth rate of empirical result compared to 2012 (%)
Chile	2005~2012	5,699	823	14.4
ASEAN	2008~2012	145,589	19,291	13.3
Singapore	2007~2012	23,308	2,927	12.6

5. Discussions and Conclusion

This paper has estimated the net effect on port cargo volume generated by free trade agreement (FTA) through empirical analysis of port cargo, applying network model and modified gravity model and to investigate which model is the most appropriate to estimate the impact of FTA on the trade volumes. Our test results show that the net effects of the FTA on port throughput estimated by the network model account for 2%~6% annual increase in terms of performance in 2012. In contrast, the net effects by the modified gravity model are four to six times higher than those by the network model. Therefore, it implies that there is a large gap in the estimated FTA effect among the applied estimation models. However, this gap can be explained so far as the substitution effect caused by the FTA in trade between countries is taken into consideration. Generally, the FTA positively affects trade volume between the countries that are directly involved, but not for all. Sometimes the diversion effect occurs after the FTA, so the other country's trade volume may decrease when the directly involved countries' volumes increase. Therefore, there is a high possibility that bias may happen when performing an analysis on the effects of an FTA by considering only the two countries involved. If we do not consider the diversion effect, the FTA impact may be overestimated. In this respect, the network model may be one step ahead because it considers every trading partner and the mutual interactions among them. In this study, the estimated output from the network model was lower than any other estimator because the estimated FTA effect indicated the net creation value excluding the diversion effect. It is reasonable that the network model estimated FTA effect shows a low level because it considers all countries' mutual interactions regardless of the FTA with Korea. Our test results shows that the gravity model can be useful for analyzing the effect of FTA empirically. However, the model controls all the effects of the analysis such as the FTA effect, continental region effect, and the annual effect by dummy variables, so it is more appropriate for an empirical analysis rather than estimating the future effect of the FTA. In other words, the gravity model is helpful to compare each country's relative effect of the FTA and the trends in changes of the trade volume for each continent than to forecast the FTA's effect on trade volume. This study introduced the modified gravity model, which

replaced the dummy variables in the gravity model with new ones to resolve these weak points. However, it cannot also exclude the substitution effect. The existence of the substitution effect creates the differences in the estimated effect of the FTA between the modified gravity model and the network model.

The comparison of our test results among the three models lead us to conclude that the modified network model is the most appropriate model among the three applied models in this paper for estimating the effect of the FTA in terms of how easily the explanatory variables can be estimated, how exactly the diversion effect of trade can be excluded, and how simple the estimation is.

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Use of ship traffic density from Automatic Identification System (AIS) and Vessel Monitoring Systems (VMS) in marine spatial planning: a case study in New England coast, USA

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ABSTRACT

Analyzing current and anticipated uses of ocean and coastal areas based on scientific understanding and information is quite critical to achieve a successful Marine Spatial Planning (MSP). One of key elements in ocean and coastal use is navigation and thus vessel traffic density should be included as part of MSP. One of emerging techniques to quantify ship traffic density is to analyze Automatic Identification System (AIS) and Vessel Monitoring System (VMS) data for a designated area. This study presents a case study conducted in New England area, USA, where the ship traffic density was estimated by analyzing AIS/VMS data. The results of ship traffic density were used in MSP (e.g., Northeast Ocean Data Portal), which were later used by one of stake holders, U.S. Department of Interior, Bureau of Ocean Energy Management when they issued wind lease blocks in outer continental shelf off Massachusetts.

Key words: ship traffic density, ocean planning, environmental assessment, decision making

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1. Introduction

Marine resources are common property resources with open or free access to users. Human uses of the ocean and coasts are expanding at a greater rate, so that our capability in managing and planning them under the conventional sector-by-sector approach has been challenged. Recently, the concept of Marine Spatial Planning (MSP) was introduced to make decisions on how to use marine resources in more efficient, sustainable and ecosystem-based way (Crowder et al., 2006; Douvere, 2008; Dalton et al., 2010; Foley et al., 2010). MSP is a comprehensive, adaptive, integrated, ecosystem-based, and transparent spatial planning process, based on sound science, for analyzing current and anticipated uses of ocean and coastal areas (The White House Council on Environmental Quality, 2010). In MSP, scientific understanding and information are critical to achieve an integrated planning process (Foley et al., 2010).

In MSP, multiple anthropogenic uses including transportation, fishing, and aquaculture should be managed in a manner that reduces conflict and enhances compatibility among uses with sustained ecosystem functions. Ship traffics affect the environments in various ways including risk of collisions, spill of oils, and noise (Hatchet et al., 2008; Perez et al., 2009). For instance, the United Nations International Maritime Organization (IMO) shifted shipping lanes near the Boston Harbor in the USA based on scientific investigation of whale feeding behavior and habitat mapping, which reduces the risk of collisions with critically endangered right whales by an estimated 58% and all other baleen whales by 81% (NOAA National Marine Sanctuaries, 2009). Thus, in addition to studying marine ecosystem, understanding marine transportation system would be one of key elements in setting up MSP.

Among the numerous ways in quantifying ship traffics, the analysis of the Automatic Identification System (AIS) and Vessel Monitoring System (VMS) data is one of emerging techniques (Santos et al., 2012). AIS is an autonomous and continuous broadcast system that transmits electronic data including vessel identification, position, speed and course etc. VMS uses Global Positioning Systems (GPS) in conjunction with shipboard sensors to automatically exchange navigation information electronically. In this study, AIS and VMS data are analyzed to estimate ship traffic density, which later would be used to set up a MSP. Our goal is to present a case study showing how to quantify ship traffic density from AIS and VMS data in the New England area, USA and how this ship traffic density can be used in MSP. Sensitivity of grid resolution when analyzing AIS and VMS data is also discussed in the paper. Chapter 2 describes the data used in the present study. The data analysis method and main results can be found in the following chapter. Chapter 4 shows some sensitivity results depending on temporal and spatial data analysis grid. Finally, how these ship traffic analysis results were utilized in setting up MSP is included in Chapter 5.

2. Data sets

As part of international security regulations, most commercial marine vessels are required to install the Automatic Identification Systems (AIS). The International Maritime Organization (IMO) requires AIS to be fitted aboard passenger ships carrying more than 165 passengers and commercial vessels with gross tonnage of 300 or more and (IMO, 1974). The AIS is used by marine vessels in coordination with Vessel Traffic Services (VTS) to monitor vessel location and movement primarily for traffic management, collision avoidance and other safety applications.

AIS transmitters send data at least every 2 seconds while underway and every 3 minutes while vessels are at anchor. AIS binary message includes time stamp (to nearest second), longitude and latitude (to 1/10,000 minute), position accuracy, speed over ground (0.1 knot resolution), course over ground (to 0.1 degree), true heading, and others (Table 1). In addition, the following data are broadcast every 6 minutes: IMO's ship identification number, vessel name, ship information including type, dimensions, and draught, destination and estimated time of arrival (ETA).

Table 1. Typical data elements received from AIS

Attribute	No. of bits	Description
Message ID	6	Identifier for this message 1, 2, or 3
Repeat indicator	2	Used by the repeater to indicate how many time a message has been repeated
User ID	30	MMSI number
Navigational status	4	Under way using engine, at anchor, not under command, restricted maneuverability, constrained by her draught, moored, aground, engaged in fishing, under way sailing, etc.
Rate of turn	8	$\pm 127^\circ$
SOG	10	Speed over ground in 1/10 knot steps
Position accuracy	1	High (<10 m) vs. low (<10 m)
Longitude	28	Longitude in 1/10,000 min ($\pm 180^\circ$)
Latitude	27	Latitude in 1/10,000 min ($\pm 90^\circ$)
COG	12	Course over ground in 1/10 $^\circ$
True heading	9	0-359 $^\circ$
Time stamp	6	UTC second when the report was generated
Reserved for regional applications	4	Reserved for definition by a competent regional authority
Spare	1	Not used
RAIM-flag	1	Receiver autonomous integrity monitoring flag of electronic position fixing device
Communication state	19	Communication state

The AIS data used in this study were provided by NOAA Gerry E. Studds Stellwagen Bank National Marine Sanctuary. Five receiving stations were operated by the US Coast Guard, located at Boston, Gloucester, Scituate, and Provincetown, Massachusetts, USA as well as on Fishers Island, New York, USA. The majority of the data used in this study is from the period between September 1, 2007 and August 31, 2008, but data from other period were also analyzed for the comparison purpose.

In addition to AIS data, data from Vessel Monitoring Systems (VMS) are used in the analysis. VMS is utilized by commercial fishing vessels, and thus supplementary to AIS data. It only provides time, position, speed and course via long-range radio technologies. VMS can be a good supplementary data set of AIS, since it is required to be installed even in vessels less than 300 gross tonnes.

3. Analysis of AIS and VMS data

Archived AIS data were extracted and decoded by AISparser® (<http://www.aisparser.com>). Binary AIS data were reformatted into comma separated files, and passed onto Matlab® for further analysis. VMS data were saved already in Oracle database, so just exported into comma separated format and then loaded onto Matlab. In Matlab, the chronologically-ordered continuous data from both AIS and VMS sources were rearranged as for vessel order based on ship identification number. For each vessel, the location data were saved along with time stamp and sorted into chronological order, resulting in a vessel's transit.

The location data was then divided into each track line based on time. In our analysis protocol, it is regarded as a separate track line when the time between two consecutive points is longer than 6 hours. AIS data was temporally dense enough to be used for analysis, while the VMS data were sparse so that temporal interpolation was necessary. When the points between two consecutive locations in VMS data were longer than 10 minutes, the data points were interpolated for every 5 minutes. For example, Figure 1 shows a track line of SHIP ID #3353 on the date of March 5, 2008. Black crosses represent the raw data, and red dots are for 5-min interpolated locations. When it had slow speed, the dots could make a line in the main plot but could be seen better in the inset plot. As seen in the zoomed-in box of Fig. 1, this vessel came down from North and stayed along 41.5°N line for hours, and then went out to east direction.

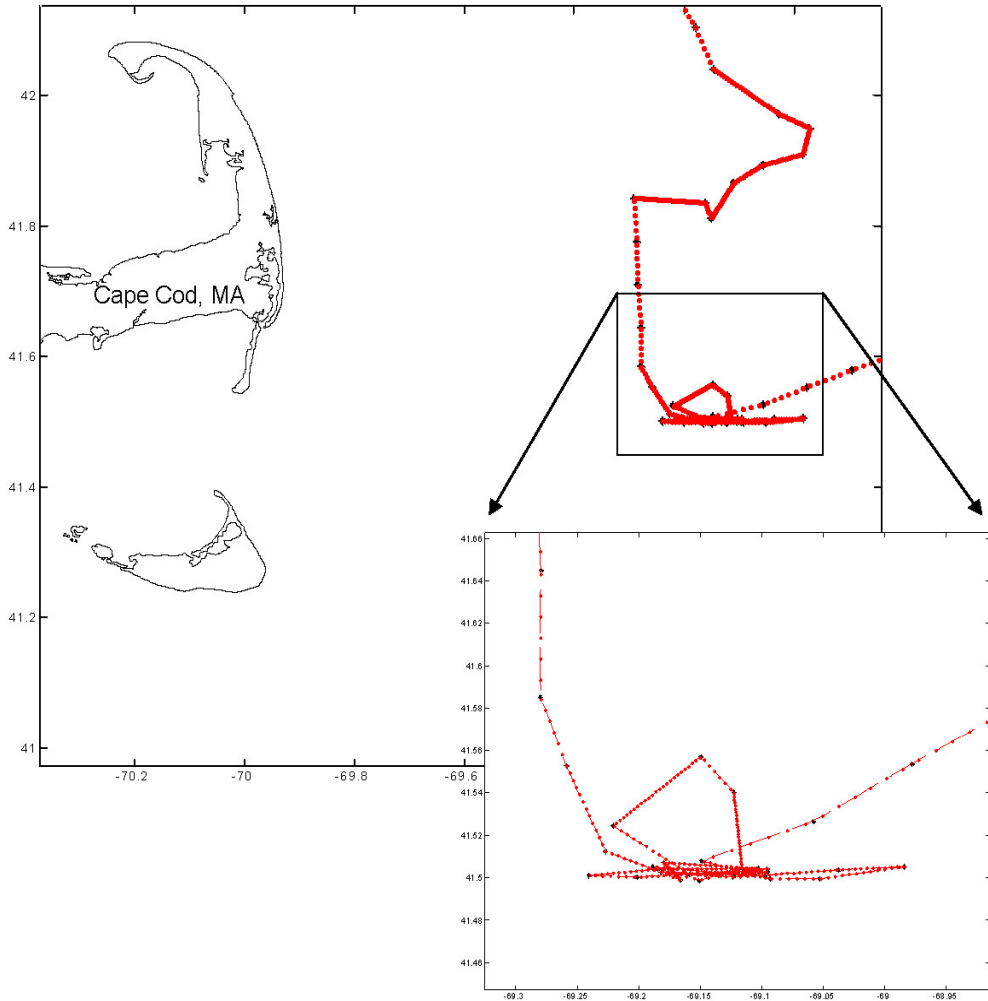


Figure 1. A track line of SHIP #3353 for March 5, 2009 trip. Black crosses represent raw data points and red dots are 5-min interpolated points.

Figure 2a shows all the raw positioning data recorded in VMS for SHIP #3353 between Jan. 2004 - Sep. 2008, which is a total of 17,522 points. The vessel transmitted the location info to the VMS roughly every 30 minutes in this particular vessel. For the analysis, only a year of data set (Sep. 1, 2007 - Sep. 1, 2008) was utilized (see red dots in Fig. 2b). One may note that this vessel spend most of time in the area east of Cape Cod, and did not steam through Northern Right Whale critical habitat area (i.e., a triangle zone around 41°N, 69°W) and north of Stellwagen Bank National Marine Sanctuary (i.e., line of ~42.8°N).

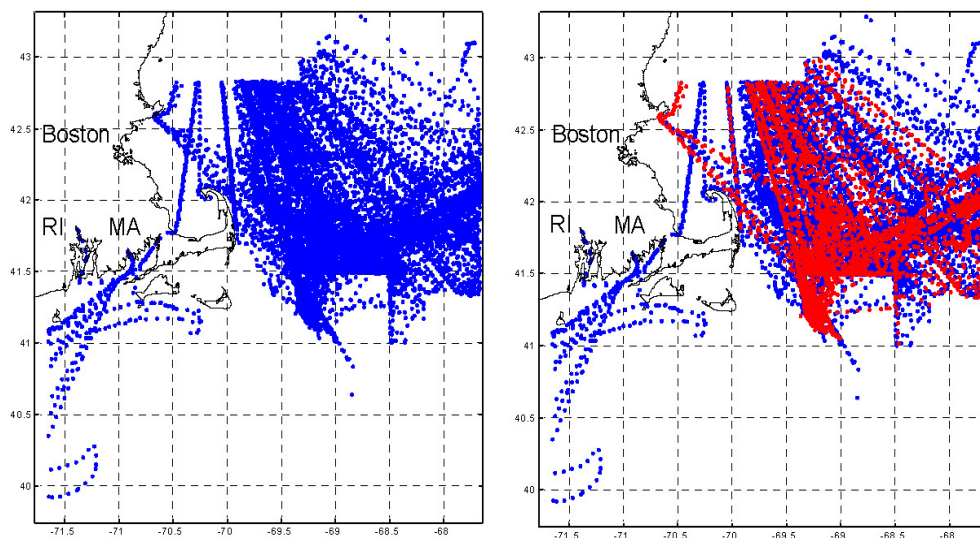


Figure 2. (a) Raw VMS data for SHIP #3353 during Jan. 2004 - Sep. 2008. (b) Same as (a) but data for Sep. 1, 2007 - Sep. 1, 2008 are in red dots.

In order to convert ship track data into traffic density, the study area was divided into a grid with 1 x 1 km cells. When a vessel enters into a cell, it is counted once. While it stays in the same cell within an hour, it is not counted again. If it stays more than an hour, it is counted once every hour after its first entrance. This allows a ship which repeatedly follows the same course over time to be counted properly, while only counting a vessel once even though it may be recorded several times as it passes through a particular cell.

Occupation by a ship in a grid cell was counted for each track line of each vessel for a year, and this is totaled for the ship traffic density for that year. Figure 3 shows the vessel density for SHIP #3353 during 1-year period (September 1, 2007 - August 31, 2008). This can be comparable to the data shown in Fig. 2b, but the traffic density in each cell is represented by color here. It is hard to understand the traffic density in Figure 2 although one could get a sense of where the ship went. In Figure 3, warmer color (e.g., red) depicts higher ship traffic density than cooler color. It should be noted that this vessel occupied the outside of the empty “triangular” area many time (up to 88 times for a year), but did not go into the triangular area often. It indicates that this particular vessel did most of fishing activities around the triangular zone, so those areas should be considered as high navigation uses in MSP procedure. The triangular area matches with the western bound of the Northern Right Whale Critical Habitat Area (Department of Commerce, 1994).

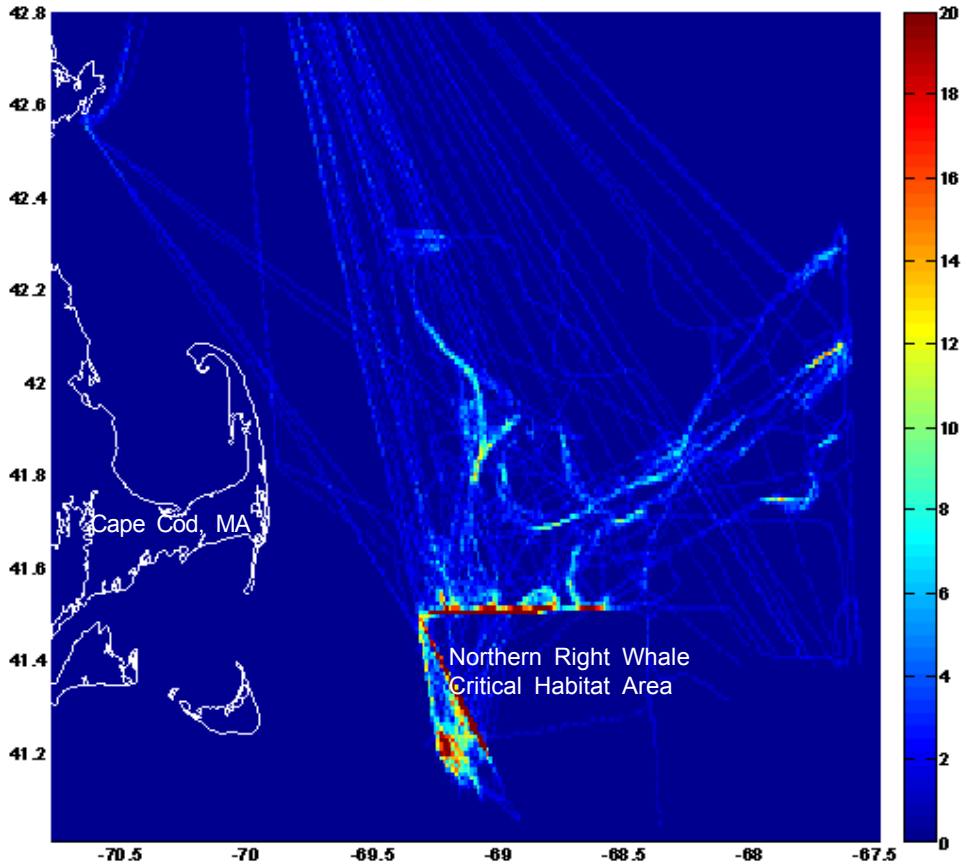


Figure 3. Density of vessels for SHIP #3353 during Sep. 1, 2007 - Sep. 1, 2008.

Ship traffic density for each vessel was accumulated for all the vessels that navigate the study area during the period of interest (e.g., September 1, 2007 – August 31, 2008). A total of ship tracks for ~1,035 vessels from AIS data were counted and summed for the estimate. Figure 4 shows the yearly ship traffic density represented by color for each grid cell. Although the color scheme is maxed out at 100 for the best presentation, the maximum occupancy was up to 8,608 times which might be from the anchor area. In Figure 4, the traffic separation scheme (i.e., traffic lanes) is clearly shown as higher traffic density. Inbound and outbound to/from Boston and New York harbors are denoted by red lines. Use of intracoastal waterways between Massachusetts Bay and Rhode Island coast can also be counted from the density plot.

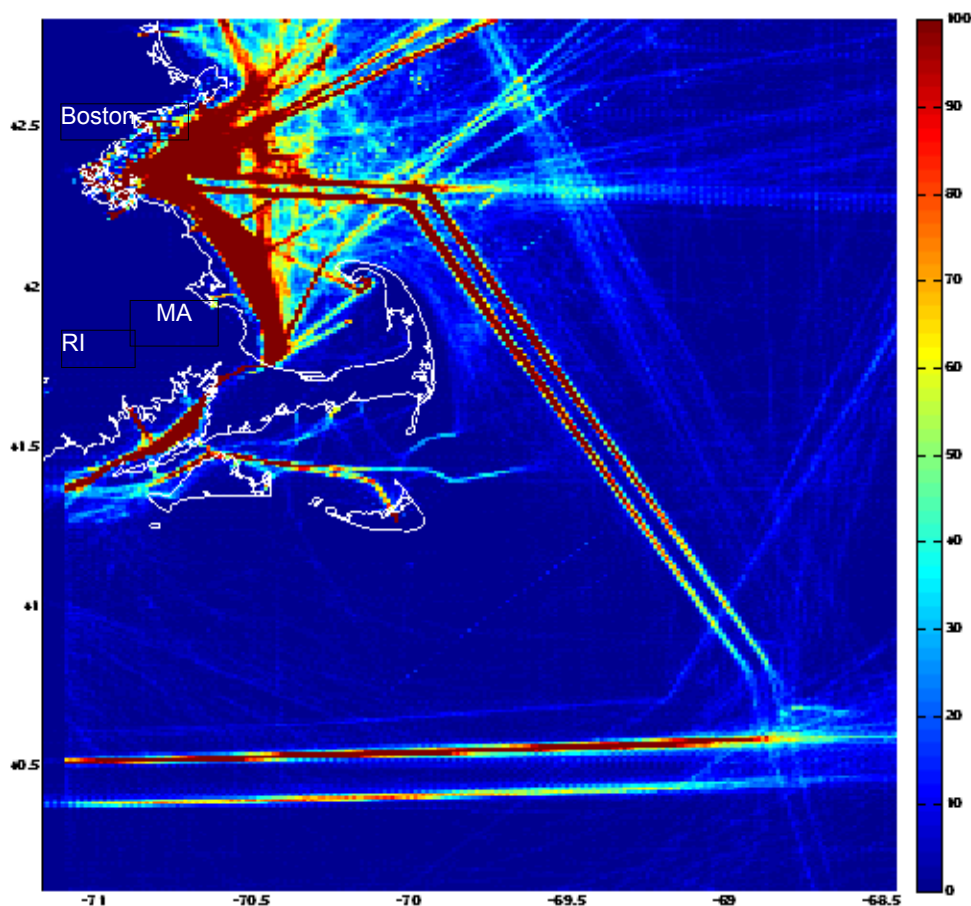


Figure 4. Density of ship traffic based on AIS data during September 1, 2007 - August 31, 2008.

After accumulating all the data from 1,266 vessels from VMS data, the vessel density for the entire study period is shown in Figure 5. This shows the zone of high navigation traffic as well as the location of major port for fishing in Massachusetts and Rhode Islands. When comparing to similar plots derived from the analysis of AIS data (Figure 5), one may note a traffic-empty triangular section located east of the Cape Cod, so called Northern Right Whale Critical Habitat Area. There is also a rectangular box of less traffic in the east of Boston Harbor, which shows the western Gulf of Maine area closure. Relatively heavier activity of fishing occurred near these empty zones, which should be considered in MSP.

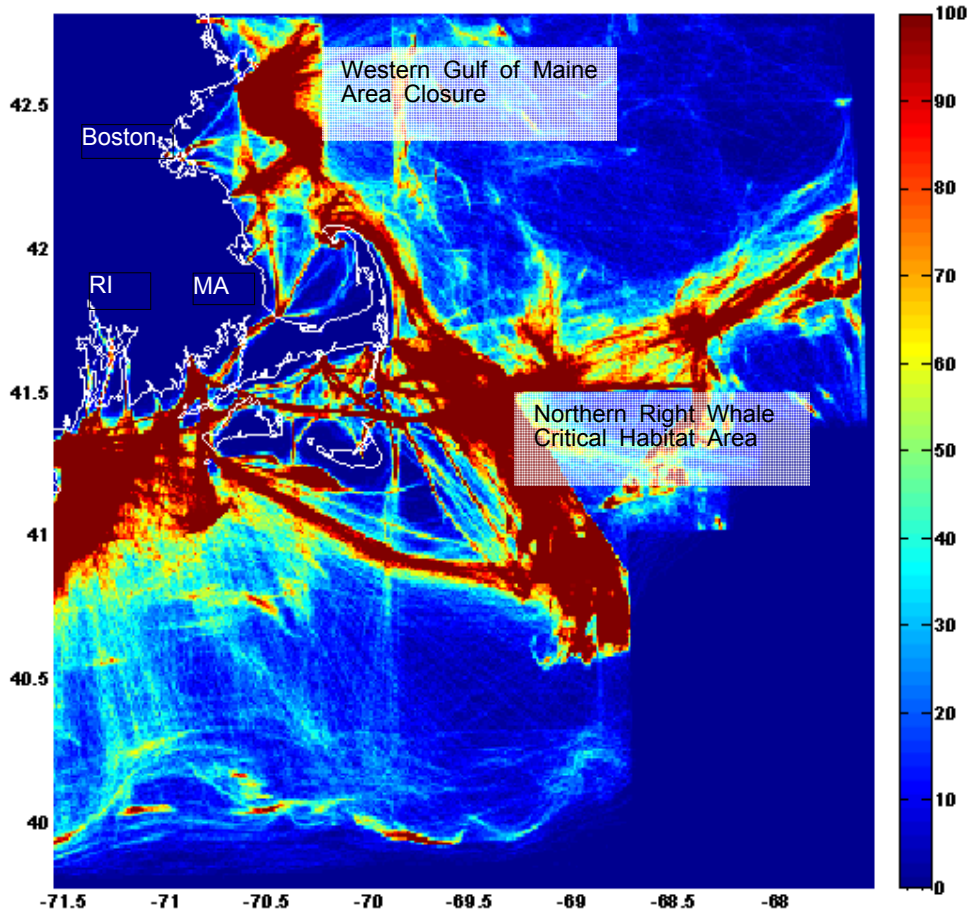


Figure 5. Density of fishing vessel traffic based on VMS during September 1, 2007 - August 31, 2008.

4. Sensitivity of grid resolution on ship traffic density estimates

In this section, the effect of grid resolution (i.e., grid cell size) on the estimation of ship traffic density is evaluated by comparing two different grid cell size, 1 km vs. 250 m. Before going further detail, it is necessary to check out another assumption for temporal resolution. As discussed in the previous section, the traffic density was estimated in an hour basis in this study. At this juncture, it should be mentioned that 1-hour is an arbitrary number we picked after several trials, but it can be altered any number if necessary. In this 1-hour basis scheme, we counted a vessel when it enters a specific grid cell, and does not count it again while it stays in the same grid cell within 1 hour. Thus, in case

that a vessel stays in a specific grid cell less than an hour, it is counted only one time. This rule was simply applied to any grid cell size.

The application of this simple rule for two different grid sizes, then, caused quite different results of traffic density for each case. For easy understanding, a simple example is shown in Figure 6. For instance, a vessel shows up in grid #5, passes through 6-14 and heads out from #13 cell in smaller grid scheme. While it steams through each small grid cell (i.e., 250 m), it was counted once for each grid. In the view point of larger grid cell (i.e., 1 km), however, the count number can be different depending on how long this ship stays in the larger cell. If the entire trip happens within an hour, then it would be counted as one for the larger cell. However, it could be counted 10 times if the entire trip takes for 10 hours. Since the count for the larger grid cell is mainly dependent on the duration of the trip, the relationship between the traffic density in smaller and larger cell may not be simply linear. However, it should be noted that the sensitivity test results show that maximum density in 1-km grid was 4,547 which is roughly 4 times larger than the maximum found in 250-m grid (1,040 counts). This indicates that the ship traffic density might be proportional to the size of grid cells as long as same duration criterion (1 hour in this study) is applied.

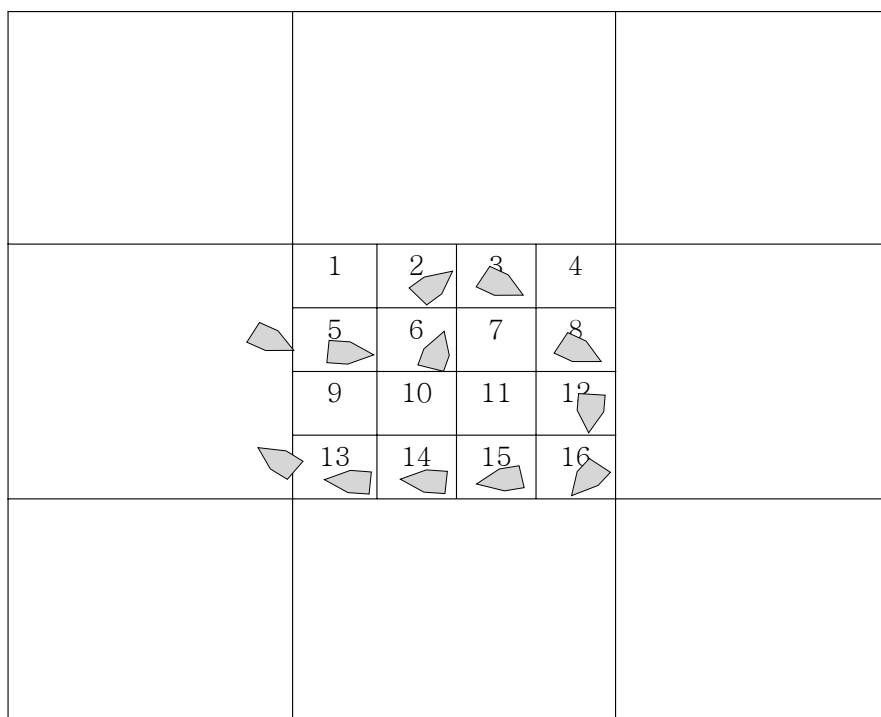


Figure 6. Diagram showing how to count traffic density in two different grid cell size

5. Application of ship traffic density in MSP

Northeast Regional Ocean Council (NROC) operates three standing committees, one of which is Ocean Planning Committee (OPC). The OPC is responsible for helping to scope and provide oversight for regional ocean planning projects. Recently, NROC published Northeast Ocean Data Portal (NODP), an interactive atlas of human and environmental aspects of the ocean in New England region (<http://northeastoceandata.org/>). This website is a decision support tool for ocean planning, which provides interactive maps including data, tools and information to resource managers, planners, scientists, and stakeholders (Figure 7). The web mapping service (WMS) protocol was used to present the ship traffic density data into a single Geographical Information System (GIS) layer in the system. The ship traffic density results in this paper are also presented in NODP.

The ship traffic density results are presented as part of ocean use along with infrastructures like LNG terminals and submarine cables, energy facilities, ocean disposal sites, and fishing and aquaculture areas in this MSP exercise. Policy makers and stakeholders were able to use those ocean use data when they made decisions on issuance of commercial wind lease blocks or conducting site assessment. For example, when Bureau of Ocean Energy Management (BOEM) developed the wind energy area, they acquired environmental and socioeconomic information from this MSP data (e.g., BOEM, 2012a, 2012b). They also considered the effect of navigation and vessel traffic in the environmental assessment package by referring the ship traffic density layer presented in NODP site (e.g., Fig. 4-12 of BOEM, 2012 a).

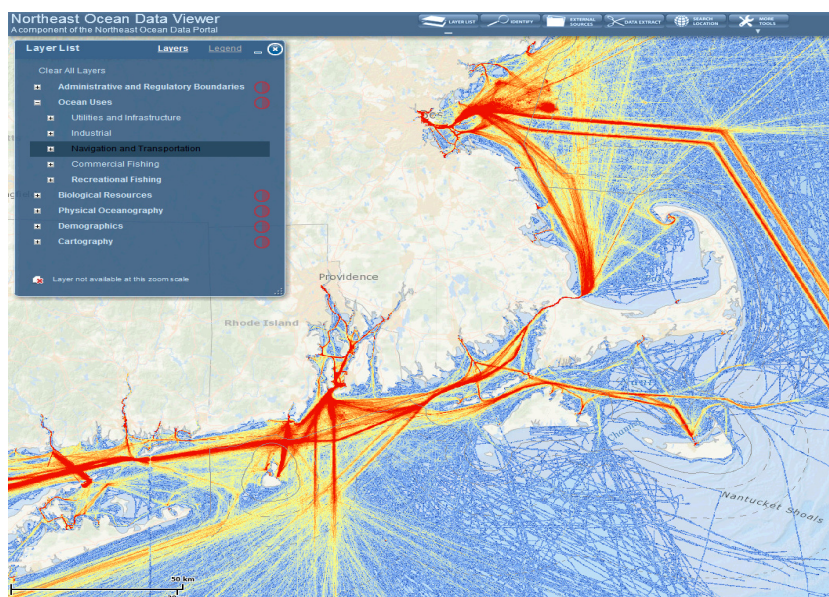


Figure 7. Screen shot of Northeast Ocean Data Viewer showing ship traffic density data as part of ocean use

6. Summary

In this article we present a case study, where Automatic Identification System (AIS) and Vessel Monitoring System (VMS) data were analyzed to estimate ship traffic density in the New England coast, USA. The continuous, chronologically ordered AIS/VMS data were decoded and rearranged for each vessel. The track data of each vessel is counted for prescribed grid cells, once it enters into the cell and one for every hour of staying in the same cell. The counts of entire vessels were totaled for 1-year period, which can be presented in an interactive map. The results clearly show that the location of high navigation use as well as high fishing activities. The sensitivity test results show that the ship traffic density is proportional to the grid cell size.

The ship traffic density data discussed in this paper were published as part of Marine Spatial Planning (MSP) operated by Northeast Ocean Data Portal (NODP). The web mapping service protocol was used to illustrate ship traffic data as an interactive map. These data/layers were later used by one of stake holders, U.S. Department of Interior, Bureau of Ocean Energy Management when they issued wind lease blocks in outer continental shelf off Massachusetts. This case shows an example where established scientific information listed as part of MSP is used in making decisions by a government agency.

Acknowledgement: Primary funding for this study was provided by SeaPlan (<http://www.seaplan.org/>). YGP acknowledges ‘Development of satellite based ocean carbon flux model for seas around’, sponsored by the Ministry of Ocean and Fisheries, for providing partial funding for the research.

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A Study on the Comparative Analysis of Port Competitiveness Using AHP

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Abstract

Addressing change in the global sea transportation system in 21st century such as the introduction of “Hub and Spoke” systems, ports across the world have been respectively making various efforts to take the lead in playing their roles as regional hub ports. Considering this change, this research is attempting to find newly rising factors impacting on port competitiveness, especially focusing on the factors that reflect strategic investments in terms of port policy—through comparing major container ports throughout five continents including North America, Indian Sub-continent, and Greater Asia. To indentify key factors, the research uses the Analytic Hierarchy Process (AHP) as the major analytical tool, while identifying priorities from the perspective of consumer-facing competitiveness and policy-facing competitiveness by using a survey result. The research provides relevant entities such as local port authorities, local governments, and national governments with policy implications and future tasks.

Key words: port competitiveness, AHP, port selection

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1. Introduction

Since the beginning of 21st century, global trade volume has been persistently increasing, accompanied by a huge change of international transportation system, and, as a consequence, triggering sea change of global logistics. Global maritime transportation system has been developed with the aim to realize lower costs and efficient movements of cargoes and passengers. Along with the improvement of transportation vehicles, there have been developments of ports and their improvements continuously in regional and local levels.

One of the most representative examples can be said to be the introduction of “Hub and Spoke” system. With this introduction, ports across the world have been respectively making various efforts to take the lead in playing their roles as regional hub port. These phenomena are found not only in the Northeast Asian region, but in global level including North America, Northern and Southern Europe. Against this backdrop, there have been rapid emergences of new port development projects and their operation plans.

Regional major ports tend to, in general, implement development of cutting-edge facilities and operation plans in order to, on the one hand, maintain the existing customers, and, on the other hand, to attract new customers. This sort of competition can be seen in small and medium size ports as well. Small and medium size ports invest various efforts and attempts in order to become regional hub port, in particular, by providing customers with extraordinarily favorable incentives and by conducting port facility expansion and improvement of their operation systems, while struggling to catch further growth opportunities. In this circumstance, lack of rational port competitiveness evaluation in some region causes various adverse effects such as excessive competition among ports, and over-investment into port development.

In the past, there have already been research findings over various port competitiveness evaluations for port development and freight attraction policy. However, it is not easy to say that such evaluations have perfect effectiveness, mainly because most of the evaluations focused on ports in Northeast Asian region, and had difficulty to apply their research findings to other port's competitiveness in other regions including North America, Greater Asia, Europe, and the Middle East. Other common weakness of the existing evaluation methodology is that, by restricting the research objective into comparison of port size (and cargo volume)—in other words, by using the customer-facing competitiveness, the research findings have a limitation to reflect competitiveness changes led by strategic investments—in other words, lack of owner-facing competitiveness. Making up for such a weakness needs two other key additional works: geographical research area expansion, and inclusion of strategic investment factor in assessment of port competitiveness into the research.

In line with this observation, this research sets up a research scheme consisting of such elements as follows: 1) expansion of geographical range into five continents including South Korea, Northeast Asia, North America, Indian Subcontinent, and Greater Asia; 2) proposal of a new port competitiveness evaluation model particularly characterized by the reinforcement of introduction of “policy decision” factor. The main purpose of the research is to provide shipping companies and cargo owners with practical criteria for their rational sea port selections. The other purpose of this research is to prevent port policy makers from over-investment and/or over-competition, mainly by providing them with opportunities of using reasonable models and indicators based on more improved evaluation model.

To indentify key factors, the study uses the Analytic Hierarchy Process (AHP) as the major analytical tool, while identifying priorities from the perspective of consumer-facing factors and policy-facing factors, and provides relevant decision makers such as local port authorities, local governments, and national governments with policy implications and future tasks.

In Chapter 2, this paper identifies key factors impacting on port competitiveness by reviewing the existing theoretical trends and researches. Based on the efforts of the Chapter 2, Chapter 3 in this research paper attempts to establish a model for a more effective port evaluation. Chapter 4 focuses on identification of priorities by using of the model established in the Chapter 3. The research conclusion is provided in Chapter 5.

2. Theories and the Existing Studies on Port Competitiveness

2.1 Concept of Port Competition

The concept “port competitiveness” refers to the state that ports in relation of rivalry develop and conduct strategic options in order to obtain the status of comparative advantage. In this situation, a port needs to have certain amount of ability to initiate such a competition game and eventually become a winner against the other (or others). If a port has such ability, one can say that the port has the “port competitiveness.”¹⁾ In the sense that it shows the criteria of port selection to ship-owners and cargo owners, and can be used to port operators as indicators that enable them to lay out reaction strategies while grasping opportunities and threats of their own ports, the port competitiveness can be treated as by far the most important concept.²⁾

1) Deaver, T. D., (1995) “The Implications of Increased Competition among Ports for Port Policy and Management,” 22(2), pp.125-133.

2) Kim Jin-gu (2002) “An Application of Hierarchical Fuzzy Process: A Study on the Evaluation of Port Competitiveness in International Shipping & Port Logistics,” Korean Journal of Logistics, Vol. 10, No. 2, p.43.

2.2 The Elements of the Port Competitiveness

As mentioned in its definition, the port competitiveness is so important for numerous players associated with the port industry, not only in the public sector but also in the private sector, and involving various areas ranging from maritime economic policy at national level to long-term business strategy at an individual company level.

Port competitiveness is formulated and decided by the interaction of numerous elements. As shown in the table 1, the elements include economic aspect and technological aspect, but sometimes or frequently internal politics.

Table1. List of the elements of port competitiveness

property classification	specific factors
Port Location	-Capacity of transportation connectivity -Economy scale of hinterland -Existence of port hinterland road -Nearness to main trunk
Port Facility	-A dedicated berth, EDI system -Ability to provide computer system for cargo handling -Allows for large volume shipments -Average time in transit -Cargo care and handling -Complete preparation of multimodal transport -Extent of port EDI -Existence of terminal operating system -Has loading and unloading facilities for large and /or odd-sized freight -Length of berth -Number of liners calling at ports -Operating system -Port operation time -Port productivity -Port scale -Road network to be fully equipped -Securing deep draft -Sufficiency of berth
Cargo Volume	-Cargo volume local to the port -Cargo volume of handling transshipment -Concentration of volume by export/import -Handling volume of export/import cargo
Service Level	-Ability of sales representative to handle problems -Ability to provide consolidation service -Ability to provide a just-in-time service -Ability to provide custom clearance service -Ability to provide custom clearance service -Ability to provide non-standard equipment -Ability to service outbound and inbound -Loading time -Offers convenient pickup and delivery times -Offers flexibility in meeting special handling requirements

property classification	specific factors
Service Level	-Port due + tug, pilot, line handling, etc. -Port extensiveness of services -Port's ability to accommodate special requirements -Presence of auxiliary services -Prompt response -Punctuality -Rate of lashing and tally, etc. -Schedule reliability
Cost	-Cargo expense (cargo handling charges) -Freight rates, Rates and charge, cost of service, low tariff -Guaranteeing of delivered price -Handling charge per TEU -Has low freight handling shipments -Price competitiveness -Pricing flexibility in meeting competitors' rates
others	-Accurate documentation -Balancing inbound and outbound cargo -Building Port MIS -Cargo safety -Changes of social environments -Courtesy of inquiry -Courtesy of sales representative -Customs regulation -Directness of sailing -Ease of communication with port's staff -Easiness of slot exchange agreement with other lines -Effectiveness of terminal operation -Electronic computation network -Entering niche market -Existence of cargo tracing system operation -Financial factors of port -Flexibility-ability -Good condition of containers -Good financial condition -Information Technology (IT) connectivity -Internal politics -IT and Management/worker relationship -Knowledgeability of sales personnel -Number of sailing -Oceanic distance -Port feeder connectivity to other ports -Port safety -Port's management-worker relationship -Port's operator reputation worldwide -Profitability of handling cargo at the port -Prompt of issue documentation -Regularity, reliability -Reputation -Securing exclusive use of equipment -Securing fairway -Securing navigation facilities/equipment -Securing railroad connection -Strength of legal/financial system of the port's

2.3 Literature Review

Most of the existing research outcomes relating port competitiveness evaluation tend to approach the issue with the limited geographic space—namely, specific regional space, and with narrower perspective—in other words, from the perspective of port service customers. The most frequently cited elements regarding port competitiveness, which are found and treated in the numerous existing research papers and works, can be boiled down to: port location, cargo volumes, level of services provided by port, port facilities, and port costs. The cargo flows or cargo throughput is said to be the major target of port competition analyses.

Most of the existing research outcomes tend to treat cargo volume—including export & import cargo volume, transshipment cargo volume, especially created by containers—as the most important factor. On the other hand, in terms of port facility capacity, main elements able to be compared with are maximum/minimum handling capacity, operation system, labor productivity and etc. Regarding port location issue, the analyses on the comparative strength and weakness in the existing research outcomes mostly focus on the geographical location, which consists of such elements as the accessibility to manufacturers, trunk lines, port expandability. In terms of port service, more frequently visited elements are average time of cargo handling in port and operation time including waiting time. Finally, in terms of cost competitiveness, major objectives of comparison tend to be loading & unloading cost per TEU and port service charges.

The factors used in the existing literature on the port competitiveness evaluation are summarized as shown in the table 2.

Table 2. Comparison of major port competitiveness factors by authors

Author	UNCTAD (1992)	Murphy (1992)	Starr (1994)
Factors of port selection	Geographic location, Port service, Port cost, Port socialism and economic, Port safety, Port system level	Port facility, Cargo damage claim, Cargo operation charge, Water depth, Cargo discharge ability	Geographic location, Railway transport on land, Port facility, Labor force sufficiency
Author	Suthiwartnarueput (1988)	McCalla (1994)	Collison (1984)
Factors of port selection	Port cost, Vessel schedule liability, Cargo operation speed, Vessel call frequency, Damage claim	Port facility, Railway transport on land	Vessel schedule liability, Documents dealing time, Port service level
Author	Tongzon (2001)	UNCTAD (2004)	Lirn (2003, 2004)
Factors of port selection	Geographic location, Transport speed, Restriction to cargo, Information system, Port service	Port service, Port cost, Information system, Space of Storage, Port safety	Port cost, Vessel schedule liability, Cargo operation speed, Vessel call frequency, Damage claim
Author	Song (2004)	Chang (2006)	Shou Jian Min (2007)
Factors of port selection	Port facility, Cargo damage claim, Cargo operation charge, Water depth, Cargo discharge ability	Port safety, Cargo safety operation, Vessel schedule liability, Service level	Port cost, Port safety, Port service, Information system, Port facility

Source: summarized by authors based on major references

3. AHP Method and a Hierarchic Structure Model

3.1 The Concept of Analytic Hierarchy Process (AHP)

The AHP is a structured technique for dealing with complex decisions. Rather than prescribing a “correct” decision, the AHP helps decision makers find one that best suits their goal and their understanding of the problem—it is a process of organizing decisions that people are already dealing with, but trying to do in their heads.

Based on mathematics and psychology, the AHP was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions.

It has particular application in group decision making, and is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, and education.

Users of the AHP first decompose their decision problems into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. The elements of the hierarchy can relate to any aspect of the decision problem—tangible or intangible, carefully measured or roughly estimated, well- or poorly-understood—anything at all that applies to the decision at hand.

Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another two at a time, with respect to their impact on an element above them in the hierarchy. In making the comparisons, the decision makers can use concrete data about the elements, or they can use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations.

The AHP helps to convert these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. This capability distinguishes the AHP from other decision making techniques.

In the final step of the process, numerical priorities are calculated for each of the decision alternatives. These numbers represent the alternatives' relative ability to achieve the decision goal, so they allow a straightforward consideration of the various courses of action.

3.2 Restructuring Port Competitiveness Evaluation Model

3.2.1 Extraction of Detailed Assessment Properties

Before a properties test for drawing out port competitiveness factors in five continents, this study sets up the overall structure of analytic hierarchy for drawing out properties.

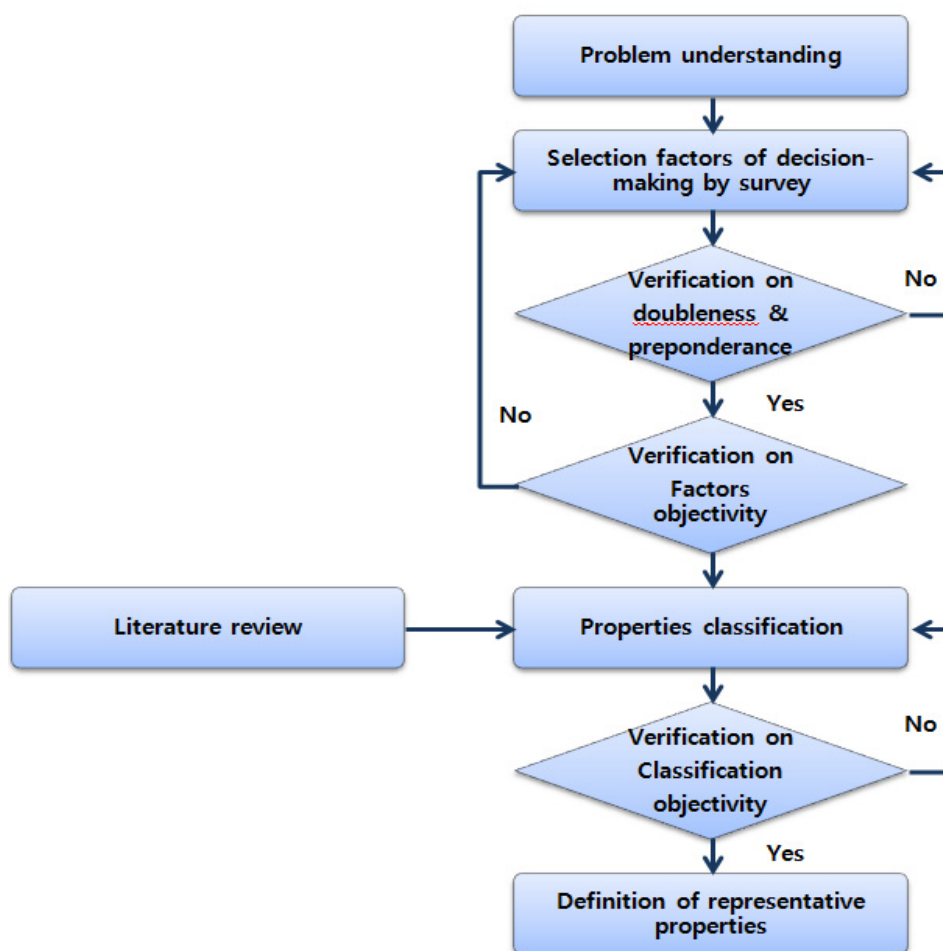


Figure 1. Research flow for the analysis on properties test

Consulting the secondary literature by analyzing the existing researches and reflecting experts' opinion, this research collected major evaluation elements of port competitiveness. And then, the research removed overlapping elements by reflecting experts'

opinion based on the results from Delphi analyses and pilot surveys, selecting 10 factors most valuable for port competitiveness evaluation. The research restructures the factors impacting port competitiveness into two hierarchical levels: The upper level and lower level.

The upper level brings the factors into two lines of properties for categorization: volume competitiveness (or customer-facing competitiveness) and investment competitiveness (or owner-facing competitiveness). Each of two categories has respectively five other lower factors totalizing ten. These ten factors consist of the lower level of port competitiveness in this research.

Table 3. Major Factors Comparison

Property Classification	Specific factors	Reference
Volume Competitiveness (Customer-facing)	Port Location	Brooks(1983,1984,1985), Chang(2006), McCalla(1994), Pearson (1980), Song(2004), UNCTAD(1992, 2004), Machow and Kanafani(2001), French(1979), McCalla(1994), Peters(1990), Starr(1994), Tongzon(2001), Wilingale(1981), Jun Il-soo(1993), Lee Seoktae · Lee Chul-young(1998), Ha Dong-woo · Kim Su-yup(1998), Yeo Ki-tae(1999), Lee Hong-Girl(2006), Jung Tae-won · Kwak Kyu-seok(2001), Busan New Port Co.(2002), Yeo Ki-tae(2004), Kwen Jae-yeon(2011)
	Port Facility	Chang(2006), Song (2004), Slack(1985), Wilingale(1981), Jun Il-soo (1993), Lee Chul-young(1998), Ha Dong-woo(1996), Ha Dong-woo · Kim Su-yup(1998), Jung Tae-won · Kwak Kyu-seok(2001), Lee Hong-Girl(2006), Busan New Port Co.(2002), Yeo Ki-tae(2004), Chang(2006), Lim(2003, 2004), Murphy(1992), Yeo Ki-tae(1996), No Yu-jin(2007)
	Cargo Volume	Song(2004), Lu(2000), Slack(1985), UNCTAD(1992), Lee Seoktae · Lee Chul-young(1998), Yeo Ki-tae(1999), Jung Tae-won · Kwak Kyu-seok(2001) · Lee Hong-Girl(2006)
	Service Level	Tongzon(2001), Lee JiaBing (2009), UNCTAD(1992), French(1979), Peters(1990), Young Gull Kim (2009), No Yo Jin(2007), Shou JianMin (2007)
	Cost	French(1979), UNCTAD(1992), Yeo Ki-tae 외(1996) · Lee Seoktae · Lee Chul-young(1998), Yeo Ki-tae(1999), Lee Hong-Girl(2006), No Yu-jin(2007), Busan New Port Co.(2002), Brooks(1983,1984,1985), Murphy(1992), McGinnis(1979), UNCTAD(1992)
Investment Competitiveness (Owner-facing/Public Policy)	Price	Lu(2000), Tengku(1995), Starr(1994), UNCTAD(1992), Collison(1984), Suthiwartnarueput(1988), No Yu-jin(2007), Busan New Port Co.(2002), Jun Il-soo(1993), Lee Seoktae · Lee Chul-young(1998)
	Institutional Structure	French(1979), World Bank Report(2007), Wilingale(1981), Jun Il-soo(1993),
	Legal Framework	Collison(1984) · Suthiwartnarueput(1988) · Tengku(1995) · Starr(1994), Hur Yun-su(2006) · Jun Il-soo(1993) · Lee Seoktae · Lee Chul-young(1998)
	Financial Resources	Lu(2000), World Bank Report(2007), UNCTAD(1992),
	Port Reputation	Brooks(1983,1984,1985), Lu(2000), World Bank Report(2007),

3.2.2 Modeling of AHP

The successful solution of multi-criteria decision making problem by application of AHP depends on two important tasks: the task of selection of essential factors to evaluate option assessment, and, the task of systematically acceptable setting up of hierarchical structure.

Based on the existing research, and consulting AHP experts' and port experts' opinion, this research provides a list of factors finally selected (Table 4), and presents a diagram to show the overall hierarchical structure (Figure 1).

Table 4. Finally Selected Factors for Evaluation

Main items	Specific factors	Contents
Volume Competitiveness (Customer-focused)	Port Location	- Port accessibility, Deviation from main trunk routes - Land distance and connectivity to major shippers - Inter-modal link
	Port Facility	- Yard and terminal area - The size of berths - Support system-level departures and unloading of ship
	Cargo Volume	- Volume of total container cargoes - Cargo proportion of transshipment cargo
	Service Level	- Loading/discharging/cargo turn around speed of different cargo - Including port congestion(take berth speed), Night navigation available or not - PSC inspection/ Cooperation attitude/ Informatization level
	Cost	- Inland transportation cost - Cost related vessel and cargo entering - Cost for cargo handling, transfer and storage
Investment Competitiveness (Owner/Public Policy focused)	Price	- Incentives and price discounts according to the cargo
	Institutional Structure	- Government, local autonomous entity, private sectors
	Legal Framework	- Stability of port's labor
	Financial Resources	- Effective financing of port development
	Port Reputation	- Recognition and reputation of port

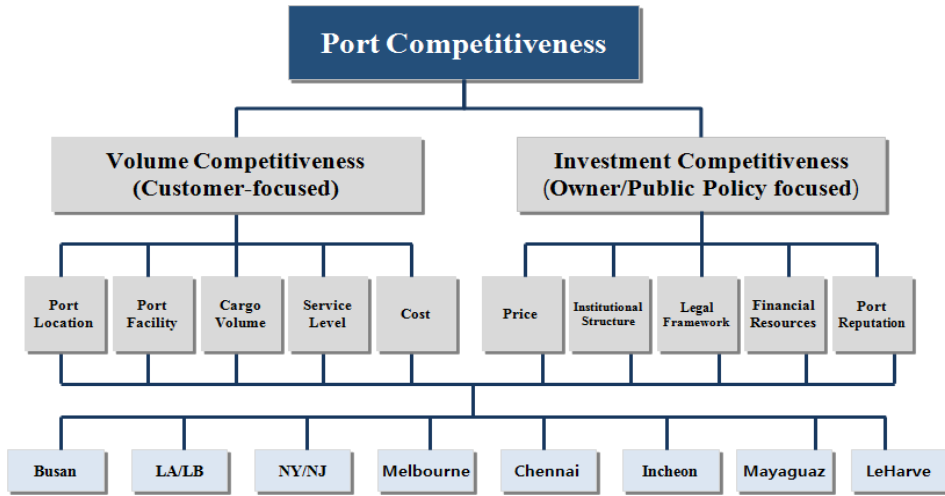


Figure 2. Restructured AHP Scheme for Port Competitiveness Evaluation

4. Result of AHP Analysis

4.1 Survey Target

The survey was conducted by using authors' human networks and literature collection. As a result, the survey selects eight ports across the five continents. Among them, Busan is the largest hub port aiming to be the hub port in the Northeast Asian region. Incheon is the largest South Korean commercial port in the Yellow Sea basin. LA/LB represents North America's west coast, as does NY/NJ in the east coast. Melbourne is well-known for Australian representative sea port. The survey's port list includes Chennai,³⁾ India's most modernized port, Port of Mayaguaz in Puerto Rico, and Port of LeHarve,⁴⁾ one of the most largest sea ports in France. The survey was conducted by the network of eight universities in the five continents, all of which are linked with University of Rhode Island.

The questions were given to port managers, researchers, and relevant officials representing 8 ports through the networks. A total of 28 responses were collected.

3) The Chennai (formerly called "Madras") is the capital city of the Indian state of Tamil Nadu, located on the Coromandel Coast off the Bay of Bengal.

4) The second largest sea port in trade volume in France, and the 54th largest port in total cargo volume (2011). See to "World Port Ranking 2011." (<http://aapa.fies.cms-plus.com>).

Table 5. Port Affiliation & Position

	Port Director	Elected Official	Port Senior Manager	Researcher	Shipper	Carrier
Busan	2	2	1	3		1
LA/LB	1	1	1		2	1
NY/NJ	1				1	
Melbourne				1		
Chennai					1	
Incheon	1		1			
Mayaguez	1			2		
LeHarve				2		
Others				2		

Based on the survey result, this research identified priority of each factors classified into the two categories: volume competitiveness (or customers' viewpoint) and investment competitiveness (or policy viewpoint), and then, evaluated competitiveness among ports.

4.2 Volume Competitiveness Aspect

As shown in the table 6, port location rises as the most important factor in terms of volume competitiveness of ports (0.282)—in other words, from the perspective of customers including cargo owners and logistics companies. The service level (0.276) and port cost (0.184) followed the next. High scores given to port location and service level in this research is similar with the result of other previous research findings.

Table 6. Volume Competitiveness: Pair-wise Comparison Matrix, Weight & Priority

	Cargo Volume	Port Facility	Port Location	Service Level	Port Cost	Weight	Ranking
Cargo Volume	1	3.33	0.445	0.95	0.885	0.087	5
Port Facility		1	0.848	2.544	2.14	0.171	4
Port Location			1	3.269	2.889	0.282	1
Service Level				1	3.056	0.276	2
Port Cost					1	0.184	3

4.3 Investment Competitiveness Aspect

In terms of investment competitiveness (or policy viewpoint), the priority of institutional structure was shown as the highest (0.246). However, it is shown that the

factor “financial resources” plays so much significant role in respondents’ determination over the port competitiveness. The score given to financial resources was 0.243—similar one given to the institutional structure (Table 7). These results make it possible to reach an interpretation that institutional structure and financial resources are equally important to the decision making of port investors.

Table 7. Investment Competitiveness: Pair-wise Comparison Matrix, weights & Priority

	Price	Institutional Structure	Legal Structure	Financial Resources	Port Reputation	Weight	Ranking
Price	1	1.245	1.49	1.43	1.434	0.163	4
Institutional Structure		1	2.158	2.178	2.184	0.246	1
Legal Structure			1	1.768	1.595	0.153	5
Financial Resources				1	2.10	0.243	2
Port Reputation					1	0.195	3

4.4 Comparison of Port Competitiveness: Volume or Customer

With the survey results, this research conducted a comparison of eight ports’ volume competitiveness by converting the results into quantitative values. Among the targeted eights, Busan ranked the top, LA/LB the second, and Incheon the third. The Busan Port obtained higher score than others in port location, service level, and port cost. However, mainly due to relative lack of detailed analysis on the comparison results in terms of port size, cargo specialization, characteristics, and competition (or dependence) relations, there seems to be some limitation in the findings’ applications.

Table 8. Overall Values of Volume Competitiveness

	Cargo Volume	Port Facility	Port Location	Service Level	Port Cost	Overall Values	Ranking
all	0.087	0.171	0.282	0.276	0.184	-	-
Busan	0.5011	0.3750	0.3099	0.2062	0.1773	0.1570	1
LA/LB	0.1415	0.1610	0.2856	0.2014	0.1930	0.0983	2
LeHarve	0.1313	0.1240	0.1112	0.1488	0.0743	0.0610	5
Incheon	0.0900	0.1508	0.0937	0.1921	0.2075	0.0834	3
NY/NJ	0.0332	0.1467	0.0520	0.1781	0.2130	0.0735	4
Chennai	0.0272	0.0202	0.0307	0.0500	0.1123	0.0281	6
Melbourne	0.0321	0.0104	0.0455	0.0103	0.0125	0.0133	8
Mayaguez	0.0435	0.0120	0.0714	0.0138	0.0104	0.0160	7

4.5 Comparison of Port Competitiveness: Investment or Policy

As the case of volume competitiveness, this research converted the survey results into quantitative values for gaining easiness of comparison in terms of “investment competitiveness.” The result shows that Incheon is the top, LA/Long Beach, the second, and Busan, the third. Higher scores given to Incheon in institutional structure, financial resources, and port reputation help the Incheon Port to ascend toward the top in investment competitiveness—in other words, the competitiveness from the policy viewpoint. The port competitiveness from the policy viewpoint is likely to be realized in the future, rather than at present. In this regard, it can be said that Incheon has a relatively higher investment potential. However, as in the case of Busan in the earlier comparison of the volume competitiveness, mainly due to relative lack of detailed analysis on the comparison results in terms of port size, cargo specialization, characteristics, and competition (or dependence) relations, there seems to be similar limitation in the findings’ applications.

Table 9. Overall Values of Investment Competitiveness

	Price	Institutional Structure	Legal Structure	Financial Resources	Port Reputation	Overall Values	Ranking
all	0.163	0.246	0.153	0.243	0.195	-	-
Busan	0.2002	0.2229	0.1776	0.2430	0.2271	0.1070	3
LA/LB	0.1670	0.1994	0.1742	0.2740	0.2602	0.1075	2
LeHarve	0.1114	0.0542	0.0976	0.0912	0.1017	0.0456	5
Incheon	0.1779	0.2311	0.2710	0.2610	0.1451	0.1089	1
NY/NJ	0.1776	0.1517	0.1235	0.0703	0.0909	0.0614	4
Chennai	0.0622	0.0135	0.0321	0.0122	0.0843	0.0206	8
Melbourne	0.0557	0.0271	0.0638	0.0383	0.0800	0.0269	6
Mayaguez	0.0479	0.1006	0.0604	0.0100	0.0100	0.0228	7

5. Conclusion

Hub & spoke port system is globally spreading, and in this stream, numerous sea ports make their various efforts to become a hub port in their respective regions. As the first step for realizing their goal, many ports have conducted port competitiveness researches for finding their own unique strengths and advantages. In order to overcome the limitation of data, these researches have focused on global container ports mainly due to their relative easiness to access data, or concentrated their efforts on comparisons of peer ports in neighboring countries or in the same region.

In order to make a differentiation from the existing studies, this research attempted to find common indicators of port competitiveness by conducting a comparative evaluation over the competitiveness of eight ports spread across the five continents, utilizing a bifurcated indicators—the volume competitiveness from the customers' viewpoint, and investment competitiveness from the policy viewpoint.

Through the survey targeted to port experts including researchers and port managers, the research found that, at least in terms of customer-facing competitiveness, some factors including port location, service level, and port cost—traditionally perceived as the most important—still have explanative power for port competitiveness. Meanwhile, from the perspective of policy competitiveness, institutional structure, financial resources, and port reputation play more major role in making port competitiveness.

Regarding the volume competitiveness among the targeted eight ports, Busan ranks the top, which shows that Busan has a global competitiveness—especially supported by the factors such as port location, service level, and port cost. On the other hand, in terms of the port competitiveness from policy viewpoint, Incheon ranks as the top followed by LA/LB, which implicates that the both ports have the comparative advantage in terms of growth potential in the future, and investment easiness.

When comprehensively considered, each competitiveness factors proved to have relatively equal importance, which can be interpreted in a way that, in global market's term, individual factor has similar weight of importance, and that the research result reflects particularity of the region where each port is located. Despite that, one important lesson able to be drawn from this research is that possible effective way to increase the port competitiveness is to pursue balanced approach for improvement of respective factors impacting the port competitiveness—so to speak, combination of approaches of volume-competitiveness and investment-competitiveness. In the past, most governments and port authorities have considered the tasks of port competitiveness improvements typically in terms of volume competitiveness. In the future, however, decision makers in governments need to reflect factors such as institutional structure, financial resources, and port reputation in their sea port policy in order to enhance port competitiveness more effectively.

Meanwhile, this research has a certain level flaws and limitations in the some critical points. First, the research lacks classification of targeted ports' types—for example, container-specific type and bulk-specific type. Second, more serious consideration over the representativeness of targeted ports should have been done in designing the research model. Third, there existed little discussion over competition/non-competition relations between the continents. In further researches, these points need to be considered more seriously. The expansion of targeted experts such as port operators and port users including shipping companies, cargo owners, and logistics companies armed with more specialized expertise will contribute to the improvement of objectivity of port competitiveness evaluation.

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The Future Tasks of GICOMS in Preparation for the Age of e-Navigation

Hwa Young Kim*

Abstract

This paper aims to find out future tasks of GICOMS(General Information Center on Maritime Safety & Security) through identification of required system for implementation of e-Navigation. We derive nine advancement subjects for model of advanced GICOMS through brainstorming with experts of maritime safety. And then, we analyze the structure of extracted nine advancement subjects using by fuzzy structural modeling method, and propose a structural model that grasps the correlation between elements. As a result, we find out that “advancement of GICOMS” is the final goal in preparation for the age of e-navigation in the highest level, and “improvement a system of information production”, “improvement a scheme of information providing”, “linkage between GICOMS and VTS” and “building global networks for safety cooperation” are located in the lowest level. Especially, “advancement of GICOMS” is influenced by “advancement function of VMS” and “Activation of usage” in the middle level. We suggest that state-of-the-art IT facilities, equipment and expertise should be utilized to improve and enhance the user-centered transition such as maritime workers for advancement of GICOMS based on proposed structure model.

Keywords: GICOMS, Maritime Safety Information System, e-Navigation, FSM, Future tasks

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1. Introduction

Korea constructed and has operated the GICOMS (General Information Center on Maritime Safety & Security) for Maritime Disaster Management and Safety since 2001. The main functions of GICOMS are preparing cross nationally general management on maritime disaster, safety and security; preparing to cope with distress accidents of vessels and fishing boats effectively; preparing to ensure safe navigation of Korean flag ship from pirates and any forms of terror. If GICOMS is operated smoothly, it will minimize human and property damage on marine accidents and improve efficiency of disaster management.

The improvement of GICOMS for e-Navigation service means that: it requires improvement on operating GICOMS and an investigation system, and needs to have an afresh construction. Also, the GICOMS means to realistically and gradationally be prioritized when setting up(Lee, Han, Jo & Park., 2012).

Therefore this paper aims to structure the target system and analyze the systematically influencing relationship between elements on each stratum in building the advancement structural model of GICOMS by using the Fuzzy Structural Modeling (FSM) method. Chapter 2 discusses the current state of Information system on Maritime safety and security in domestic and abroad pivots on e-Navigation. In chapter 3, analyzes a survey targeting marine experts for considering the hierarchy of proposing the advancement structural model of GICOMS for future tasks of the age of e-Navigation and grasping the hierarchical distribution and connection relations from the surveyed data.

2. A trend of maritime safety information system

2.1 International trends

The Domestic Information System on Maritime Safety and Security has sparked the interests of universities, institutes, and government and now active in international conferences. Moreover, it continues to research the strategy of e-Navigation, which is based on the aid of a navigation installer and management since 2006(Park.,2006). The Korean Coast Guard is currently operating the Vessel Monitoring System (VMS) to fulfill its task of sea surveillance from GICOMS in order to save lives and prevent marine accidents(Ryu.,2013). Also, they constructed the Intelligent Marine Traffic Management System for preventing anticipative marine accidents and improving countermeasure ability to crisis.

Developed oceanic countries, such as Europe, are proceeding with a study on

2.2 Domestic trends

2.2.1 A current condition of operation on GICOMS

GICOMS (General Information Center On Maritime Safety and Security) is the National Maritime Crisis Management System for strengthening safety, security and protection of the environment using information and communication technologies. The purpose of this system is to minimize marine accident using general information about vessels, sailors, traffics, security, port facilities and freight, etc.. Therefore, this system can contribute for establishment of scheme of e-Navigation as the beginning design.

The past safety and disaster system was a prompt action and delayed status report due to hindering accessibility and sharing information dispersed by organizations. According to the Maritime and Fisheries Information Implementation Plan on the basis of 「Framework Act on Information Promotion」 article 6, GICOMS is constructed for integration of information system and efficiency of maritime safety work. Table 1 shows that the configuration of GICOMS made from 33 information systems of maritime disaster safety such as the National Security Council(NSC), Ministry of Oceans and Fisheries(MOF), Ministry of Security and Public Administration(MOSPA), Korea Coast Guard(KCG), Korean Navy, etc., and GICOMS provides the Vessel Monitoring Service (VMS)(Ryu., 2013).

Table 1. A configuration of GICOMS

Classification	Main function	Main system	Related agency
GICOMS	Integrated Database	Ship's information	MOF
		Port information	MOF, Port Authority
		Seafarer's information	MOF
		Security information	MOF, KCG
		Accident information	MOF, KMST
	Vessel Monitoring System	AIS (Automatic Identification System)	MOF(VTS)
		Satellite system	MOF, Telecommunication service provider
		Smartphone	Telecommunication service provider
	Information Exchange	System linkage with external agency	NSC(National Security Council), KCG, MOSPA, MOF etc.
		Providing of accident information	Shipping company, Shipowner, citizen etc.

2.2.2 GICOMS analysis

① Information environment analysis

The government prepared a system for securing maritime safety and protecting maritime environment through a maritime safety management structure, maritime traffic environment improvement, prevention of maritime accident, strengthening of vessel security, etc. This is the main contents of the Future National Maritime Strategy, promotes the next generation of development motorization of e-Navigation and constructs enhancement of national competitiveness and a high-grade of integration maritime safety management through the strengthening of IMO activities (Ryu., 2013).

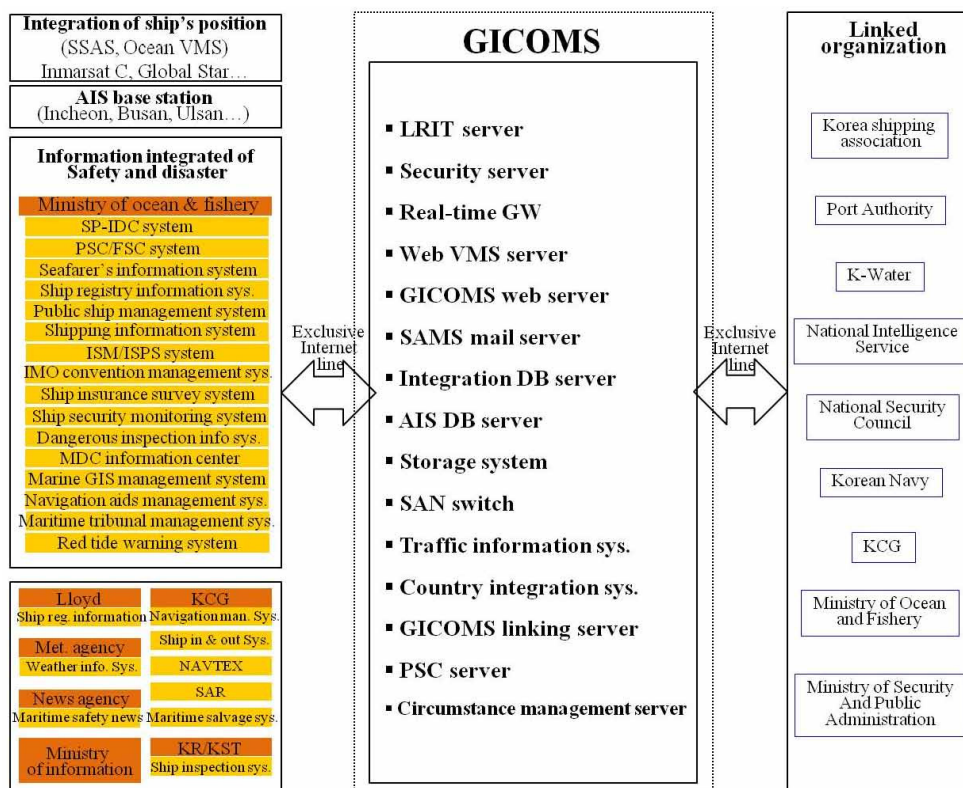
② Software system analysis

The maritime safety system is connected to the information system of the Ministry of Oceans and Fisheries and related organizations, which creates a huge system. Maritime safety province is a typical information system on maritime safety and related organizations include Marine Traffic Management System, Shipping and Port-logistics Information System, Hazardous Material Information System, Vessel Registration Information System, Maritime Rescue and Disaster Information System, Navigation Safety Information System, Commercial Marine Accident Management System.

The main functions of GICOMS, which is a typical maritime safety information system of maritime safety province, are contextual information management on maritime accident, vessel movement, international vessels and the ISPS Code, that can check the security content of vessels and ports, ISM Code and the port state control information, etc.

③ Network System Analysis

GICOMS is operated with the Location Cooperative Information System, AIS base stations, Safety and Disaster-related System through a satellite network by utilizing the internet, and administration network. GICOMS network system in Figure 2 consists of LRIT server, Security sever, Real-time GW, Web VMS server, GICOMS web server, SAMS mall server, integration DB sever, AIS DB sever, Storage system, SAN switch, etc(Ryu., 2013). And GICOMS has integrated the systems of the Ministry of Security and Public Administration (MOSPA), Ministry of Oceans and Fisheries(MOF), Korea Coast Guard(KCG), Korea Shipping Association(KSA), etc. In real time, GICOMS is equipped with standardized systems of organization to collect, supply, integrate, and propagate a navigating situation of vessels in the national coast.



Source: Drawn by the author from Ryu (2013)

Figure 2. A network system configuration of GICOMS

3. Model for construction of advanced GICOMS

3.1 FSM method

Using the valid FSM technique as an object to structure the investigation of the complex social problems (Zadeh, 1965 & Yang, 2002), expresses the various elements and uses the results to analyze the consciousness structure of the GICOMS advanced propulsion items.

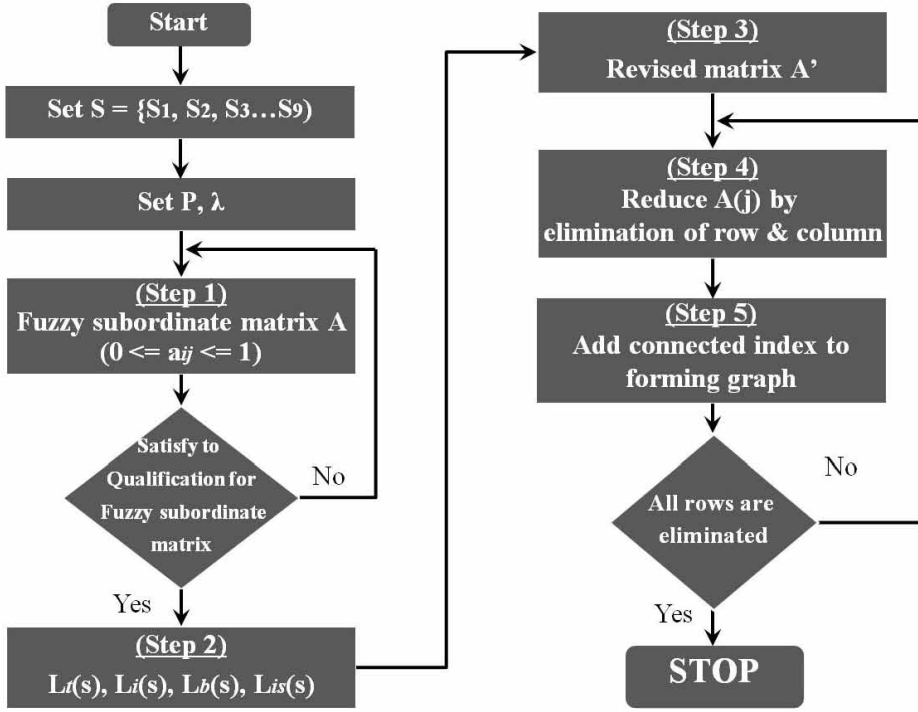


Figure 3. A flowchart for FSM algorithm

The system indicates $S=\{S_1, S_2,...,S_n\}$ in the FSM method and the fuzzy subordinate matrix A of the fuzzy subordinate relationship between extracted elements in response to textual relation indicates $A=[0,1]$. A is $n \times n$ matrix and elements $a_{ij}(i,j=1,2,...,n)$ of A is drawn by fuzzy binary relationship of calculation in (1). Lastly A_{ji} indicates the subordinative extent. The structural model composed of the FSM algorithm is in Figure 3 and details as follows:

$$a_{ij} = f_r(S_i, S_j), 0 \leq a_{ij} \leq 1 \quad (f_r : S \times S \rightarrow [0,1]) \quad (1)$$

In step1, fuzzy subordinate matrix $A=[a_{ij}]$ to satisfy fuzzy non-reflux ratio and fuzzy asymmetric rate sets up and modifies A to satisfy fuzzy interest rate rumination, fuzzy non-reflux ratio, asymmetric interest and interest rate rumination are defined as follows. Threshold value is a real number of the pre-given half open interval or semi-open interval $(0,1]$.

First, fuzzy non-reflux ratio is established to satisfy $f_r(S_i, S_j) \leq P$ about $\forall (S_i, S_j) \in S \times S$.

Second, fuzzy asymmetric rate is established to satisfy $f_r(S_i, S_j) < P$ or $f_r(S_j, S_i) < P$ about $\forall(S_i, S_j) \in S \times S (i \neq j)$.

Third, fuzzy interest rate rumination is established to satisfy $f_r(S_i, S_k) \geq M$ about $M = V_{j=1}^n (f_r(S_i, S_j) \wedge f_r(S_i, S_k)) \geq P$ on the $\forall(S_i, S_j), (S_j, S_k), (S_i, S_k) \in S \times S, (i \neq j, j \neq k, i \neq k)$.

In step2, the highest level($L_t(s)$), middle level($L_i(s)$), the lowest level($L_b(s)$) and independent level($L_{is}(s)$) gives combined relationships between levels and indicates extracted elements, each belonging to a level. They have determined, by definition, as calculation (2), calculation (3), calculation (4), calculation (5) respectively.

$$L_t(s) = \{S_k | V_{j=1}^n a_{kj} < P \leq V_{i=1}^n a_{ik}\} \quad (2)$$

$$L_i(s) = \{S_k | P \leq V_{i=1}^n a_{ik}, P \leq V_{j=1}^n a_{kj}\} \quad (3)$$

$$L_b(s) = \{S_k | V_{i=1}^n a_{ik} < P \leq V_{j=1}^n a_{kj}\} \quad (4)$$

$$L_{is}(s) = \{S_k | V_{i=1}^n a_{ik} < P, V_{j=1}^n a_{kj} < P\} \quad (5)$$

$\forall a_{ij}$ of each definition of levels means $\max(a_{ij})$, the block is defined element unit $B(s_i)$ from element unit $L_t(s)$ depend on the element S_i in level unit $L_b(s)$.

In other words the block matrix is the highest level of single hierarchy, which designates Q_j , and establishes $Q_j \subseteq L_t(s)$.

Elements belong to the same block Q_j when the matrix denominates. The subordinate relationships between the elements, which are constructed by the fuzzy subordinate matrix. At this time, the small matrix is configured to correspond to each blocks that is defined to the single-layer matrix $A^{(i)}$.

In the step3, for subordinate relationships between elements to analyze, remove the column of $L_t(s)$, row of $L_b(s)$ and column & row of $L_{is}(s)$ for step 2 and Structure A as A' using line and row. The reason to remove the line and row, are due to the fact that they are unnecessary for structure analysis depending on the level of matrix definition.

In step4, from step3, a reconstructed A' is made from the single-layer matrix $A^{(i)}$ depending on the block matrix Q_j . The single-layer matrix defines the combinable elements matrix to perform a structure analysis.

In step5, choose the fuzzy structure parameter λ and structure the structural graph of the single-layer matrix $A(j)$. The nonsingular matrix of S_j is $S_{ik} (k = 1, 2, \dots, n')$, S_{ik} substitutes $a_{\bullet j}^*$ from $a_{\bullet j}$ and is eliminated according to calculation (6) and draws the structural graph that decides directly the subordinate elements about S_j . [] indicates column vector.

$$[a_{\bullet j}^*] = [a_{\bullet j}] \wedge [\overline{a_{\bullet j}}] \wedge \dots [\overline{a_{\bullet in'}}] \quad (6)$$

4.2 Model design

To construct the advancement structural model of GICOMS, experts in maritime safety have been brainstorming to extract and select detailed assignments. Subsections of the discerned nine advancement subjects for Advancement structural model of GICOMS can be seen on Table 2. The survey was implemented by experts in maritime and port.

Table 2. GICOMS improvement propulsion item

Classification	Item details
S ₁	Advancement of GICOMS
S ₂	Improvement a system of information production
S ₃	Improvement a scheme of information providing
S ₄	Linkage between GICOMS and VTS
S ₅	Building global networks for safety cooperation
S ₆	Construction correspondence system for e-Navigation
S ₇	Reinforcement prevention system of marine accidents
S ₈	Advancement function of VMS
S ₉	Activation of usage

The method of the survey consists of about 9 questions from Table 2 and compares the comparative effects instinctively. The effect is, ‘an element, S_i and influences another element, S_j. The Grade is the completed results of elements a_{ij} [0,1]. The questionnaire was distributed to a total of 30 respondents who engaged in field of maritime safety and uses the 25 questionnaires to satisfy the fuzzy non-reflux ratio & fuzzy interest rate rumination, which conducted a structural structure analysis about GICOMS advanced propulsion items

4.3 Structural model

Parameter value λ is important to produce the structural graph. Threshold value P decides on the ‘subordinate relationships between elements’ and class subdivision, and determines the subordinate relationship of dependency class. The P value performs the hierarchy structure to create many levels, depending on the decreasing number, and increases the possibility that it is not the fuzzy asymmetric rate, but establishes assigning and changing of the valid P value gradually, in order to produce valid results. Therefore this analysis conducted a consciousness structure modeling to obtain valid threshold value on all the questionnaires responses in consecutive order.

The fuzzy subordinate matrix $A^k = [a_{ij}^k]_{9 \times 9}$ ($k = 1, 2, \dots, 25$) is produced by the data

of the 25 questionnaire responses used in calculation (7), and rounded to the nearest thousandths. The results can be seen in calculation (8).

$$A = [a_{ij}]_{9 \times 9} = \sum_{k=1}^{25} \left[\frac{a_i^k}{25} \right]_{9 \times 9} \quad (7)$$

$$A = \begin{matrix} & S_1 & S_2 & S_3 & S_4 & S_5 & S_6 & S_7 & S_8 & S_9 \\ \begin{matrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \\ S_7 \\ S_8 \\ S_9 \end{matrix} & \begin{bmatrix} 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 & 0.00 \\ 0.73 & 0.00 & 0.55 & 0.40 & 0.35 & 0.68 & 0.55 & 0.55 & 0.55 \\ 0.65 & 0.53 & 0.00 & 0.43 & 0.38 & 0.68 & 0.68 & 0.45 & 0.78 \\ 0.65 & 0.55 & 0.40 & 0.00 & 0.38 & 0.68 & 0.70 & 0.65 & 0.63 \\ 0.58 & 0.40 & 0.40 & 0.33 & 0.00 & 0.65 & 0.45 & 0.48 & 0.45 \\ 0.68 & 0.63 & 0.63 & 0.53 & 0.53 & 0.00 & 0.65 & 0.55 & 0.60 \\ 0.65 & 0.28 & 0.48 & 0.58 & 0.30 & 0.53 & 0.00 & 0.55 & 0.65 \\ 0.65 & 0.35 & 0.50 & 0.60 & 0.40 & 0.58 & 0.60 & 0.00 & 0.60 \\ 0.65 & 0.40 & 0.55 & 0.40 & 0.30 & 0.48 & 0.50 & 0.48 & 0.00 \end{bmatrix} \end{matrix} \quad (8)$$

$A = [a_{ij}]_{9 \times 9}$ is the average of $A^k = [a_{ij}^k]_{9 \times 9}$ ($k = 1, 2, \dots, 25$), diagonal elements $a_{ij}(i = j)$ presumes 0 as a matter of accommodation. The consciousness structure modeling is conducted by a structure analysis, as the fuzzy structural modeling technique algorithm is based on calculation (8).

4.4 Structural Graph

The structure analysis of all survey respondents is conducted by the ‘Advancement Structural Model of GICOMS’. For validity threshold value analyzes the relations between the elements, threshold value P shares 0.60, 0.65, 0.70, and is conducted by the structure analysis as parameter value is 0.5.

The results of the structure analysis is the appropriate level of structure indicated in threshold value $P=0.65$, and parameter value $\lambda=0.5$. A structural graph of the structural model is shown in Figure 4 and indicates the influence of the relationships and priority between subsections.

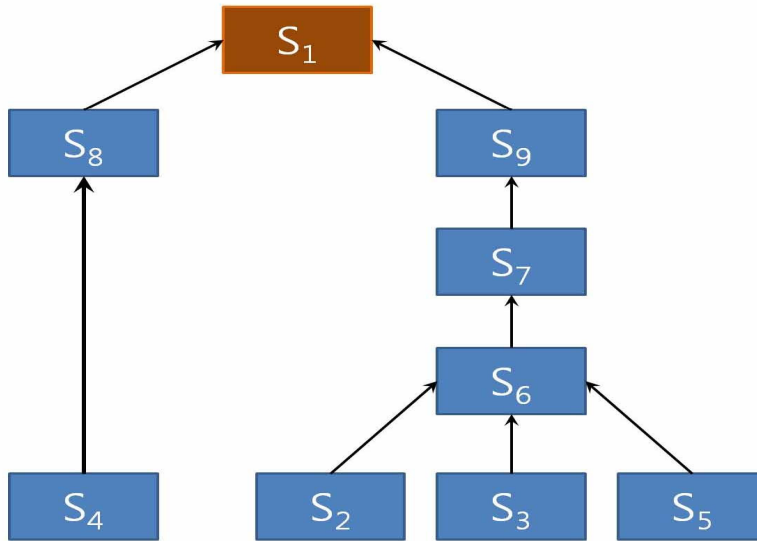


Figure 4. Structure graph by structural model

The ‘Advancement subject’ of the ‘Advancement structural model of GICOMS’ have analyzed the influence of the relationships and priority between the subsections, of the ‘Advancement of GICOMS(S₁)’ in the highest level. This is the final goal and indicates the content influenced by another content.

The second influenced content indicate the ‘Construction Correspondence System for e-Navigation (S₆)’, ‘Reinforcement Prevention System of Marine Accident (S₇)’, ‘Advancement function of VMS (S₈)’ and ‘Activation of usage (S₉)’ in the middle level.

Contents influenced by another element in the lowest level are the ‘Improvement of a System of Information Production (S₂)’, ‘Improvement of a Scheme of Information Providing (S₃)’, ‘Linkage between GICOMS and VTS (S₄)’, and ‘Building Global Networks for Safety Cooperation (S₅)’, which are influenced and related to the ‘Construction Correspondence System for e-Navigation (S₆)’ in the middle level. The ‘Linkage between GICOMS and VTS (S₄)’ is influenced and related to the ‘Advancement Function of VMS (S₈)’ in the middle level.

The ‘Construction Correspondence System for e-Navigation (S₆)’ is at the lowest level of middle level 3 grade, which is related to the 3 contents of the lowest level, and influenced by the ‘Reinforcement prevention System of Marine Accident (S₇)’. The ‘Reinforcement Prevention System of Marine Accident (S₇)’ is influenced only by the ‘Activation of Usage (S₉)’ in the middle level. Lastly, the ‘Advancement of GICOMS (S₁)’ in the highest level is influenced and related to the ‘Advancement Function of VMS (S₈)’ and ‘Activation of Usage (S₉)’ in the middle level.

5. Conclusion

This paper examined a case study of a similar system for the implementation of the e-Navigation internal and external techniques, structured the structural model, and produced nine GICOMS advanced propulsion items in order to develop, operate and construct GICOMS to the e-Navigation platform internally. Moreover, when identifying the process that was conducted, a structural model was suggested. It can grasp the consciousness structure analysis and correlation between elements through the questionnaire survey by targeting experts using the FSM technique. The result of the interrelation analysis about GICOMS advanced propulsion items are as follows:

First, the ‘Advancement of GICOMS (S_1)’ is an element of the highest level influenced by other element.

Second, the lowest level elements are the ‘Improvement of a System of Information Production (S_2)’, ‘Improvement of a Scheme of Information Providing (S_3)’, ‘Linkage between GICOMS and VTS (S_4)’, and ‘Building Global Networks for Safety Cooperation (S_5)’. Middle level elements are ‘Construction Correspondence System for e-Navigation (S_6)’, ‘Reinforcement Prevention System of Marine Accident (S_7)’, ‘Advancement Function of VMS (S_8)’ and ‘Activation of Usage (S_9)’.

Third, the ‘Improvement a System of Information Production (S_2)’, ‘Improvement a Scheme of Information Providing (S_3)’ and ‘Building Global Networks for Safety Cooperation (S_5)’ are the lowest level elements that effect the middle level elements. The ‘Construction Correspondence System for e-Navigation (S_6)’ effect the ‘Reinforcement Prevention System of Marine Accident (S_7)’. In addition, the ‘Advancement Function of VMS (S_8)’, and ‘Activation of Usage (S_9)’ are middle level elements that effected by the ‘Linkage between GICOMS and VTS (S_4)’, and ‘Reinforcement Prevention System of Marine Accident (S_7)’ respectively.

Finally, ‘Linkage between GICOMS and VTS (S_4)’, and the ‘Reinforcement Prevention System of Marine Accident (S_7)’ are elements that directly influenced the highest level of the ‘Advancement of GICOMS’.

As a result, the following scheme is recommended to obtain a more sophisticated GICOMS which is based on the structure model of the research; but first facilities, equipment and professional manpower are be needed to improve and be supplemented by utilizing the cutting edge IT. Furthermore, it is required to target the active usage and switch to the “Advanced Function of VMS (S_8)”.

A decision is needed to promote the “Construction Correspondence System for e-Navigation(S_6)” and “Building Global Networks for Safety Cooperation(S_5)”.

The constitutive model and analysis result of this research would be able to utilize not only the purpose to efficiently and effectively improved GICOMS but also to investigate the correlations between each elements in preparation for the age of e-Navigation.

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