

Review on some aspects of legal and scientific understandings regarding outer continental shelf limits in the Arctic Ocean

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ABSTRACT

Among the most controversial criteria in the delimitation of outer continental shelf are ridge provisions in article 76 of the United Nations Convention on the Law of the Sea. In 2001, Russia claimed its sovereign rights to the continental shelf in central Arctic Ocean. Focusing on this Russian submission to the Commission on the Limits of the Continental Shelf (CLCS), this article aims to widely address the historical, legal and scientific aspects of the continental shelf that are necessary to be reviewed by coastal States seeking to claim the extended continental shelf beyond their 200 nautical miles (M) territory. Ridge provisions with the natural prolongation standard can be invoked as a useful tool in order to remove the 350 M constraints for outer limits of the continental margin. Three features should be carefully considered to classify ridges correctly: geological continuity, crustal neutrality and envelop of the foot of the continental slope. Geomorphological data ought to be carefully considered together with geological and geophysical data to prepare the submission to the CLCS. The CLCS has a full responsibility to interpret the provisions and apply the legal and scientific criteria in reviewing the submission by coastal States. Given the high possibility of getting easily rejected due to the heavy workload of the CLCS, a coastal State should expend considerable amounts of time and efforts in claiming its outer limit of continental shelf based on a ridge and natural prolongation.

Key words: Arctic, territorial claims, continental shelf, sovereign rights, Commission of the Limits of the Continental Shelf, Lomonosov and Alpha-Mendelev Ridges.

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1. Introduction

The Arctic Ocean is rising rapidly in terms of its international, political and economic importance. Plentiful minerals will likely transform the Arctic region into a booming economic frontier in the 21st century. The Arctic Ocean basins are expected to hold large deposits of oil, natural gas, methane hydrate and large amounts of valuable minerals.¹

With the shrinking of the polar ice cap in the Arctic due to global warming, this region also draws global attention as it offers attractive transportation possibilities as well as more viable energy exploitation. Two navigable pathways, the Northern Sea Route (NSR) and the Northwest Passage (NWP), have been historically recognized and seem to be open for navigation in the near future.² By August 2008, ice blockage in Laptev Sea melted enough to open NSR and NWP simultaneously for the first time in 125,000 years since the last Ice Age.³ Both passages can significantly reduce the time and costs of the existing transportation and logistics.

With such a rapid increase of attention on the Arctic, five coastal states (Canada, Denmark, Norway, Russia and the United States)⁴ have competitively made efforts to reinforce their territorial and jurisdictional claims in the region. In December 2001, Russia proposed outer limits of its continental shelf beyond the 200 nautical mile (M) of Exclusive Economic Zone (EEZ) in the Arctic, thereby becoming the first state to submit such information to the Commission on the Limits of the Continental Shelf (CLCS) in accordance with the UN Convention on the Law of the Sea (LOS⁵). A central argument of this claim was that the Lomonosov and Mendeleev Ridges were natural extensions of the Russian

1 The Arctic Council's *Arctic Oil and Gas 2007* assessment, published in May 2008, states that: More than five percent of the world's known oil reserves and over 20 percent of its known gas reserves are in the Arctic, the vast majority of both in arctic Russia. There are estimates that as much as a quarter of the world's undiscovered oil and gas lies in the Arctic. See AMAP (2007), p.32.

2 The Northern Sea Route (NSR) is the shortest link between Western Europe and East Asia along the northern coast of Russia. A contemporary ship travelling along this route, for example, from the Netherlands to Japan, will cover about 14,000 km, compared to 20,000 km (the length of the route along the Suez and across the Indian Ocean) or 24,000 km (the Atlantic, the Panama Canal and the Pacific). Large ships that cannot pass through either canal have to go around Africa covering nearly 27,000 km. The entire passage opening of the NSR historically lasted only 20~30 days per year (ACIA, 2004). The Northwest Passage (NWP) also connects Asia and Europe along the northern coast of Canada but had a much more limited navigation history with the only one significant merchant voyage by the ice-breaking tanker 'Manhattan' in 1969.

3 For example, see Lean (2008).

4 A further three states (e.g., Finland, Iceland and Sweden) are also generally considered to be Arctic states. For various optional definitions of the Arctic region, see Rayfuse (2007), p.197.

5 In this paper, we separately use two acronyms, LOS and UNCLOS, to avoid the confusion between the law and the conference itself. LOS stands for (the UN Convention on) the Law of the Sea, referring to the provisions of law itself. UNCLOS abbreviates the United Nations Conference of the Law of the Sea, meaning the conferences gathered three times under the call and sponsorship of the UN General Assembly (i.e., UNCLOS I, II and III).

continental shelf.⁶ Norway also submitted to CLCS its proposal for extended outer limit of continental shelf in the Arctic in 2006. The CLCS responded on Russia's submission to conduct further research and collect more data to revise its proposal, but has yet to respond to Norway's submission.⁷ Canada, Denmark and the US are also likely to define their continental shelf limits over the next few years. In August 2007, Russia embarked on a mission to the Lomonosov Ridge sending the submersible that planted a national flag on the seabed below the North Pole. In response to the Russian's maneuver, the other Arctic coastal states began their own scientific and political activities. Denmark launched a month-long Danish Continental Shelf Project with several Swedish institutes to seek the evidence that Lomonosov Ridge is attached to the northern Greenland, attempting to make the ridge a natural extension of Danish territory.⁸ The US continued expansion of offshore activities in the Chukchi Sea and Norway developed resources in Barents Sea. Canada announced a range of initiatives, including eight new patrol vessels, plans for the construction of a High Arctic military base and deep sea port and a rejuvenated programme of environmental and climate research.⁹

Besides the jurisdictional claims of coastal states to the international waters around the Arctic pole, an oil exploration venture company recently argued that it had a prior claim to the 'Arctic Commons.' The argument draws on legal principles such as the Law of Discovery, Rights to Claim Territory and rights to operate in international waters for the common good of mankind.¹⁰ Natural resources in the international waters of the Arctic should be common heritage for mankind and be explored in a sustainable manner for the justified benefit of future generations. Therefore, the argument of coastal states regarding jurisdiction of continental shelf beyond 200 M in the Arctic directly affects other nations' interests in worldwide. As many nations do, Korea also regards the Arctic development as one of the 'Blue Ocean Projects', a promising opportunity to expand and develop the national welfare. Thus, the territorial issues of the Arctic deserve international attention.

Given the confidentiality rule, there is no way to know precisely what LOS provisions Russia invoked in the 2001 submission or might invoke in the revised submission to come.¹¹ It is highly possible that the natural prolongation and ridge concept plays an important role in the Russian's submission. In order to better understand the Arctic territorial

6 It means that almost half of the continental shelf in the Arctic would go under Russia's jurisdiction if the submission is accepted. For claims and agreed boundaries in the Arctic Ocean, see the map from IBRU (2008).

7 As of March, 2009.

8 See Mellgren (2007).

9 See Powell (2008), p.828.

10 The Arctic Oil and Gas Corporation (an oil venture) established the 'Arctic Ocean Commons Prospect' claim, based on a submission to the UN General Assembly in May 2006 by three private companies. See *Ibid.*, p.829.

11 The confidentiality is originally aimed to protect proprietary and sensitive data of the submitting state. However, it practically masks the data from other states that may have legitimate concerns about the appropriateness of the data for delimiting the outer continental shelf. See Macnab (2004), p.12.

issues initiated by Russia, the main purpose of this paper is to provide wide information ranging from historical, legal and scientific aspects of the continental shelf, focusing on the provisions of the LOS article 76. Russian claims to the Arctic in 2001 are also addressed in terms of historical and scientific perspectives. This paper, because of its comprehensive approach and in-depth analysis, is also intended as an educational material for graduate students of law and/or earth sciences.

2. Historical perception on continental shelf

Awareness of the historical background often helps to understand the current situation. Until the 20th century the seabed was generally regarded as an international area.

No legal distinction was made between the continental shelf and the deep ocean floor and coastal States had only sovereign rights over the seabed within their 3 M territorial sea.¹² In the first decades of the 20th century, however, coastal States started declaring sovereign rights to the exploitation of sedentary species on the continental shelf, or even asserting rights of control over specific areas of the shelf. Sovereign rights lie somewhere in between sovereignty and jurisdiction.¹³ With technical advances, the interest in having control over the shelf resources beyond the existing territorial sea increased and the developments were rapid.

The first clear assertion of the idea that the resources of the continental shelf belong to the coastal State is the Proclamation made by the U.S. President Truman in 1945.¹⁴ The Truman Proclamation claimed that the continental shelf was considered as contiguous area to the continent which is covered by no more than 100 fathoms of water

12 The territorial sea concept gradually solidified in the 18th century. Its maximum breadth has long been disputed and said to be equal to the range of a land-based cannon in that century. Eventually, through decades of naval warfare, one English league (3 nautical miles) became a much-cited customary standard. Scandinavian nations claimed 4 M territorial seas, based on the length of the Scandinavian league. By the 20th century, 3 M was the maximum allowable breadth for the territorial sea under customary international law. See Kalo *et al.* (2007), p.375.

13 Legally speaking, sovereignty and jurisdiction are distinctive terms to be separately treated. Sovereignty is the power of a state to do everything necessary to govern itself, such as making, executing and applying laws; imposing and collecting taxes; making war and peace; and forming treaties or engaging in commerce with foreign nations. Jurisdiction generally describes an authority over a certain area, which is often interpreted as police power in the context of the coast guarding. See *Ibid.*, p.380.

14 The Truman Proclamation mentioned four reasons to justify the exercise of jurisdiction over the natural resources of the subsoil and sea bed of the continental shelf by the contiguous nation: 1) The effectiveness of measures to utilize and conserve resources, 2) The natural appurtenant to land-mass of the coastal nation, 3) The seaward extension of natural resources, 4) Monitoring activities off the coast in the context of self-protection. See Continental Shelf of the United States, Proclamation No. 2667, Sept. 28, 1945, 10 Fed. Reg. 12303.

(equivalent of 600 feet or 200 metres).¹⁵ It was followed by similar illegal claims of many other States. The South American countries Chile, Peru and Ecuador went one step further with the Santiago Declaration in 1952.¹⁶ The international response to this 200 M claim, was opposition, especially from the maritime nations with large navies or fishing vessels, in contrast to nearly immediate favorable response to the Truman Proclamation. The 200 mile club of nations did, however, gradually begin to gather developing nations first in Latin America and then in Africa. In the midst of this unsettling trend toward extended jurisdiction in the ocean, the First United Nations Conferences on the Law of the Sea (UNCLOS I) gathered in Geneva in 1958 to consider four law-making treaties proposed by the International Law Commission.¹⁷ These four treaties successfully built the framework of the LOS, but hardly addressed the debate on the extended national jurisdiction rather than recognized the Truman continental shelf doctrine. The delegations in Geneva were unable to agree on the maximum breadth of the territorial sea.¹⁸ In 1960, UNCLOS II was called for by UN General Assembly to meet again in Geneva, attempting to reach to an agreement on this issue, but failed. Only ten years after UNCLOS II, a third conference was summoned in order to address this issue. The decade-long negotiations within UNCLOS III from 1973 to 1982 settled by consensus upon a definition of an allowable zone of coastal nation rights, jurisdictions and duties that could extend out to 200 miles offshore, which is known as the EEZ.

Apart from the territorial sea boundary, the legal status and limit of the continental shelf had been addressed during the three UNCLOS. Four law-making conventions during UNCLOS I provided generally accurate codifications or articulations of the customary LOS. For example, the Convention on the Continental Shelf, one of the four conventions, gave to the coastal State the exclusive right to explore the continental shelf and exploit its resources. It also made clear that the rights of the coastal State over the continental shelf did not affect the legal status of the superjacent waters as high seas or that of the air space above.¹⁹ Importantly, this right is viewed as inherent and does not require the state

15 This claim was almost certainly illegal at the time because it asserted national authority over resources of the seabed extending far beyond the 3 M border of the US territorial sea and under the waters of the free high seas.

16 In 1947, Chile first claimed the jurisdiction to the natural resources of the 200 M in response and against to the Japanese return to the whaling ground off the South America's long coast. The same year saw Peru assert its 200 M territorial sea. In 1952, based on the Santiago Declaration of Chile, Ecuador and Peru, which proclaimed the legality and rightness of 200 M zones. Ecuador extended its territorial sea to 200 M. Those nations did not claim full sovereignty only over the seabed and subsoil but also over the superjacent waters and the air space above.

17 More than 80 nation-state delegations participated in these deliberations and, following a few weeks of negotiations, adopted the four 1958 Geneva Conventions on the Law of the Sea. Four conventions are regarding 1) the Territorial Sea and the Contiguous Zone, 2) the Continental Shelf, 3) the High Seas and 4) Fishing and Conservation of the Living Resources of the High Seas, respectively.

18 The U.S. and other maritime countries wanted to retain the 3 mile limit, while the 200 mile club of nations would like to argue 200 mile limits. A growing number of coastal nations preferred a 12 mile breadth.

to make an explicit claim to continental shelf resources.²⁰ However, there are some differences between the physical extent of today's legal continental shelf and that recognized in 1958. The convention chose to establish the 200 metre isobaths, a depth line that approximates the average natural limit and is also close to the 100 fathom line marked on then-nautical charts. For future technical improvement, it allowed the further extension of the legal shelf beyond the 200 metre isobath to the limit of technical exploitation of the natural resources of the seabed and subsoil.²¹

In the North Sea Continental Shelf cases in 1969, the International Court of Justice (ICJ) confirmed that these provisions of the Geneva Convention represented customary law. However, the ICJ also laid much stress on the continental shelf being the natural prolongation of the coastal State's land mass.²² This conclusion of the ICJ was to have big influence on the development of this issue (natural prolongation) during the UNCLOS III. While there was general agreement at the UNCLOS III to draw on the provisions of the Geneva Convention with regards to the legal status of the continental shelf and its inner limit, there were divergent views on what the definition of the outer limit should be.²³ During the UNCLOS III, a compromise was reached that coastal States could extend their continental shelf jurisdiction beyond 200 M. Therefore, the continental shelf regime evolved from the traditional limit of 3 M territorial sea to the full natural prolongation beyond the 200 M EEZ.

3. Provisions of the LOS regarding the continental shelf

3.1. *Legal status of the shelf and coastal State's rights*

According to article 77 of the LOS, the coastal State exercises over the continental shelf sovereign rights for the purpose of exploring it and exploiting its natural resources.²⁴ The coastal nation does not enjoy full sovereignty over the continental shelf, but functional rights and jurisdiction, as is the case in the EEZ.²⁵ This includes the right to construct

19 See article 2, paragraph 1 and 2 of the 1958 Convention on the Continental Shelf.

20 See article 77, paragraph 3 of the LOS, stating *The rights of the coastal State over the continental shelf do not depend on occupation, effective or notional, or on any express proclamation.*

21 This was called as the *exploitability criterion*.

22 The ICJ said the following: *More fundamental than the notion of proximity appears to be the principle of the natural prolongation or continuation of the land territory.*

23 Many countries favored toward the 200 M limit. However, a number of coastal nations with a potential for extended continental shelves supported a definition which would extend the continental shelf beyond the 200 M limit.

24 See article 77, paragraph 1 of the LOS.

25 See article 56, paragraph 1 of the LOS.

artificial islands, installations and structures²⁶ and to authorize and regulate drilling²⁷ on the continental shelf. The coastal State also has the right to regulate, authorize and conduct marine scientific research on its continental shelf²⁸ and can, in principle, withhold its consent to the conduct of resource oriented research on the shelf by another nation based on certain conditions.²⁹

The sovereign rights of the coastal State are exclusive in the sense that if it does not explore the continental shelf or exploit its natural resources, no one may undertake these activities without the express consent of the coastal State.³⁰ All these rights are inherent on the grounds of its sovereignty over the land territory.

The continental shelf only includes the seabed and the subsoil. The superjacent waters and the airspace above do not fall thereunder and thus the rights of the coastal State over the continental shelf do not affect the legal status of the superjacent waters and the airspace above.³¹ The exercise of the rights of the coastal State over the continental shelf must not infringe or result in any unjustifiable interference with navigation and other rights and freedoms of other States on the high seas and within the EEZ.³² According to article 79 (1), all States are entitled to lay submarine cables and pipeline on the continental shelf.

3.2. Outer limits of the continental shelf

Two distinctive approaches can be used to understand the geographical range of the continental shelf. Continental shelf in the traditional scientific sense is the platform on which the land lies above the 200 meter isobaths. In broader and legal sense, continental shelf extends throughout the natural prolongation of the land territory to the outer edge of the so-called continental margin, or to a distance of 200 M from the baselines where the outer edge of the margin does not reach up to 200 M (Fig. 1). The continental margin consists of the seabed and subsoil of the shelf, the slope and the rise. In the rise, there are typically sediments that have washed down from the continents through the geological time scale, whose thickness is one of the important technical criteria to judge the natural prolongation of land mass. The foot of the slope also plays a very important role in delimiting the breadth of the continental shelf. As a general rule, the foot of the slope shall be determined at the point of maximum change in the gradient as the base of the slope in

²⁶ See article 80 of the LOS.

²⁷ See article 81 of the LOS.

²⁸ See article 246, paragraph 1 of the LOS.

²⁹ See article 246, paragraph 5 of the LOS.

³⁰ See article 77, paragraph 2 of the LOS.

³¹ See article 78, paragraph 1 of the LOS.

³² See article 78, paragraph 2 of the LOS.

the absence of evidence to the contrary (Fig. 1).³³ Beyond the continental margin is the deep ocean floor or abyssal plain. Article 76 of the LOS provides the legal definition of the continental shelf, including the determination of the foot of the slope, outer edges of the continental margin, maximum limits of the shelf and the ridge.

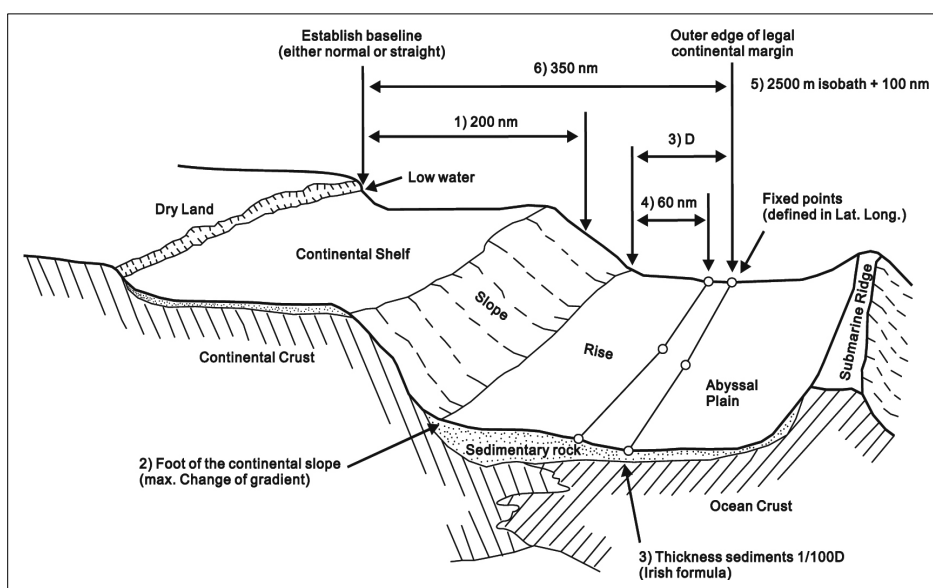


Figure 1. Generalized profiles across a continental margin showing the geomorphology and the outer limits of the continental shelf (arrows) determined by various criteria in article 76: 1) the 200 nautical mile (M) limit, 2) the foot of the continental slope, 3) the Gardiner Line (Irish formula), 4) the Hedberg Line (60 M from the foot of the shelf), 5) the 2500 m isobaths projected seaward by 100 M, 6) the 350 M limit from territorial baseline (modified from International Hydrographic Bureau, 2006).

Paragraph 1 of article 76 defines the continental shelf as the combination of the seabed and subsoil in the submarine areas that extend beyond its territorial sea throughout the natural prolongation of its land territory to the outer edge of the continental margin, or to a distance of 200 M from the baselines. This paragraph prescribes two criteria for determination of outer limits of the shelf: either the natural prolongation or the distance of 200 M. The distance provides a minimum breadth of the continental shelf of 200 M in cases where the natural prolongation does not reach to 200 M. Natural prolongation is the key parameter in the general part of the definition of the continental shelf. Coastal States claiming for the extended continental shelf beyond the 200 M necessarily invoke this provision on the natural prolongation. By the plain meaning of the word prolongation, the required continuity must be unbroken from the shoreline to the outer edge of the continental margin.

³³ See article 76, paragraph 4(b) of the LOS.

Article 76 (3) describes that the continental margin comprises the submerged prolongation of the land mass of the coastal State and consists of the seabed and subsoil of the shelf, the slope and the rise. The continental margin does not include the deep ocean floor with its oceanic ridges or the subsoil thereof.

Apparently, the definition of continental margin in article 76 shows that it draws on geomorphology and submarine landscape, not on the crustal type (i.e., continental or oceanic crust). There is no LOS provision regarding crustal type in spite of many cases representing the influence of crustal type on negotiation process. This implies that the submerged prolongation of the landmass of a coastal State, regardless of its sediment characteristics, belongs to its continental margin (legal continental shelf).

For the continental shelf of an island, there is no distinction made between the determination of the outer limits of the continental shelf of a mainland and that of an island. The continental shelf of an island is determined in accordance with the same provisions of the LOS applicable to other land territory.³⁴

The foot of the slope is the primary feature in the delimitation of the continental shelf beyond the 200 M limit (Fig. 1). It is the reference baseline from which the breadth of limits is measured by the sediment thickness with at least 1 per cent of the shortest distance to outermost fixed points (Irish formula), or by not more than 60 M to fixed points (Hedberg formula).³⁵ The Irish formula employs drawing the line connecting points not more than 60 M apart, at each of which points the thickness of sediments is at least 1 per cent of the shortest distance from such point to the foot of the slope. Thus, if the formula is to apply at a distance of 100 M from the foot of the slope, 1 M thickness of sediment must be present there. The CLCS invokes a principle of continuity in the application of this formula to state that “(a) to establish fixed points a coastal State may choose the outermost location where the 1 per cent or greater sediment thickness occurs within and below the same continuous sedimentary apron; and that (b) for each of the fixed points chosen, the CLCS expects documentation of the continuity between the sediments at these points and the sediments at the foot of the continental slope.”³⁶ The Hedberg formula includes drawing a line connecting points not more than 60 M from the foot of the slope (Fig. 1). A State may apply the two formulas alternatively, i.e., it may apply the Irish formula in certain portions of its continental shelf and the Hedberg formula in other portions, in a manner to maximize its continental shelf ranges.

Article 76 (5) confines the maximum breadth of the legal continental shelf within 350 M from the baseline of the territorial sea or within 100 M from the 2,500 metre isobaths, which is a line connecting the depth of 2,500 metres. The former criterion (350 M constraint) is based purely on a distance criterion, whereas the latter (the 100 M from the 2500 m

³⁴ See article 121, paragraph 2 of the LOS.

³⁵ See article 76, paragraph 4(a) (i) and (ii) of the LOS.

³⁶ See CLCS (1999), pp.56~67.

isobaths) is based on a depth/distance criterion. Both criteria may be used alternatively and only one of them has to be respected in each portion of the continental shelf. Thus, the outer limits of the continental shelf could extend beyond the 350 M in some cases. It should be emphasized, however, that these constraints are solely limited to the fixed points comprising the line of the outer limits of the continental shelf on the seabed, drawn in accordance with the Irish and Hedberg formulas.

3.3. Ridges

According to paragraph 6 of article 76, the 100 M from the 2,500 meter isobaths constraint may not apply to submarine ridges-the maximum limit on such ridges is fixed at 350 M from the baselines. However, this paragraph does not apply to submarine elevations that are natural components of the continental margin, such as plateaux, rises, caps, banks and spurs. Three types of sea floor ridges are mentioned and differently treated in article 76 of the LOS.³⁷

These so-called “ridge provisions” above incorporated into Article 76 (3) and (6) were among the last provisions to be agreed on during the UNCLOS III. The ridge issue has since been regarded as one of the most complex and contentious parts of the articles. The CLCS states in its technical guideline that None of these terms is precisely defined. It seems that the term “ridge” is used on purpose. The link between the *oceanic ridges* and the submarine ridges is unclear. Both terms are distinct from the “*submarine elevations*”³⁸ Although article 76 of the LOS does not define these terms, the CLCS interprets their notions and verifies their distinction as following:

*“The distinction between the “submarine elevations” and “submarine ridges” or “oceanic ridges” shall not be based on their geographical names used so far in the preparation of the published maps and charts and other relevant literature. Such a distinction for the purpose of article 76 shall be made on the basis of scientific evidence taking into account the appropriate provisions of these guidelines.”*³⁹

The main objective of article 76 (3) mentioning oceanic ridges is to exclude the deep ocean floor from the continental margin, along with its subsoil and oceanic ridges.

³⁷ Oceanic ridges: (The continental margin) does not include the deep ocean floor with its oceanic ridges or the subsoil thereof (para.3); Submarine ridges: on submarine ridges, the outer limit of the continental shelf shall not exceed 350 M from the baselines from which the breadth of the territorial sea is measured (para.6); Submarine elevation: (Maximum limit of 350 M) does not apply to submarine elevations that are natural components of the continental margin, such as plateaux, rises, caps, banks and spurs (para.6).

³⁸ See CLCS (1999), *supra* note 36, p.52.

³⁹ *Ibid.*, p.53.

The main point here is that the continental margin ends where the deep ocean floor begins. It should be pointed out that an oceanic ridge that is located anywhere other than within the deep ocean floor is not excluded from the continental margin. The term “oceanic” in paragraph 3 is used to refer to ridges that are fundamentally and genetically linked to the deep ocean floor by sharing geological characteristics and origin with the deep seafloor and its subsoil. There appears to be two ways in which a ridge may be classified as an oceanic ridge of the deep ocean floor.⁴⁰

First, when an underwater ridge is located beyond the outer edge of the legal continental margin and shares geological characteristics and origin with the deep ocean floor, it is an oceanic ridge of the deep ocean floor. Second, when an underwater ridge is located within the continental margin but detached from the envelope of the foot of the continental slope and extends into the deep ocean floor, it should be regarded as an oceanic ridge.

Some submarine ridges that lie entirely beyond the foot of the continental slope and are either wholly within the deep ocean floor or around the outer edge of the continental margin, may have originated from the continental margin, but were later separated from it by geological crust movements. In geological perspective, such ridges should not be classified as oceanic ridges because they do not share geological characteristics and origin with the deep ocean floor. However, since they lie beyond the foot of the slope over their full range, such ridges cannot become parts of the outer edge of the continental margin. In this respect, such ridges should be treated as an oceanic ridge in exactly the same manner under article 76.

By virtue of article 76 (6), submarine ridges could be ridges that are not natural components of the continental margin but still comprise the continental margin because they fall within the common envelop of the foot of the slope. Concurrently, such submarine ridges are distinguishable from the oceanic ridges of the deep ocean floor. The maximum constraint of 350 M on such ridges was probably introduced to limit the inclusion of strong oceanic characteristics. However, the classification of ridges should not be based solely on a distinction between different geological crust types. This point was also highlighted by the CLCS:

“Therefore, the Commission feels that geological crust types cannot be the sole qualifier in the classification of ridges and elevations of the sea floor into the legal categories of paragraph 6 of article 76, even in the case of island States.”⁴¹

The CLCS (1999) further emphasizes the need to consider a range of character-

40 For more details on the ridge issue, see Breke and Symonds (2004).

41 See CLCS (1999), *supra* note 36, p.54 (para. 7.2.9).

istics, including those already mentioned above, in the classification of ridges:

*“Therefore, the Commission feels that in case of ridges its view shall be based on such scientific and legal considerations as natural prolongation of land territory and land mass, morphology of ridges and their relation to the continental margin as defined in paragraph 4 and continuity of ridges.”*⁴²

Morphology alone is clearly not sufficient to distinguish such “submarine ridges” from the “submarine elevations” that are natural components of the continental margin. Consequently, a “submarine ridge” is a ridge that is morphologically an integral part of the continental margin, but partial or entire ridge is different from the landmass of the coastal State, in that it also shares geological characteristics and/or origin with the deep ocean floor. At the same time, a “submarine ridge” must, at least in its landward part, be genetically linked with the continental margin and not belong to the deep ocean floor with its oceanic part. As it is difficult to define the details concerning various conditions, the CLCS states that it is appropriate that the ridge issue should be examined on a case-by-case basis.⁴³

Article 76 (6) includes a selection of submarine elevations: “such as plateaux, rises, caps, banks and spurs.” This wording is explicitly unhelpful to identify submarine elevations. A submarine elevation has not been included in any oceanographic or legal dictionary so that there is no formal definition that describes the morphological and geological characteristics of submarine elevations. The only specialized dictionary addressing submarine morphological forms was published by the International Hydrographic Bureau in 2001.⁴⁴ Although such highs are commonly associated with continental margins, they may also be found in other settings (e.g., deep sea basin). Thus, the morphological expression of these features is not a sufficient criterion to distinguish between the submarine ridges and the elevations. Since these elevations are natural components of the continental margin, it is important to consider the geological processes that form the submarine elevations within continental margins and how continents grow.

Although there is no reference to a specific type of crust in submarine elevations, it seems appropriate to invoke the principle of geological continuity. That is, these morphological features must have the same general geological characteristics and/or origin as the landmass of the coastal State from which the continental margin naturally extends in order to classify them as natural prolongations.

In conclusion, it seems that in the classification of features that are “natural compo-

⁴² *Ibid.*, p.54 (para. 7.2.10).

⁴³ *Ibid.*, p.55 (para. 7.2.11).

⁴⁴ IHO and IOC (2001). *Standardization of Undersea Feature Names*. International Hydrographic Bureau, Bathymetric Pub. No. 6, 3rd edition. Available from <<http://www.iho.shom.fr/publicat/free/files/B6efEd3.pdf>>

nents of that continental margin” or “submarine ridges”, their fundamental and physical relationships with the continental margin in the sense of the LOS (i.e., in terms of the foot of the slope and their geological characteristics and origin) are more important than their morphological classification.

3.4. The 10-year time limit for submissions

Submission to the CLCS regarding the outer limits of the continental shelf beyond the 200 M is obligated to meet a deadline of 10 years after the entry into force of the LOS for the corresponding State.⁴⁵ Many of coastal States which already ratified the LOS in 1994 showed their major concern on the submission deadline which would have been on November 16th in 2004. Additionally, the CLCS was not established until May 1997 and the delay of deadline should be a realistic issue. At the 11th Meeting of States Parties in May 2001, the decision was made regarding the date of commencement of the ten-year period for making submissions to the CLCS set out in article 4 of Annex II to the LOS.⁴⁶ It was decided that, for a State for which the LOS entered into force before May 13th in 1999, the date of beginning of the 10-year time period for making submissions to the CLCS is May 13th in 1999.⁴⁷ By this decision, coastal States which mostly ratified the LOS before the 1999 should observe the submission deadline on May 13th in 2009. For coastal States in the Arctic Ocean, Russia was the first nation to submit a claim to the CLCS in 2001. Part of this claim relates to the Arctic Ocean beyond the 200 M from the coast.⁴⁸ Norway followed and made a submission to the CLCS regarding its extended continental shelf claim including the Arctic Ocean in November 2006.⁴⁹ Canada’s deadline for submission is in 2013. It is 2014 in the case of Denmark.⁵⁰ For the USA which is a non-party to the UNCLOS, no deadline for submission to the CLCS has been decided yet.

Other opinions were voiced by some delegations during the 11th Meeting of States Parties regarding the 10-year rule. One critical opinion is highly debatable whether the deadline affects the substantive rights protected in the LOS. Article 77 (3) states that rights

⁴⁵ See Article 4 of Annex II to the LOS.

⁴⁶ See the CLCS document on Issues with respect to article 4 of Annex II to the Convention. Available from <http://www.un.org/Depts/los/clcs_new/issues_ten_years.htm>

⁴⁷ The rationale to decide this date as the beginning is that the CLCS has adopted its Scientific and Technical Guidelines on that date and States could have a clear idea of how to prepare their submissions only after this date. See Documents of the Meeting of the State Parties to the UNCLOS, No. 72 (SPLOS/72). Available from <<http://daccessdds.un.org/doc/UNDOC/GEN/N01/387/64/PDF/N0138764.pdf?OpenElement>>

⁴⁸ See Submission by Russian Federation to the CLCS in 2001. Available from <http://www.un.org/Depts/los/clcs_new/submissions_files/submission_rus.htm>

⁴⁹ See Continental Shelf Submission of Norway: in respect of areas in the Arctic Ocean, the Barents Sea and the Norwegian Sea. Available from <http://www.un.org/Depts/los/clcs_new/submissions_files/submission_nor.htm>

⁵⁰ Canada became the party to the UNCLOS in 2003. Denmark joined in the UNCLOS in 2004.

of the coastal State over its continental shelf were inherent.⁵¹ Thus, no-compliance with the 10-year period which, in other words, means non-submission or late-submission, should not adversely affect the corresponding State's rights on the continental shelf. Another issue is of a possible further extension beyond 10 years of the time period for submission, as proposed by the Pacific Island Forum States.⁵² Several delegations recognized that such an extension would accommodate the needs of developing States which lacked the reliable expertise and finance to provide the relevant scientific and technical data for their submission to the CLCS within the deadline. The delegations agreed that meanwhile further discussions were needed on the issue of the ability of States, particularly developing States, to fulfill the requirements of article 4 of Annex II to the Convention. In that regard, the Meeting suggested that the cooperation between the CLCS, regional centers of excellence and the United Nations University should be pursued to build the capacity of developing States for submission. Eventually, in the eighteenth Meeting of the State Parties in June 2008, it was decided that the 10-year time period may be satisfied by submitting preliminary information to the UN Secretary-General.⁵³ However, the preliminary information should be regarded as a temporary tool to delay the deadline of submitting a full submission to the CLCS. For the due consideration by the CLCS, the full submission should be made in accordance with LOS article 76, the Rules of Procedure and the Scientific and Technical Guideline of the CLCS. Based on this decision, most of the coastal States have strived for the submission within the 10-year deadline. For example, 50 cases have been submitted to the CLCS and 41 cases of preliminary information have been submitted to the Secretary-General by the deadline date of May 13th of 2009.⁵⁴ The CLCS have already performed the full examination of eight submissions. Based on the current examining speed of the CLCS, it would be expected that the full examination of 42 cases will be finished in 2091.⁵⁵

51 See *supra* note 20.

52 See the Statement by Mr. Jeem Lippwe, Minister, Permanent Mission of the Federated States of Micronesia to the UN, on behalf of the members of the Pacific Islands Forum that maintain Permanent Missions to the UN in New York, Before the 11th Meeting of the State Parties to the UNCLOS, New York, 16 May 2001. Available from <<http://www.fsmgov.org/fsmun/unclos01.html>>.

53 Preliminary information includes the indication of the outer limits of the continental shelf beyond 200 M, the status of preparation and intended date of making a full submission. See the CLCS document, SPLOS/183. Available from <<http://daccessdds.un.org/doc/UNDOC/GEN/N08/398/76/PDF/N0839876.pdf?OpenElement>>

54 For updated list, see <http://www.un.org/Depts/los/clcs_new/commission_submissions.htm>. Japan already submitted to the CLCS the claim to establish the extended continental shelf beyond 200 M in seven regions located to the south and the south-east off the mainland of Japan in November 12th, 2008. China and Korea submitted the preliminary information instead of full submission on the same date of May 11th, 2009. For these countries' submissions, see the CLCS website <http://www.un.org/Depts/los/clcs_new/clcs_home.htm>

55 The CLCS holds two 6-week examining sessions (March and August) in a year and usually spends four sessions (equivalent of two years) for one case. Therefore, given 41 cases of preliminary information, the CLCS examination would be ended in 2173 (Personal communication with Dr. Park, Yong-Ahn, a member of the CLCS).

Submissions involving disputed areas are exempted from the deadline.⁵⁶ The Annex I to the Rule of Procedure of the CLCS concerns the issue on submissions in case of a dispute between States with opposite or adjacent coasts or in other cases of unresolved land or maritime disputes. Under paragraph 3 of this Annex I, a State may make a partial submission so as not to defect the delimitations of boundaries between States in any other portion of the continental shelf. If a partial submission is made, a submission for the areas not included in the initial submission may be made after the 10-year period. What coastal States in this case might consider is to submit a joint claim with adjacent claiming states, without regard to the delimitation of boundaries between States.⁵⁷ For example, five joint submissions have been turned in to the CLCS to date.⁵⁸

4. Ridges in the Arctic Ocean (Russian submission to CLCS in 2001)

4.1. *Summary of submission by Russia*

Russia has recognized the multiple potential of the Arctic and is moving rapidly to assert its national interests. On December 20, 2001, Moscow has submitted documentation claiming outer limits of its continental shelf covering an area of 1,191,000 km² in the Arctic Ocean-the size of Germany, France and Italy combined. It became the first State to submit its application to the CLCS. The Russian claim extends its judicial continental shelf to the North Pole. As seen in (Fig. 2),⁵⁹ most of the area claimed by Russia is located beyond the Russian 200 M exclusive economic zone (EEZ) in a triangle-shaped zone. Given the confidentiality rule of the CLCS process, there is no way to directly know what provisions Russia invoked in its 2001 submission to the CLCS. However, it is also possible to draw some conclusions speculated on the grounds of documents made public for the Russian claims.⁶⁰ Previous studies represented that Russia would regard Lomonosov and

56 See Paragraph 3 of Annex 1 to the Rule of Procedure of the CLCS. Available from <<http://daccessdds.un.org/doc/UNDOC/GEN/N08/309/23/PDF/N0830923.pdf?OpenElement>>

57 According to the paragraph 4 of Annex I, the CLCS recommends separate submissions or a joint submission in cases involving continental shelf boundaries.

58 Joint submissions were made by 1) France, Ireland, Spain and the UK in the Celtic Sea and the Bay of Biscay (May 2006), 2) Republic of Mauritius and Rep. of Seychelles in the Mascarene Plateau (December 2008), 3) Micronesia, Papua New Guinea and Solomon Islands concerning the Ontong Java Plateau (May 2009), 4) Malaysia and Viet Nam in the South China Sea (May 2009), 5) France and South Africa in the Crozet Archipelago and the Prince Edward Islands (May 2009) in chronological order. For updated information, refer to website in supra note 51.

59 A map of the Russian claim in the Arctic Ocean is a part of the Executive Summary of Russian submission. Available from <http://www.un.org/Depts/los/clcs_new/submissions_files/submission_rus.htm>

60 The executive summary of Russian submission (2001), US reaction to Russian claim and some articles on this issue can be cited for this purpose.

of the Arctic Ocean seabed. If Russian submission is accepted by the CLCS, almost half of the Arctic Ocean would be entitled to Russian Federation in terms of the sovereign rights to the continental shelf. For readers to better understand the Russian context in the Arctic sovereignty, we would like to provide what the Russians have viewed and claimed the Arctic Ocean historically.

4.2. Russia's historical perspective on the Arctic sovereignty

The Russians consider the development of the Arctic regions, the Northern Sea Route (NSR) and recent offshore oil and gas discoveries as one of the brightest pages in the Russian history. Recognizing the important contribution by foreigners (Holland, Great Britain, Norway and other countries), historical tsarist Russia, the Soviet Union and the Russian Federation as a successor have been the major discoverer of most of the Arctic islands and lands and first to achieve practical mastery of navigation along the NSR. In September of 1916 a note by the Russian Foreign Ministry was sent to all nations asserting the Russian claim to all territories explored and unexplored, discovered and undiscovered between the Russian coast on the Arctic Ocean and the North Pole, with the exception of previously recognized territories of other nations.⁶³ Thus, the recognition of economic and strategic value of the region was clearly demonstrated by the Russian government. The resolution of April 15, 1926 by the Presidium of the Central Executive Committee of the USSR proclaimed the establishment of the geographical boundaries of the Soviet sector of the Arctic between 32° 04'35" E and 168° 49'30" W. Within the boundaries of the indicated sector, the Soviet Union claimed to exercise full sovereignty of all land and islands located in the Arctic Ocean, north of the coast of the Soviet Union, as far as the North Pole.⁶⁴ The Soviet Union announced that the Arctic Ocean has special characteristic that justified their claim to nearly half of the entire ocean. Although Russia has never given a special decree since that time, it has been their policy to press for the sector principle. Interestingly, the sector principle is not based on any internationally accepted sea law whatsoever. Therefore, it does not legitimize Russia's claim and it certainly does not offer a reasonable solution in determining jurisdiction over the disputed area.

With respect to development of the Northern Region, the first ice-air reconnaissance was performed in 1924. Gradually, the aviation began regular ice-air reconnaissance and thus Polar Aviation was developed.⁶⁵ The network of Polar Stations has been growing steadily. In December, 1932, by the special resulting of the Council of People's Commissars of the USSR, the Main Directorate of the NSR, the state-owned company 'GlavSevMorPut',

63 See Krypton Constantin (1956), pp.77~78. The Northern Sea Route and the economy of the Soviet North (London: Methuen & Co., Ltd, 1956), pp.77~78.

64 Morskoy Sbornik, No. 6, 1970, pp.83~88.

65 Morskoy Flot, No. 7, 1967, pp.9~11.

was established. The Soviet mastery of the NSR was demonstrated in 1939. Prior to World War II, duration of navigation reached over 100 days in the western part of the NSR and over 70 days in its eastern part.

After the war the efforts for further mastering of the NSR continued. Systematic planned research in the Arctic was intensified during the period of 1949-51, followed by three years of passivity. After 1954, the Soviet Union has maintained at least two drifting stations on the ice. The total number of these stations in a 34-year period starting with 1937 (Papanin station) has reached 20 in 1970.⁶⁶ Polar aviation was reinforced with a greater number and better quality of aircraft. By the mid 1950s, the NSR came out to be fully operational.

Russia intends to create Arctic troops to maintain security of the Russian part of the Arctic Ocean under the conditions of the current political situation in the world. The document posted on the official website of the Russian Security Council said that the Arctic troops and the Russian Coast Guard system would be set up to maintain the military security under various conditions of the military and political situation.⁶⁷ These decisions by the Russian Security Council are aimed at enhancing security protection for the increasing traffic along the NSR. To control Arctic regions, an effective coast guard system is to be established, as well as a developed border infrastructure in Russia's Arctic zone and strong and well-equipped military contingents in those military districts. Russia's Northern and Pacific Fleets will be engaged in protecting the Arctic and sub-Arctic areas.

4.3. Other States' responses and Russia's further statements

Five States responded to the Russian submission, including the United State (US), Canada, Denmark, Japan and Norway.⁶⁸ Except for the US, other nations commented only regarding the overlapping boundary between the Russian's extended continental shelf and their EEZ. The Canadian response indicated that neither the submission itself nor its acceptance by the CLCS would prejudice the delimitation of the continental shelf between Canada and Russia.⁶⁹ Norway stated that the unresolved delimitation issue in the Barents Sea should be treated as a maritime dispute in accordance with Article 5(a) of the Annex I to the Rule of Procedure.⁷⁰ Japan responded regarding the Sea of Okhotsk that both countries have continued vigorous negotiations, in a friendly atmosphere, in terms of the territorial issue of the four southernmost Kuril islands or delimitation of the continental shelf and EEZ.⁷¹ Denmark mentioned its irrelevant status to submit opinions, due to the lack of

⁶⁶ Vodnyi Transport (December 15th, 1970).

⁶⁷ See at <<http://en.rian.ru/analysis/20090330/120824719.html>>.

⁶⁸ All five nation's notifications regarding the submission by Russia to the CLCS are available from <http://www.un.org/Depts/los/clcs_new/submissions_files/submission_rus.htm>.

⁶⁹ See Notification from Canada, Ref No. CLCS.01.2001.LOS/CAN (Feb. 26, 2002).

⁷⁰ See Notification from Norway, Ref No. CLCS.01.2001.LOS/NOR (April 2, 2002).

specific data and non-membership to UNCLOS.⁷²

The US was the only one that referred to the scientific and technical aspects of the Russian submission which “has major flaws as it relates to the continental shelf claim in the Arctic.”⁷³ Regarding the Lomonosov Ridge, The US claimed that “the Ridge is a freestanding feature in the deep, oceanic part of the Arctic Ocean Basin and not a natural component at the continental margins at either Russia or any other State.”⁷⁴ More detailed statements were provided with respect to the Alpha-Mendelev Ridge, saying that “The Alpha-Mendelev Ridge System is the surface expression of a single continuous geologic feature that formed on oceanic crust of the Arctic Ocean basin by volcanism over a “hot spot The Alpha-Mendelev hot spot is now forming from magma funneled from a hot spot to the actively spreading Mid-Atlantic Ridge. The Ridge is therefore a volcanic feature of oceanic origin... It is not part of any State’s continental shelf.”⁷⁵ In order to support these statements, four specific data were provided in terms of bathymetric, aeromagnetic, seismic, bedrock collection by the US response. The US conclusively recommended that the Russian submission should be considered in a deliberate manner, given its particular complexity.

In a further statement to the commission in April 2002, the Russian Federation explained the hydrographic surveys and bathymetric mapping that it had undertaken in order to establish the 2,500 meter isobaths on the continental slope and the foot of the continental slope, performed during the years 1960~1990. Furthermore, Russia detailed the methods for deep seismic sounding and seismic reflection that led it to regard the Alpha-Mendelev Ridge System as part of its continental margin. It stated, in part: The results of the interpretations of comprehensive geological and geophysical data support the categorization of the Amerasian basin geostructures (Lomonosov and Alpha-Mendelev Ridges) as components of the continental margin The integrated interpretation of the deep seismic sounding and seismic reflection sounding provided data on the velocity characteristics, layering and thickness of the earth’s crust which are characteristic of a continental-type crust. This conclusion is consistent with generally accepted concepts.⁷⁶

71 See Notification from Japan, Ref No. CLCS.01.2001.LOS/JPN (March 14, 2002).

72 See Notification from Denmark, Ref No. CLCS.01.2001.LOS/DNK (Feb. 26, 2002).

73 See Notification from the United States of America, Ref No. CLCS.01.2001.LOS/USA (Mar 18, 2002).

74 *Ibid.*, p.3.

75 *Ibid.*, p.2.

76 Statement made by the Deputy Minister for Natural Resources of the Russian Federation During Presentation of the Submission Made by the Russian Federation to the Commission on 28 march 2002, p.5, UN Doc.CLCS/31 (April 5, 2002).

4.4. Recommendation of CLCS regarding Russian submission

A subcommission of the CLCS was created to examine Russian submission. The subcommission met several times during the spring of 2002, requesting additional materials as needed from the Russian Federation and then reported its recommendation to the CLCS. In June 2002, the CLCS by consensus adopted final recommendations for transmission to Russia.⁷⁷

As regards the Central Arctic Ocean, the CLCS recommended that the Russian Federation make a revised submission in respect of its extended continental shelf in that area based on the findings contained in the recommendations.

In the case of the Barents and Bering Seas, the CLCS recommended to Russia, upon entry into force of the maritime boundary delimitation agreements with Norway in the Barents Sea and with the USA in the Bering Sea, to transmit to the CLCS the charts and the coordinates of the delimitation lines as they would represent the outer limits of the continental shelf of Russia extending beyond 200 M in the Barents Sea and the Bering Sea respectively.

Regarding the Sea of Okhotsk, the CLCS recommended to the Russia to make a well-documented partial submission for its extended continental shelf in the northern part of that sea. The CLCS states that this partial submission shall not prejudice questions relating to the delimitation of boundaries between States in the south for which a submission might subsequently be made, notwithstanding the provisions regarding the 10-year time limit established by article 4 of Annex II to the CLCS. In order to make this partial submission, the CLCS also recommended to Russia to make its best efforts to effect an agreement with Japan in accordance with paragraph 4 of annex I to the Rules of Procedure of the CLCS.

5. Conclusions

The continental shelf of a coastal State in the sense of article of 76 of UNCLOS is the seabed and subsoil of the submarine areas beyond the territorial sea over which it has jurisdiction. Article 76 refers to this area as “the natural prolongation” of the land territory of the State. The most controversial criteria in delimitation of continental margin are how to define the natural prolongation and how to distinguish submarine elevations from submarine and oceanic ridges. To classify the ridge correctly, three features should be carefully considered: i) geological continuity, ii) crustal neutrality, iii) envelop of the

⁷⁷ Fifty-seventh session, Agenda item 25 (a), Oceans and the law of the sea, Report of the Secretary-General, Addendum, A/57/57Add.1 (Oct. 8, 2002), pp.9~10.

foot of the continental slope. An extended continental shelf submission needs to include sophisticated documentation that indicates the above three characters in specific ridges and submarine elevations. The elongated morphology of the features does not make the submission consistent with the article 76 (6), nor does the nomenclature of the features as ridges. Regarding the Lomonosov and Alpha-Mendelev Ridges, the Russia Federation needs to present geological evidence to the CLCS that both of the ridges constitute natural components of the Russian continental margin.

For coastal States seeking to the extended continental shelf beyond their 200 M EEZ, the ridge is the very attractive tool to make the submission accepted. In reality, many States have claimed the extended continental shelf beyond the 200 M limit based on the ridge provisions. The submarine elevations can even further extend the continental shelf beyond the 350 M constraint. However, since neither the expressions “submarine elevations” nor “natural components” are defined in the LOS, it is required that the CLCS should refine those characterizing features in its technical guideline. How the CLCS deals with the geological data regarding such contentious ridge provisions as the Lomonosov and Alpha-Mendelev Ridges will have implications not only for the Arctic Ocean but also worldwide. The Arctic Ocean coastal States may follow the Russian example and take advantage of the Arctic Ocean ridges. The US has already adopted the position that the Chukchi Plateau is a natural component of the Alaskan Arctic shelf and thus allows for the determination of extended continental shelf beyond the 350 M constraint. Denmark may claim the Lomonosov Ridge to be a natural prolongation of the North American shelf and Canada may raise claims to the Alpha-Mendelev Ridge. In other areas, a number of other nations may also raise claims to extended continental shelf beyond the 350 M, using the legal provision of submarine elevations. The CLCS’s attitude toward the Russian arguments will influence the scope of future claims from “ridge coastal States”.

Given the high number of submission, it is possible, solely from the authors’ viewpoint, that the CLCS would find itself in a stance where it would tend to lean towards rejecting rather than accepting the submission. If a coastal state fails to include geological justifications in its submission, members of the CLCS who may not fully communicate with the submission State regarding the geological complexity of the particular case may well find rejecting reasons against a given ridge or submarine elevation as natural prolongation of a continental margin. For a successful acceptance of extended continental shelf by the CLCS, a coastal State should allocate a considerable amount of budgets and efforts in developing its outer limit of continental shelf based on a ridge or submarine elevation.

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Measuring the environmental value of Saeng Island in Busan, Korea with allowing for zero values

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ABSTRACT

This paper attempts to deal with zero willingness to pay (WTP) responses from dichotomous choice (DC) contingent valuation (CV) surveys. It also will apply a recently proposed one-and-one-half-bound (OOHB) question format in order to obtain an appropriate welfare measure such as the mean WTP. To this end, the spike model suggested by Kriström (1997) is adjusted and applied to modeling OOHB DC-CV data with zero WTP responses. The mean WTP per household was 2,716 Korean won per annum and the overall results show that the OOHB spike model outperforms the conventional OOHB model significantly.

Key words: willingness to pay, contingent valuation, spike model, one-and-one-half-bound

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1. Introduction

Coastal resources provide various important benefits to our lives. These benefits include biophysical and environmental values as well as social and commercial ones. Experts and professionals with an interest in and responsibility for i) protecting coastal environmental assets (or natural resources) and ii) managing national/local environmental planning and program, should have a clear concept designed to give quantitative measures of the environmental benefits from natural assets. The major coastal assets in Korea range from water and sediment quality, beaches, local and national marine parks, coastal habitats to endangered species and other biological resources.

This paper aims to examine the socioeconomic benefit of a proposed regulatory management policy on the protection of an uninhabited island located in the southeastern part of Korea, Saeng Island by using the economic valuation method.¹ In order to measure the value of Saeng Island in Busan, Korea, a contingent valuation (CV) was applied to quantify the economic value to households in Korea for implementing the island conservation and management policy.² More specifically, we apply the one-and-one-half-bound (OOHB) dichotomous choice (DC) question format recently proposed by Cooper *et al.* (2002) that can reduce the potential for response bias in multiple-bound formats such as the double-bound model while maintaining much of its efficiency gains.

In the sample used in this study, it happened that 60.5% of all respondents reported zero willingness to pay (WTP). In practice, zero WTP responses which are often found in DC-CV studies act as a corner solution of the consumers' utility-maximization when the goods and services to be valued do not contribute at all to the individual's utility (e.g., Yoo *et al.*, 2001; Strazzera *et al.*, 2003). One alternative to deal with zero WTP responses is to use the spike model as suggested by Kriström (1997). This model takes into account a spike at zero that is the truncation, at zero, of the negative part of the WTP distribution.³

The spike model is, therefore, adjusted and applied to modeling OOHB DC-CV survey data with zero WTP responses in order to obtain an appropriate welfare measure such as the mean WTP. As shown in Section 3, ignoring information at zero may influence the results significantly.

1 Management is directed by the Act on the Conservation and Management of Uninhabited Islands become effective in August 2007.

2 Researches applying contingent valuation to Korean coastal resources and natural assets are recently active, and previous ones have only focused on valuing wetland (Kwak *et al.*, 2007; Pyo *et al.*, 2001), national marine park (Kwak *et al.*, 2002) and estuary (Yoo, 2007), not that of the uninhabited island.

3 The spike model was originally proposed for single-bound DC-CV model. Yoo and Kwak (2002) used the spike model in a double-bound DC-CV setting.

2. Models

2.1 Conventional OOHB DC-CV model

In the OOHB survey design, the respondent is given two prices up front and told that, while the exact cost of the goods to be valued is not known for sure, it is known to lie within the range bounded by these two prices. One of the two prices is selected at random and the respondent is asked whether she/he would be willing to pay this amount; she/he is then asked about the other price only if doing so would be consistent with the stated price range.

According to Cooper *et al.* (2002), the OOHB DC-CV model can be described as follows. Let $i = 1, \dots, N$ be the index for each respondent in the sample and A be the bid amount presented to a respondent. Each respondent is presented with two prices, A_i^L and A_i^U where $A_i^L < A_i^U$. If A_i^L is randomly drawn as the first price, then the possible responses are yes-yes, yes-no and no. If A_i^U is randomly drawn as the first bid, then the possible answers are yes, no-yes and no-no. Binary-valued indicator variables of these six possible outcomes are I_i^{YY} , I_i^{YN} , I_i^N , I_i^Y , I_i^{NY} and I_i^{NN} , respectively,

such that:

$$\begin{aligned}
 I_i^{YY} &= 1(\text{ith respondent's response is 'yes-yes'}) \\
 I_i^{YN} &= 1(\text{ith respondent's response is 'yes-no'}) \\
 I_i^N &= 1(\text{ith respondent's response is 'no'}) \\
 I_i^Y &= 1(\text{ith respondent's response is 'yes'}) \\
 I_i^{NY} &= 1(\text{ith respondent's response is 'no-yes'}) \\
 I_i^{NN} &= 1(\text{ith respondent's response is 'no-no'})
 \end{aligned} \tag{1}$$

where $1(\cdot)$ is an indicator function, whose value is one if the argument is true and zero otherwise.

WTP (hereafter denoted as C) is recognized as a random variable with a cumulative distribution function (cdf) defined here as $G_c(\cdot; \theta)$, where θ is a vector of parameters. Given the assumption of a utility-maximizing respondent, the log-likelihood function takes the form:

$$\begin{aligned}
 \ln L = \sum_{i=1}^N \{ & (I_i^{YY} + I_i^Y) \ln [1 - G_c(A_i^U; \theta)] \\
 & + (I_i^{YN} + I_i^{NY}) \ln [G_c(A_i^U; \theta) - G_c(A_i^L; \theta)] \\
 & + (I_i^N + I_i^{NN}) \ln G_c(A_i^L; \theta) \}
 \end{aligned} \tag{2}$$

Following the practice of previous studies, formulating $1 - G_C(\cdot)$ as logistic cdf and combining this with $\theta = (a, b)$ yields:

$$G_C(A; \theta) = [1 + \exp(a - bA)]^{-1} \quad (3)$$

Let C^+ be the mean WTP when C can be positive or negative and C^{++} be the mean WTP when C must be greater than or equal to zero. Welfare measures based on Equation (3) can be computed as follows:

$$C^+ = a/b \quad (4)$$

$$C^{++} = (1/b) \ln[1 + \exp(a)] \quad (5)$$

2.2 Spike model in OOHb DC-CV setting

The spike model is adjusted to modeling OOHb DC-CV data in this subsection. It is noted that the ‘no’ and ‘no-no’ respondents are composed of two groups: those who really have a zero WTP and those who have a positive WTP that is less than A_i^L . For people who gave a ‘no’ or ‘no-no’ response, an additional follow-up question was asked: ‘Are you willing to pay anything at all?’ Those providing a ‘no’ answer to this question represent a valid representation of their zero WTP. Thus, ‘no’ answers to the question after deleting protest zeros are taken as zero WTP responses.

For people who were asked the additional follow-up question, the two binary-valued indicator variables can be defined as:

$$\begin{aligned} I_i^{AY} &= 1(\text{ith respondent's response to the additional question is 'yes'}) \\ I_i^{AN} &= 1(\text{ith respondent's response to the additional question is 'no'}) \end{aligned} \quad (6)$$

To estimate the distribution of WTP, WTP is assumed to be distributed as a logistic on the positive axis. The log-likelihood function for the OOHb spike model is given by:

$$\begin{aligned} \ln L = \sum_{i=1}^N \{ & (I_i^{YY} + I_i^Y) \ln [1 - G_C(A_i^U; \theta)] \\ & + (I_i^{YN} + I_i^{NY}) \ln [G_C(A_i^U; \theta) - G_C(A_i^L; \theta)] \\ & + I_i^{AY} (I_i^N + I_i^{NN}) \ln [G_C(A_i^L; \theta) - G_C(0; \theta)] \\ & + I_i^{AN} (I_i^N + I_i^{NN}) \ln G_C(0; \theta) \} \end{aligned} \quad (7)$$

where:

$$G_C(A;\theta) = \begin{cases} [1 + \exp(a - bA)]^{-1} & \text{if } A > 0 \\ [1 + \exp(a)]^{-1} & \text{if } A = 0 \\ 0 & \text{if } A < 0 \end{cases} \quad (8)$$

Thus, the spike is defined by $[1 + \exp(a)]^{-1}$. Using (8), the mean WTP in the spike model can be calculated as:

$$C^+ = (1/b) \ln[1 + \exp(a)] \quad (9)$$

3. Empirical results

3.1 Data

The empirical findings of this study are based on the data from a survey conducted in 2006 to value a proposed conservation and management policy of Saeng Island in Busan, the second largest city of Korea. In order to draw a random sample of the residents of Busan, sampling was conducted by a professional polling firm. The survey was implemented by face-to-face interviews with well-trained interviewers to offer the most scope for detailed questions and answers. The survey questionnaire was set up with the assistance of experts at the polling firm. The pre-testing was done using a small focus group (30 persons) assembled to discuss their understanding of and reaction to the questions prior to main survey. As a result, the questionnaire and visual aids made it easier to understand the general information about the Island and were simplified because the overall perceptions of the group of the environmental importance of the Island were high.

The questionnaire format consists of i) introductory questions like respondents' perception after general background information on the Island, ii) respondents' attitudes toward various characteristics of the Island, iii) yearly WTP question for proposed policy of conserving and managing the Island and iv) household information. 60.5% of the respondents reported a zero WTP. The spike model, therefore, appears to be ideally suited for estimating WTP in the sample, since a sizable fraction of the population has a zero WTP.

3.2 Empirical results

The conventional model in (2) and the spike model in (7) were estimated by the maximum likelihood estimation method. The conventional model assumes that the additional

follow-up question has not been used. Table 1 describes the estimation results. All the parameters in the spike model are statistically significant at the 1% level, while the constant term in the conventional model is not. Welfare measures are also provided in Table 1. To estimate the mean WTP, we used equation (4) in the conventional model and equation (9) in the spike model. Several interesting findings emerge from these results.

The conventional model gives an estimated mean of -307 won per annum and an estimated t-statistic of -0.38.⁴ Thus mean WTP is not statistically significant at the 5% confidence level. However, the mean WTP in the spike model, computed as 2,716 Korean won per annum, is significant at the 1% level. Moreover, the Monte Carlo simulation technique of Krinsky and Robb (1986) was used with 5,000 replications to get the 95% confidence intervals for the point estimates of mean WTP. The confidence interval of the mean in the spike model is quite tight, while that in the conventional model is not and even includes zero. The information at zero drastically decreases the standard error of the mean and makes the confidence interval fairly tight in this application.⁵

Table 1. Estimation results for the conventional and the spike models

Variables	Conventional model	Spike model
Constant	-0.0709 (-0.39)	-0.4125 (-4.09)*
Bida	-0.2310 (-7.94)*	-0.1871 (-10.95)*
Spike		0.6017 (24.31)*
Number of observations	400	400
Log-likelihood	-280.9	-447.3
Mean WTP	-307	2,716
Standard error ^b	813	268
t-value	(-0.38)	(10.12)*
95% confidence interval ^c	[-1,934-885]	[2,321-3,214]
Truncated mean WTP	2,850	
Standard error ^b	261	
t-value	(10.93)*	
95% confidence interval ^c	[2,460-3,363]	

Notes: The numbers in parentheses below the coefficient estimates are t-values, computed from the analytic second derivatives of the log-likelihood. * indicates significance at the 1% level. ^a The unit of measurement is 1,000 Korean won. ^b Standard errors are computed by the use of the delta method. ^c The confidence intervals are calculated by the use of the Monte Carlo simulation technique of Krinsky and Robb (1986) with 5,000 replications.

The household truncated mean WTP in the conventional model is computed to be 2,850 Korean won per annum, which is statistically significant at the 1% level. Thus,

4 At the time of the survey, GBP 1.0 was approximately equal to 1,900 Korean won.

5 Several other models (not reported here to save space), including covariates, were estimated. They imply that the likelihood of reporting 'yes' to a given bid is positively correlated with income, as expected. Adding covariates does not change the qualitative conclusions.

there is no significant difference between the mean in the spike model and the truncated mean. This result can be interpreted as indicating that a conventional analysis with truncation of the integral at zero provides a reasonable approximation to the spike model (Hanemann and Kriström, 1995). However, without information at zero it is not clear that the integral should be truncated at this point when computing the mean WTP. In addition, the formula for the truncated mean has an unclear interpretation and inconsistent logic and hence is *ad hoc* (Haab and McConnell, 1997). Thus, the spike model is more appropriate.

4. Concluding remarks

The OOHb DC-CV method was used to measure the environmental value of Saeng Island. Moreover, this paper attempted to adjust and apply the spike model suggested by Kriström to modeling OOHb DC-CV data to deal with zero WTP responses. Overall, the survey was successful in eliciting WTP values for the island conservation and management policy. The mean WTP per household obtained using the OOHb spike model was 2,716 Korean won per annum and significant at the 1% level. This information should be used in the decisions as to whether to implement the policy. In addition, in the application reported herein, the OOHb spike model outperformed the conventional OOHb model significantly, dramatically decreasing the standard error of the mean WTP and making the confidence interval fairly tight.

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Local strength, global weakness: A maritime network perspective on South Korea as Northeast Asia's logistics hub

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ABSTRACT

Port development in South Korea has taken advantage of the country's remarkable situation and economic growth during the past decades. However, the governmental 'two-hub port strategy' is currently at stake because of fierce competition from Chinese ports. Based on a global database on the daily movements of containerships, this paper proposes an evaluation of the position of South Korean ports within Northeast Asian liner networks in 1996 and 2006. Main results show that although Chinese ports have increased substantially their position in the maritime system, South Korean ports (notably Busan) still keep a dominant hub function in this region. However, a multi-scalar analysis shows the limited global radiance of South Korean ports. Implications for policy and further research are addressed.

Key Words: Asia, betweenness, centrality, hub port, liner shipping, network analysis

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1. Introduction

Specialized on agricultural activities during the Japanese occupation (1905~1945), devastated by the Korean War (1950~1953) and wrongly oriented on an import substitution strategy between 1953 and 1961, the Republic of Korea (ROK, hereafter South Korea) was at the beginning of the 1960s one of the poorest country in the World. A radical change in the national economic policy propelled its GDP at the 14th global rank in 2007. This shift started in 1961 when the government adopted an outward-looking strategy forged on a strong alliance between the Army (General Park Chung Hee ruled South Korea from 1961~1979) and some few rich families, founders of the future *chaebols* (large Korean conglomerates). The government collected foreign grants and soft loans and through its direct control on the local banks, supported the companies which followed its national industrial plans and massively exported to developed countries such as United-States. The authorities invested also a large amount of money in social infrastructures and modern communication network guaranteeing to the conglomerates a social peace based on the repression of trade unions. In return, the ruling class benefited of various material advantages provided by the *chaebols*. Rebounding with the democratization at the end of the 1980s, the South Korean model achieved an incredible success. South Korea became member of OECD in 1996 and its industry dominated several world industries such as shipbuilding, DRAM or LCD panels.

Nevertheless, this strategy reached its limits in 1997 with the Asian financial crisis that hardly affected an economy too much depending on loans without any clear control on the corporate assets. Moreover, South Korea is not anymore a low-cost country. It is an emerged economy, showing some early signs of maturity (population getting older very quickly, delocalization of thousands factories to cheap labor countries such as China, Vietnam and India). Last but not least, South Korea is sandwiched between a high-tech advanced Japan, a booming China and a belt of under-developed states as Mongolia or the constrained North Korea (KITA, 2006). To challenge this situation, South Korea decided to improve its regional integration and to depend less on the United-States, which did not provide strong support during the 1997 crisis. South Korea should recover its historical role of bridge between China and Japan, but a role sustained by a modern and rich domestic economy, also able to be a gateway between North-East Asia and the World (Roussin, 2008). As a result, this paper will focus on this recent strategy of turning South Korea into Northeast Asia's logistics hub (Song and Lee, 2006).

More specifically, this research wishes to verify to what extent South Korea is a hub for this region. While many official reports have constantly promoted this hub strategy since the late 1980s (Yoo, 2006), a recent in-depth review of the history and rationale of the 'two-hub port policy' that is based on Busan and Gwangyang ports offers a rather pessimistic portrait about the competitiveness of South Korean ports (Lee and Kim, 2009).

Their performance in terms of traffic volume and traffic growth has lowered due to fierce competition with neighbouring Chinese ports and other local ports. For instance, Chinese ports of the Northeast provinces tend to use Qingdao instead of Busan for transshipping their cargoes. In addition, some criticism has been expressed about the true potential of the free-trade zone policy that creates huge development areas around South Korea's main ports of Incheon, Busan and Gwangyang for manufacturing and light industries (Ducruet, 2009). Such policies cannot avoid the shift of many South Korean manufacturing firms to Southeast Asia and China, resulting in less local demand for port activities (Lee and Kim, 2006). Nevertheless, South Korean ports are actively engaged in modernisation of their equipments so to keep their technological advance and solve congestion problems nearby main coastal cities (Frmont and Ducruet, 2005). It is only in the aeronautic sector that South Korea seems to increase its position, notably since the realization of Incheon's new international airport in 2001, through the successful 'Pentaport' strategy (Ducruet, 2007).

Despite the abundance and quality of recent research on Korean ports, this paper proposes a new contribution through the application of maritime network analysis. It is rather surprising that despite the rapid and profound changes occurring in the Northeast Asian port system, there is no comprehensive study of this region throughout the literature on maritime networks. More likely are studies on the Caribbean (McCalla *et al.*, 2005), the Mediterranean (Cisic *et al.*, 2007), the North Atlantic (Helmick, 1994) and the world (Joly, 1999; Ducruet *et al.*, 2008a). Other studies have focused on its neighbour North Korea, showing that South Korea has actually become North Korea's main hub in recent years (Ducruet, 2008; Ducruet *et al.*, 2008b). Approaching South Korea's hub position through the structure of connected maritime networks is relevant since 99% of its international trade volume is seaborne. The research hypothesizes that although South Korean ports have lost their position to Chinese ports in terms of total throughput, their relative position as hubs may have been maintained-or may even have been strengthened. A research based on network analysis would complement the literature on East Asian containerisation dynamics in which South Korean ports have been largely neglected compared with China, Taiwan, Japan and other ports (Comtois, 1994; Robinson, 1998; Comtois, 1999; Rimmer and Comtois, 2005; Notteboom, 2006a; Yap *et al.*, 2006).

The remainders of the paper are as follows. Section 2 introduces the source and methodology for a network analysis of liner shipping networks, together with some preliminary outcomes based on the data. Section 3 presents the main results of the network analysis applied to Northeast Asia.² Finally, section 4 proposes some implications of this study for South Korean port policy and further research.

2 The software used in this paper was created by Laboratoire Bordelais de Recherche en Informatique (LABRI), was initially created for biology. It is today extensively used for social network analysis and in transport studies notably on air transport networks, intra and inter-urban commuter flows and multinational corporations' networks in the SPANGEO project (<http://s4.parisgeo.cnrs.fr/spangeo/spangeo11.htm>). The TULIP software is free, opensource and available at: <http://tulip.labri.fr/>

2. Source and methodology for network analysis

2.1 *A global database on vessel movements*

Two main databases exist for analyzing the structure of liner shipping networks. First, Containerisation International provides annual yearbooks describing the service schedules of the world's main shipping lines. It contains information on vessels (capacity in TEUs), together with the carrier's name and on the service itself (sequence of ports and periodicity). Although it has the advantage of being reliable and financially accessible, its main problems are the absence of numerous companies and the probable difference between theory (service offered) and practice (true circulation).

For such reasons this research has selected another source: Lloyd's global database on vessel movements. Compared to the other source, data from Lloyd's Marine Intelligence Unit (LMIU) is based on the effective movements of vessels and concentrates about 98% of the world fleet of fully cellular containerships. Data for this research has been extracted for two years (1996 and 2006) and is limited to one month per year (i.e. October) because liner services are relatively constant throughout the year despite seasonal effects.

Although there is no consensual geographical definition of Northeast Asia, this paper includes all Chinese, Japanese, South Korean, Taiwanese and Far-East Russian ports in the analysis. Direct linkages between those ports constitute the architecture basing the analysis of the Northeast Asian liner network. This constitutes in itself a necessary simplification of the reality of liner shipping. While a line-bundling service calls at multiple ports through rotations of vessels and spatial continuum of the sequence, this research chooses to segment the services into a graph of distinct links. In addition, it mixes together intra and extra-Northeast Asian services. It is a binary approach to the network: there is or is not a connection between two ports within a given period of time. For instance, the Busan-Kobe connection is included in the graph regardless of the overlapping of successive (or even simultaneous) services, should they be different either in terms of scale (intra or extra) or function (line-bundling or feederling). Every link can be weighted by various measures such as:

- *Hierarchy*: total traffic (sum of all vessel capacities), number of movements, vessels, companies;
- *Density*: total traffic divided by number of vessels, movements, companies, but also frequency (e.g. movements per week).

The same applies to ports, with the possibility to use graph theory to calculate the relative position of the ports in the network. While some simple indicators may be calculated manually, such as the number of connections (i.e. maritime degree) or the traffic

distribution among those connections (e.g. concentration measures such as hub dependence),³ specific software is necessary to calculate the “centrality” of the ports. In this paper, we limit such possibility to the calculation of the so-called “betweenness centrality”: it corresponds to the number of shortest paths within the graph on which a node (i.e. port) is located. When it comes to ports and maritime transport, such measure is more likely to describe port’s maritime accessibility or “intermediacy”. Intermediacy as defined by Fleming and Hayuth (1994) corresponds to the level of insertion of a transportation hub within carriers’ networks. It is a vital component of “centrality” that is the situation of a port with regard to markets and hinterlands. In order to match the concept of intermediacy with the measure of betweenness centrality, we decide to use the term “betweenness” that accounts for the equivalent and more classical concept of “in-betweenness”.

2.2 Preliminary outcomes

The first approach to understanding the position of ports is the classical map of individual port traffic (Fig. 1). Although it does not account for their relative position, it gives an indirect but accurate idea of this position, because traffic volume in itself synthesizes a myriad of dynamics within and between ports.

There is a striking contrast in terms of growth between a group of large Chinese ports with fast growth and main Japanese and Taiwanese ports with slow growth. Ningbo, Xiamen and Shenzhen in China generate important traffic volumes and a rapid growth while in Japan, only small ports exhibit rapid growth, as seen in a number of developed countries where bigger ports enjoy lower growth rates on average (Lemarchand and Joly, 2009), as seen with the process of port de-concentration observed in the US for instance (Notteboom, 2006b).

Before analyzing the network per se, one interesting study is the comparison of the weight of the main inter-port links (Table 1).

³ Hub dependence of a port is defined by Ducruet (2008) as the share of the biggest connection in total traffic. High values (e.g. above 50%) indicate a weakness while low values (e.g. below 50%) reveal a strong position towards immediate neighbours/competitors. Other measures may be applied to the distribution of traffic among a port’s connections, such as entropy and Gini coefficient.

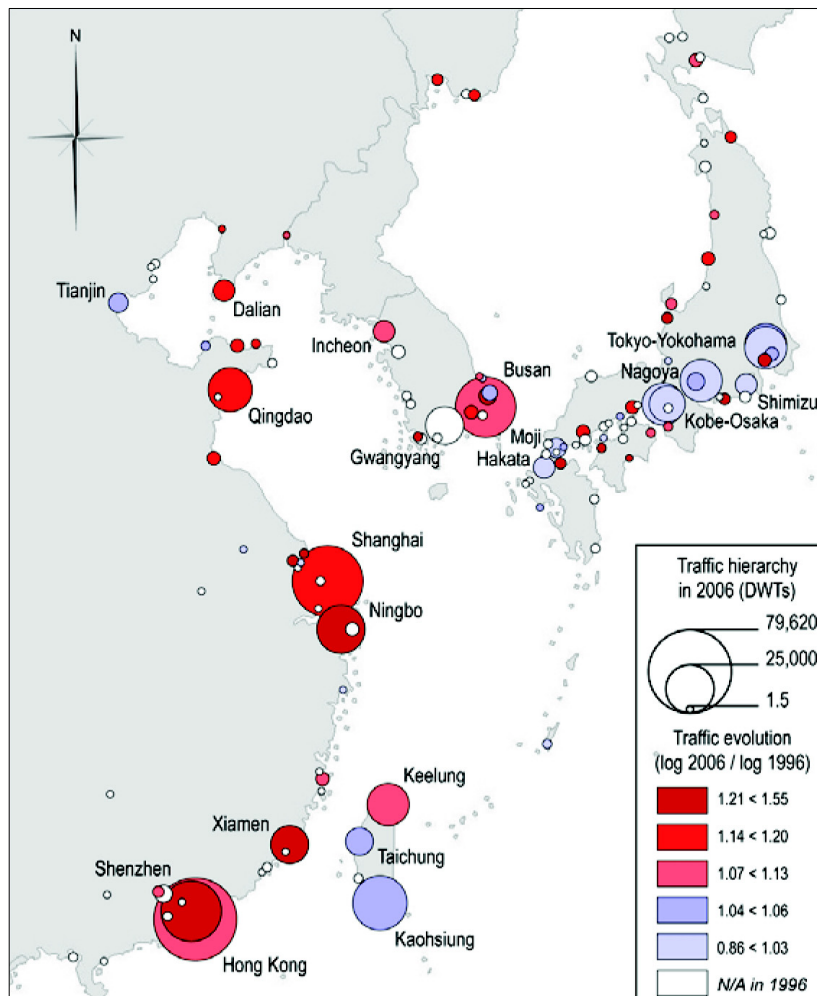


Figure 1. Liner traffic hierarchy and evolution at Northeast Asian ports, 1996–2006

The top connections reveal that connections among Chinese ports have superseded connections among Japanese ports, although in reality the Kobe-Nagoya connection has remained stable in terms of total capacity circulated. Although the growth of Chinese ports is often seen as a threat, we see that Busan has increased its rank in the table from 6th to 5th thanks to its strong connection with Shanghai. However, Busan appears only once in 2006 while it appeared two times in 1996 through the connections with Hong Kong and Kaohsiung. Hong Kong keeps its dominant position, notably with the Kaohsiung connection, but also with Shenzhen, Shanghai and Ningbo. Intra-Japan connections are now lagging behind intra-China connections in terms of total traffic volumes.

Table 1. Top 10 direct inter-port connections, 1996~2006

(Unit: DWT)

Rank	1996			2006		
	Port 1	Port 2	Traffic	Port 1	Port 2	Traffic
1	Hong Kong	Kaohsiung	10,940,760	Shenzhen	Hong Kong	27,536,943
2	Kobe	Nagoya	4,063,842	Kaohsiung	Hong Kong	14,554,136
3	Nagoya	Yokohama	3,246,985	Shanghai	Ningbo	12,552,982
4	Kobe	Kaohsiung	3,169,702	Shanghai	Hong Kong	8,957,273
5	Kobe	Yokohama	2,835,675	Shanghai	Busan	8,616,047
6	Hong Kong	Busan	2,387,515	Ningbo	Hong Kong	6,385,765
7	Hong Kong	Kobe	2,273,124	Shenzhen	Shanghai	5,552,308
8	Busan	Kaohsiung	2,227,229	Shanghai	Qingdao	5,448,910
9	Osaka	Tokyo	2,081,384	Xiamen	Hong Kong	5,161,566
10	Nagoya	Tokyo	1,912,021	Nagoya	Kobe	4,832,798

3. The maritime betweenness of South Korean ports

3.1 Betweenness and the port hierarchy

Another possible approach is to compare the number of direct connections with the hub centrality index⁴ (Fig. 2). At both years, we see that Busan has the biggest number of connections (44 and 77 respectively)⁵ and a high level of hub centrality. It clearly confirms its position as a hub, i.e. connecting a wide range of other ports with a relatively even distribution of traffic among its relations. In general, there is a good relation between the two indicators: the more connections, the stronger the position in the network.

4 This index is the inverse of hub dependence index, which corresponds to the share of the main connection in total traffic. The higher the hub centrality index, the stronger is the port vis-vis its immediate competitors.

5 A recent survey on Busan's feeder services counts a total of 110 ports connected (Armbruster, 2005). The difference with the number of direct links in 2006 is explained by the inclusion of non-direct links in the total of 110.

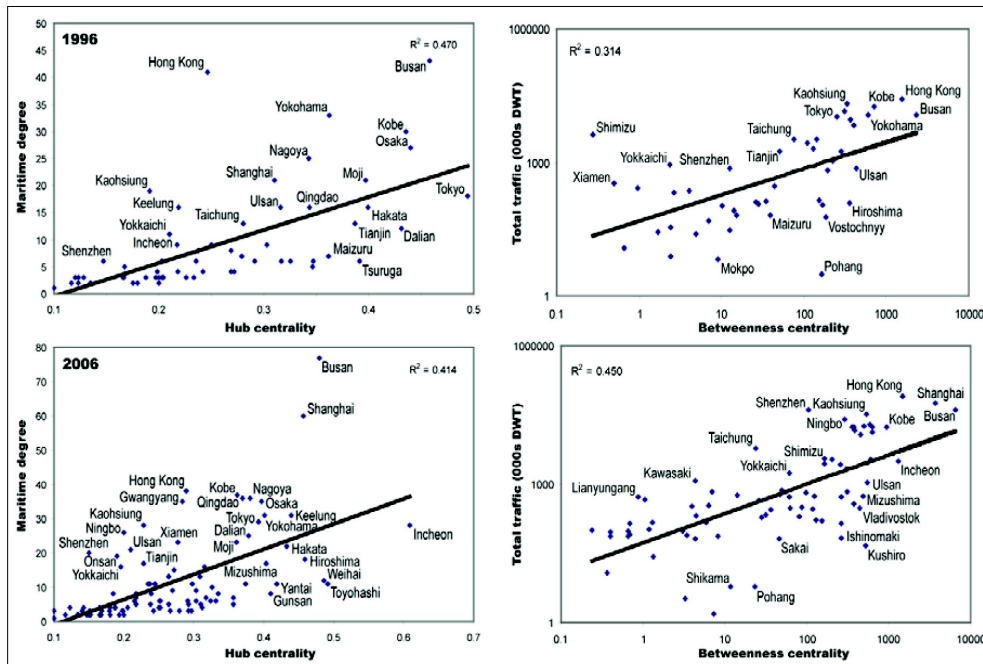


Figure 2. Connection characteristics of Northeast Asian ports, 1996~2006

Some local specificity may alter the pattern. For instance, Shenzhen has increased its array of connections but it remains dependent on Hong Kong for more than 60% of its traffic, despite the development of direct calls from global shipping lines since the late 1990s (Wang, 1998). The same applies to Kaohsiung (Taiwan) that doubled its degree from 19 to 28 but kept a strong relation with Hong Kong (i.e. from 52% to 42% of its traffic) due to the geopolitical issue with mainland China (Comtois and Wang, 2003). The evolution of these indicators also reflects the impact of port policies: Incheon, Shanghai and Ningbo have tripled their connections, but while this has resulted in a higher hub centrality (0.22 to 0.61) and lower hub dependence (46% to 16%) in Incheon and Shanghai (0.31 to 0.46; 32% to 22%); hub centrality has reduced for Ningbo (0.30 to 0.20). Although Ningbo has successfully and rapidly developed as a rival to Shanghai (Cullinane *et al.*, 2005), its growth remains dependent on the latter in terms of maritime network design. The same factor explains the profile of Gwangyang: non-existent as a container port in 1996, it deploys 35 connections in 2006 but more than 35% goes through Busan as an effect of the two-hub port system, resulting in a lower hub centrality (0.28) than its size would predict. Such dynamics suggest that the growth of secondary ports in the vicinity of load centres is possible only through a stage of hub dependence, as seen for Shenzhen, Ningbo, Incheon and Gwangyang.

Therefore, geographical proximity is one important factor in port development,

because it conditions the degree to which a given port can reach a stage of maturity and independence. Of course, geographical location is not enough explaining port hierarchies: more likely is the port selection process by shipping lines combined with national and local port policies (Slack and Wang, 2002). For older ports such as the main Japanese ports, the connections have remained quite stable between 1996 and 2006.

In terms of betweenness centrality compared with total traffic, Busan is the most central port in the whole regional network at both years and one can differentiate ports with higher traffic than centrality (e.g. Shenzhen, Yokkaichi and Kaohsiung) from the opposite profile where centrality is higher than traffic volume (e.g. Pohang, Ulsan, Far-East Russian ports and Incheon in 2006). The interplay between network position and port performance is illustrated by the fact that bigger ports have also the best betweenness: Busan, Hong Kong, Kobe, Yokohama, Shanghai and Osaka. Yet, large Japanese ports tend to be less central in the network compared with their traffic size.

3.2 Structure and dynamic of Northeast Asian liner networks

The visualization of the entire graph of liner networks in 1996 and 2006 allows for a clear overview of the network structure and port hierarchy (Fig. 3 and Fig. 4). The size of ports and inter-port links corresponds to betweenness centrality measures, while the country of belonging is also illustrated by a colour for better readability. Each graph is built regardless of the true geographical location of the ports; instead, distance between them is automatically generated depending on their relative betweenness in the network. Such methodology allows verifying i) which ports dominate the system and ii) the existence of coherent groups of ports well interconnected.

In 1996, the dominance of Busan among other ports is made evident. The liner system is a two-headed network based on Busan and Hong Kong. Each port possesses its own privileged relations with other Northeast Asian ports, based on either geographical or functional proximities. Busan polarizes a majority of Japanese ports, together with most South Korean ports (except Masan), Russian ports, Taichung and Keelung in Taiwan, Fuzhou and Dandong in China. The influence of Busan over Japanese ports is stronger for smaller ports in general (except for Nagoya and Hiroshima), with a preference for ports located at specific locations such as Northwest coasts of Japan (e.g. Sakata, Tomakomai, Kanazawa, Tsuruga, Niigata and Fushiki), the Kanmon Straits between Kyushu and Chigoku (e.g. Yawata, Ube and Oita) and Ehime island (e.g. Imabari, Komatsushima and Matsuyama). These ports have in common not to be well suited technically and geographically for welcoming the direct calls of global shipping lines. Thus, a majority of Chinese and other Japanese ports are more polarized by Hong Kong while exerting their influence upon their own sub-system. Notably, large ports such as Tokyo, Kobe and Yokohama (Japan), Shanghai, Qingdao and Dalian (China) and Kaohsiung tend to be less

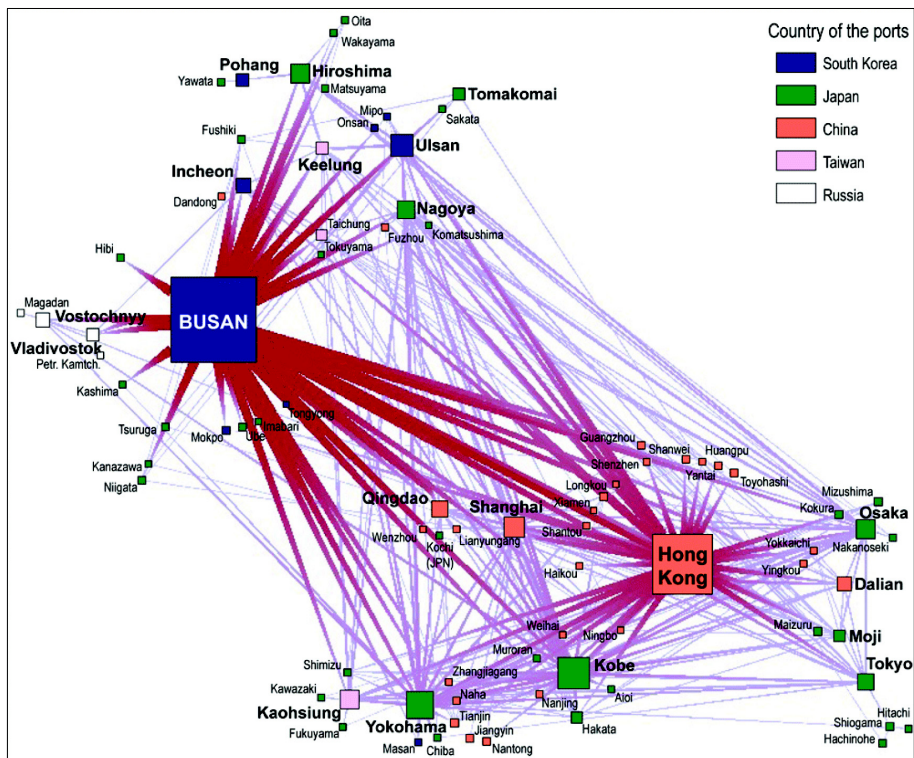


Figure 3. Liner networks within Northeast Asia, 1996

under Busan's polarization, probably because they also connect to Hong Kong and to a variety of ports outside Busan.

In 2006, the overall structure is very similar to the one of 1996, except that Shanghai has superseded Hong Kong at the second rank of betweenness and there is a greater complexity in the network. Busan has still a clear dominance over all Northeast Asian ports. While it has a wide array of dependent ports as in 1996, mostly Japanese and Russian, other South Korean ports tend to have shifted under the control of another hub. Only Incheon and Gwangyang have developed their betweenness to the point of polarizing a number of Chinese Yellow Sea ports (e.g. Rizhao, Qinhuangdao, Tangshan and Longkou). The geographical coverage of Busan's polarization on Japanese ports has remained rather stable: those are mostly smaller ports and they locate for a large part on the Northwest coasts of Japan, where big containerships do not anchor due to remoteness, spatial scattering, lack of nautical accessibility and to avoid deviation from the main trunk line (Zohil and Prijon, 1999). In fact, other ports are polarized by other hubs, either due to simple geographical proximity (e.g. Chinese ports and Shanghai, Hong Kong; Yokohama and Kawasaki), or to the more complex factor of service coverage by shipping lines. Due to the mixture of so many services of different kind in the analysis, it is not easy to identify

with precision which service or which company causes the grouping of some geographically distant ports. A myriad of random forces also cause the changes in the organization of shipping networks. The main common explanation is that ports having many connections outside of Busan are grouped together regardless of any geographical logic. In addition, the increased fluidity of liner shipping and the current reorganization of services in a changing economic and regional environment cannot be fully explained rationally. More interesting is the shift of some ports from the influence of certain hubs and the possible factors causing this shift. For instance, Hakata that was in the vicinity of Kobe in 1996 has gained some independence and is polarizing a variety of Yellow Sea ports in 2006. Similarly, Keelung (Taiwan) shifted from Busan's influence in 1996 to Kobe's influence in 2006.

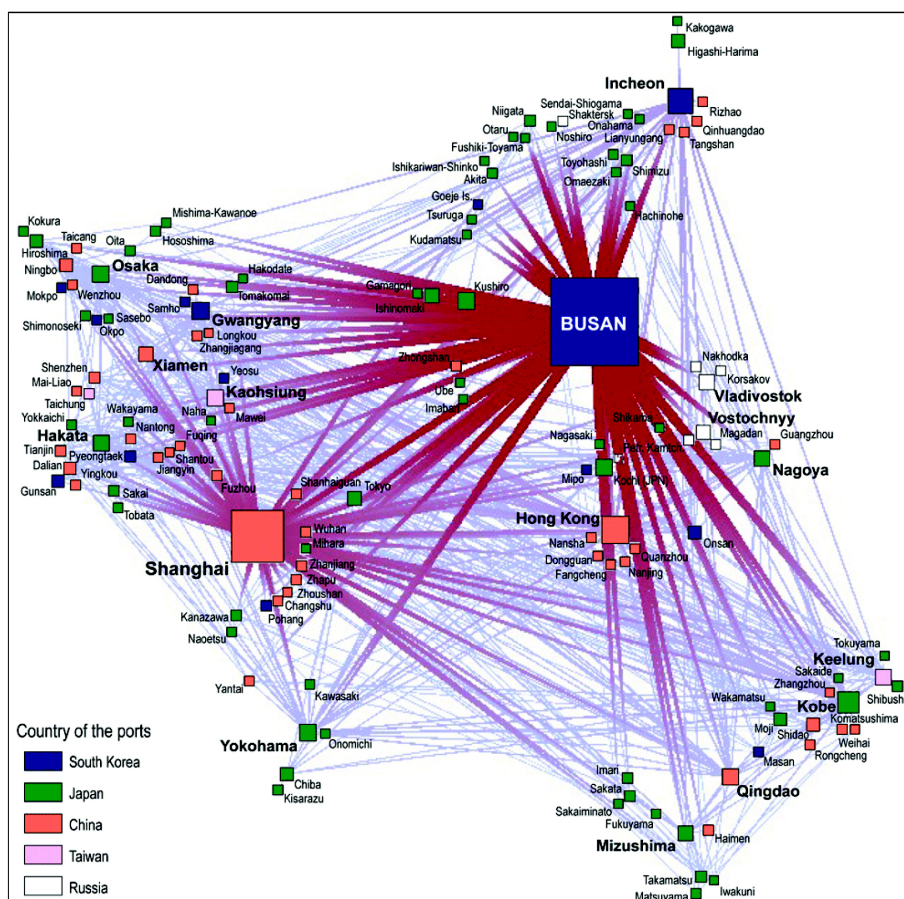


Figure 4. Liner networks within Northeast Asia, 2006

3.3 *A multi-scalar approach of betweenness*

In order to resituate the performance of South Korean and other Northeast Asian ports on a wider level, two methodologies are proposed and the results are examined successively.

3.3.1 Traffic distribution by main intra-regional and extra-regional connection

This methodology focuses on the degree to which some ports rely on South Korean ports or on other ports for their overall performance (Table 2). The share of rest of world is very important because it expresses a spatial reach outside Northeast Asia and therefore a higher performance, although the precise location of such long-distance connections is not indicated for better readability. This methodology can be considered as a verification of previous theoretical research on the geographical functions of container ports (Langen de *et al.*, 2002).

The first approach brings interesting results about the changes in ports' spatial reach. For South Korean ports, there has been a tendency to increase their traffic with each other, with fewer connections with other ports except for Busan that slightly increased (+5%) its direct connection outside Northeast Asia. Busan increasingly concentrates the main connections of other South Korean ports and only Gwangyang has an important connection outside Northeast Asia, despite its 39% traffic realized through Busan hub in 2006. Comparatively, Incheon has lost its long-distance connection but has maintained its important regional hub function, with 65% of its traffic connecting Northeast Asian ports.

Chinese ports have all increased their connection with South Korea except Hong Kong and Shenzhen where this link was already secondary. The three main Yellow Sea ports (i.e. Tianjin, Qingdao and Dalian) have one-third to one-half of their traffic polarized by South Korean ports in 2006 due to their location, but this trend is also increasing for Shanghai, although the share of South Korean ports represents only 17%. While this trend is accompanied by a reduction of intra-Northeast Asian connections and an increase of long-distance connections (+16% for China as a whole, +13% for Qingdao), the opposite occurs for Hong Kong and Shenzhen. Nevertheless, those two ports already had important shares of long-distance connections in 1996.

Table 2. Traffic distribution of selected Northeast Asian ports by geographical scale, 1996~2006
(Unit: % DWT)

Port, country	South Korea			Rest of NE Asia			Rest of world		
	1996	2006	96~06	1996	2006	96~06	1996	2006	96~06
Busan	7.4	14.6	+7.2	76.2	63.9	-12.3	16.4	21.6	+5.2
Gwangyang	-	39.1	-	-	47.7	-	-	13.2	-
Incheon	26.0	34.6	+8.6	68.8	65.4	-3.4	5.2	0.0	-5.2
Pohang	0.0	0.0	0.0	100.0	100.0	0.0	0.0	0.0	0.0
Ulsan	38.3	66.1	+27.8	60.5	33.9	-26.6	1.2	0.0	-1.2
South Korea	5.9	13.5	+7.6	78.9	66.5	-12.4	15.2	19.9	+4.7
Hong Kong	6.9	2.7	-4.2	53.0	66.1	+13.1	40.1	31.1	-9.0
Shanghai	7.0	17.1	+10.1	89.7	71.4	-18.3	3.2	11.5	+8.3
Qingdao	11.7	28.1	+16.4	87.1	57.7	-29.4	1.3	14.2	+12.9
Tianjin	14.9	53.7	+38.8	83.7	42.1	-41.6	1.4	4.2	+2.8
Dalian	15.3	31.3	+16.0	94.7	66.8	-27.9	0.0	1.9	+1.9
Shenzhen	5.2	3.0	-2.2	71.2	75.5	+4.3	23.6	21.5	-2.1
China (excl. HK)	10.7	23.3	+12.6	80.6	52.0	-28.6	8.7	24.8	+16.1
Tokyo	0.6	3.1	+2.5	67.6	72.3	+4.7	31.9	24.7	-7.2
Yokohama	1.9	4.1	+2.2	73.0	69.5	-3.5	25.1	26.4	+1.3
Kobe	4.8	6.4	+1.6	92.0	85.4	-6.6	3.3	8.2	+4.9
Osaka	13.6	10.8	-2.8	82.3	87.8	+5.5	4.1	1.5	-2.6
Nagoya	2.4	2.5	+0.1	97.2	94.4	-2.8	0.4	3.1	+2.7
Japan	7.3	9.9	+2.6	75.2	72.0	-3.2	17.5	18.1	+0.6
Kaohsiung	9.0	10.7	+1.7	73.3	67.9	-5.4	17.8	25.5	+7.7
Taiwan	9.5	11.6	+2.1	73.9	67.5	-6.4	16.7	20.9	+4.2
Russian Far-East	34.5	52.4	+17.9	65.5	47.6	-17.9	0.0	0.0	0.0

In comparison with Chinese ports, Japanese ports have a larger share of regional reach in general (52% and 72% respectively). This share has dramatically decreased in the first (-29%) and stabilized in the latter (-3%). Connections with South Korean ports are relatively low and have only slightly increased (+3%) except for Osaka (-3%). While Tokyo and Yokohama have the most international profile with about 25% of long-distance connections, probably due to their role serving the head of the urban megalopolis and their position as Japan's easternmost gateways to the Pacific connecting the US, Tokyo and Osaka have seen their long-distance connections decreasing (-7% and -3% respectively) and their regional connections increasing (+5%).

Finally, Taiwanese ports are more international while their regional connections decrease and their share of traffic with South Korean ports has increased only slightly (+2%) compared with the increase in long-distance connections (+4%). This is the opposite for Russian ports whose traffic is dominantly regional and much concentrated with South Korean ports (52%). This confirms the role of Busan as a hub for the East Sea and for growing Chinese ports.

3.3.2 Relative positioning on multiple geographical levels from local to global

This complementary analysis is proposed because measures of betweenness within Northeast Asia may hide the fact that some ports are differently positioned by liner networks on various scales simultaneously. For instance, a given port may be very central among neighbouring ports while becoming peripheral when the study area enlarges. Table 3 proposes an index of global-local centrality that shows the possible gaps between a local and a global position for each port. The index is a ratio that relates betweenness centrality within Northeast Asia with betweenness centrality in the world. The higher the result, the better the position of the port on the world level, compared to its local position.

Unsurprisingly, Busan and Incheon have seen their index declining; this is an indication that their local position has strengthened over time, due to the primacy of their transshipment hub functions. Only Hong Kong, Shenzhen, Qingdao, Hakata and Osaka have truly improved their global position compared with their regional position, but this is because such ports are more gateways than hubs, so they tend to have a weaker position regionally, compared to their global importance as gateways connecting adjacent markets through regular line-bundling services. Also, the scattering of Japanese ports and markets along the coast have prevented from the possibility of a load centring or hub strategy towards other ports in the region (Fremont and Ducruet, 2005), while Hong Kong has progressively become a gateway for South China instead of a hub (Wang, 1998).

Gwangyang is more globalized than Busan and Incheon, probably because it has been developed more recently, backed by the two-hub port strategy aiming at connecting principally the main trunk lines. Thus, Gwangyang has fewer connections than Busan and Incheon, but it is better positioned on a wider level. The difficulty of the interpretation lies in the fact that same scores may be explained by totally different situations and factors. Shenzhen, as the three-headed port of the world's factory (i.e. Chiwan, Shekou and Yantian), has been the focus of many investments from Hong Kong firms such as Hutchinson (Airriess, 2001). The impact of Busan New Port is still limited at the time of data collection, as it is expected for completion in 2015. Overall, it is interesting to underline that the local function of South Korean ports has increased, while the global function of Chinese ports has increased. In the Northeast Asian liner system, there is complementarity rather than competition, because not any port may bid for the main hub position in the region.

Table 3. Multiscalar centrality of selected Northeast Asian ports, 1996–2006

Port	Betweenness centrality (2006)		Global-Local centrality*		
	Northeast Asia	World	1996	2006	1996~2006
Hong Kong	1,492	60,142	0.95	0.98	+0.02
Busan	6,579	54,962	0.90	0.88	-0.02
Shanghai	3,724	49,507	0.92	0.92	0.00
Yokohama	631	9,735	0.94	0.94	-0.01
Gwangyang	635	9,142	-	0.93	-
Kaohsiung	542	8,958	0.96	0.94	-0.02
Qingdao	588	8,549	0.85	0.93	+0.08
Shenzhen	105	7,498	0.92	0.99	+0.07
Incheon	1,321	7,217	0.87	0.82	-0.06
Xiamen	386	5,647	0.99	0.93	-0.06
Kobe	945	4,880	0.86	0.81	-0.05
Tokyo	363	4,166	0.95	0.91	-0.04
Keelung	380	3,525	0.96	0.89	-0.07
Hakata	597	3,188	0.74	0.81	+0.07
Ningbo	292	2,969	-	0.90	-
Ulsan	551	2,919	0.82	0.81	-0.01
Kushiro	524	2,900	-	0.82	-
Mizushima	489	2,489	0.89	0.80	-0.09
Vostochnyy	380	2,307	0.84	0.84	0.00
Vladivostok	449	2,239	0.85	0.80	-0.05
Nagoya	495	2,069	0.87	0.76	-0.11
Osaka	456	1,923	0.62	0.76	+0.14
Tianjin	165	1,680	0.94	0.90	-0.04
Shidao	264	1,453	-	0.82	-
Chiba	264	1,452	0.75	0.82	+0.06

* Calculation: $1 - \frac{\text{centrality Northeast Asia}}{\text{centrality world}}$.

4. Conclusions

The network attributes of South Korean ports put them at the top of the port hierarchy of Northeast Asian ports. Such competitive position has been achieved in a relatively short period of time, following the country's rapid economic growth and a successful port policy based on hub strategy and modernisation.

However, a closer look at the geographical fundamentals of the position of South Korean ports on various scales sheds more light on their true performance. In fact, their

role seems more regional than other major Northeast Asian ports. Also, regionally, Shanghai has superseded Hong Kong for the second rank of betweenness measures, but Hong Kong and Shenzhen comfort their global position. In addition, some main Japanese ports that are often disregarded because of high pricing, congestion and hub dependence on South Korea are in fact relatively strong in the Asian and global network (e.g. Yokohama and Tokyo). Of course, the methodology proposed in this paper tends to lower the global performance of Busan simply because it has a strong position within Northeast Asia for transshipment. Ports that rely less on hub functions tend to have a better position globally than regionally. Further analysis shall try to distinguish transshipment functions from other functions among all vessel movements in order to compare ports based on attributes of same nature.

This analysis confirms that without new strategies strengthening the current position of South Korean ports, those are likely to see their regional function even threatened by Shanghai or other Chinese rivals and their global function disappear. However, the impacts of the current global crisis are still unpredictable. One main factor to give more chances to Chinese ports to success in the long run is their role as gateways for reaching distant continental destinations within and outside China. Yet, recent evidence show that although Busan's trade traffic has diminished due to the impact of the global crisis and competition from China, its transshipment activities towards Northern Chinese ports (e.g. Tianjin, Dalian) are increasing as an effect of weather conditions affecting potential Chinese hub ports (Kang, 2009).

One possible policy direction for South Korean ports is to strengthen their connections with Chinese ports while increasing the availability and quality of port-related manufacturing and logistics activities locally through the development of integrated distriparks and industrial complexes. Further research shall improve the analytical tools of network analysis applied to maritime transport, while extending to other regions of the world for a comparative perspective.

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A DSS approach with Fuzzy AHP to facilitate international multimodal transportation network

Hyun Jeung Ko^{*}

ABSTRACT

International multimodal transport corridors connect one or more adjoining countries for delivering cargos with assurance of delivery reliability while minimizing transit time and costs. Since the economic standards of the countries in a particular international corridor vary from country to country, this can affect the overall performance of the routes due to the lack of interconnections, interoperability and legal framework while delivering cargos. The facilitation of a particular international route largely depends upon the decisions of commercial players who generally select an optimal multimodal transport route with respect to economic principles. Thus, it is important for the policy makers associated with an international route to understand what commercial players want and what kinds of barriers commercial players are facing. In this regard, it is highly justified to utilize analysis tools for systemically investigating the international routes in terms of interconnections, interoperability, legal framework, etc. However, the required data for the analysis is not only vast but also not easily obtained. Considering the complexity of logistics systems and the huge volume of data involved in international routes, this study proposes a decision-aid tool within a decision support system (DSS) using Fuzzy-AHP for the systemic analysis. This can assist countries to develop strategic policy decision making for the facilitation of international intermodal transport routes linking different countries.

Key words: Fuzzy-analytic hierarchy process, decision support system, multimodal transport network, policy decision makings.

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1. Introduction

As the world's economics are getting increasingly interconnected, an inefficient transport and logistics system plays an important role in facilitating international trade by integrating different transport modes of maritime shipping, railways or roads. Herein the seamless multimodal transportation system has been in increased demand by the trend of door-to-door delivery. In particular, the area of Eurasia has already entered a new era of greater economic development by strengthening economic integration especially in Russia, CIS, China, Korea, Japan and so on. This region is currently undertaking tremendous changes and occupies more than 60% of the world economy. Furthermore, it contains three major countries of BRICs such as China, India and Russia, which are the most promising countries to become large forces in the world economy. For example, China has seen spectacular growth over the last few years at the average annual growth rate of about 8.0%; India is becoming of prime interest to multinational companies and some see it as eventually rivaling China in terms of opportunities. In addition, the economic consolidation among Russia and CIS countries is promoted, where industrial diversification strategy is implemented on behalf of oil money for balance development.

For intra-regional trade, containerized cargo is the most dynamic sector of not only Eurasia but also world trade covering the entire global industrial structure. Consequently, a well-planned multimodal international transportation system in the area of Eurasia should play an important role in facilitating the movement of cargos. In addition to the flow of goods, it can provide many advantages to countries involved. This could lead to increased size of markets for companies, international economic bargaining power and so on. In particular, Northeast Asia is an area where economic growth has been increasing rapidly so that intra-regional trade is growing. For example, Korea, one of the Northeast Asian countries, is located on the far eastern side of Asia. Therefore, Korea is a land-bridge through Russia or China to Europe with respect to a multimodal transportation network as the Trans Korean Railway (TKR) is linked with northern corridors of TAR¹ such as TSR² and TCR³. Consequently, Korea can become a gateway to the Pacific for Europe. Cargo could be shipped to and from Busan by railway through Europe. In this regard, establishing a well functioning Korean multimodal international transportation system is an essential element to securing an efficient flow of cargos for the area of Eurasia.

The efficient, reliable and cost-effective services of international transportation and logistics systems facilitate smooth movement of cargoes so that the economic development of involved countries is secured. International multimodal transport corridors serve foreign trade between two or multiple countries, which have national and domestic routes. Hence

1 Trans-Asian Railway.

2 Trans-Siberian Railway.

3 Trans-Chinese Railway.

an international corridor connects one or more adjoining countries for delivering cargo between origin and destination with a high reliability of delivery with lower transit time and costs. With respect to the usage of international routes, they are competing with each other based on their overall performance. However, the economic standards of the countries in a particular international corridor vary from country to country. This can affect the overall performance of the corridor due to the lack of interconnections, interoperability and legal framework while delivering cargo.

The facilitation of a particular international route largely depends upon the decisions of commercial players who generally select an optimal multimodal transport route with respect to economic principles. In this regard, it is crucial for the policy makers of countries associated with an international route to understand what commercial players want and what kinds of barriers commercial players are facing. In addition to knowing the needs of commercial players, it is highly justified to utilize analysis tools for systemically investigating the international route in terms of interconnections, interoperability, legal framework, etc. However, the required data for the analysis are not only vast but also not easily obtained. Considering the complexity of logistics systems and the huge volume of data involved in international routes, this study proposes a decision-aid tool within a decision support system (DSS) using Fuzzy-AHP for the systemic analysis. This can assist countries in developing strategic policy decision making for the facilitation of international intermodal transport routes linking different countries.

2. Literature review

The international multimodal transport network can typically arise in a practical situation where either importers or exporters are located in Russia, China and Uzbekistan. Another situation that represents more common transportation scenarios is the transshipment of importing or exporting goods via transfer points to reach sources of supply or customer bases located in cities that are not directly inaccessible from major seaways (Banomyong & Beresford, 2001). Besides sea transport options in Eurasia, TAR was seen as a way to accommodate the increases in international trade between Europe and Asia and facilitate the movements of freight between countries. It also aimed to improve the economies and accessibility of landlocked countries like Laos, Afghanistan, Mongolia and the Central Asian countries (UNESCAP, 1996).

The TAR consists of four corridors such as the Northern Corridor, Southern Corridor, North-South Corridor and Subregional Network (UNESCAP, 2005). The Northern Corridor links Europe and the Pacific, via Korea, China, Mongolia, Kazakhstan, Russia, Belarus, Poland and Germany, with breaks of gauge at the Chinese-Mongolian border, Chinese-Kazakhstan border and the Belarus-Polish border. The Northern Corridor consists

of five sections such as TKR, TSR, TCR, TMR⁴ and TMGR⁵. In particular, TSR covers much of this route and carries large amounts of freight from East-Asia to Moscow and on to the rest of Europe. In contrast to other sections, TKR is not functioning up to this point due to political problems with South-North Korea, but the reconnection efforts are on the way after the Joint South/North Declaration made on June 15, 2000. So, cargo from South Korea should be currently shipped by sea to Vladivostok port or Vostochny port to access the TAR.

The Southern Corridor goes from Europe to Southeast Asia, connecting Turkey, Iran, Pakistan, India, Bangladesh, Myanmar and Thailand, with links to China's Yunnan Province and, via Malaysia, to Singapore. Breaks of gauge occur, or will occur, at the Iran-Pakistan border, the India-Myanmar border and at the Thailand-China border. The North-South Corridor linking Northern Europe to the Persian Gulf. The main route starts at Helsinki in Finland and continues through Russia to the Caspian Sea, where it splits into three routes: a western route through Azerbaijan, Armenia and western Iran; a central route across the Caspian Sea to Iran via ferry; and an eastern route through Kazakhstan, Uzbekistan and Turkmenia to eastern Iran. The routes converge in the Iranian capital of Tehran and continue to the Iranian port of Bandar Abbas. A Subregional Network includes ASEAN and India-China subregions.



Figure 1. International multimodal transportation network

4 Trans-Manchurian Railway.

5 Trans-Mongolian Railway.

Despite the practical significance of the intermodal transportation network design, a minimal amount of literature has been published on this topic. Min *et al.* (2007) is one of the researchers to look into a similar problem taking place in the Chinese logistics operations. However, they did not consider qualitative factors such as delivery reliability and transit risk influencing the global intermodal transportation network design. Moynihan *et al.* (2006) built an AHP-based DSS for supplier selection, but they did not address the global supply chain issues involving the multimodal logistics operations. Godwin *et al.* (2007) developed a mixed integer programming model to solve the passenger rail network design problem in India. However, their model was confined to a single-objective, single-modal routing and scheduling problem and was posed as a stand-alone model that could not be incorporated into the decision support framework. Similarly, Kumanan *et al.* (2007) proposed hybrid heuristics combining the merits of a genetic algorithm and a particle swarm search technique to solve the problem of designing a supply chain logistics network. The proposed heuristics was limited to a single objective production and distribution problem without the specific consideration of inland logistics issues. For recent advances in logistics modeling, the interested readers should refer to Min and Zhou (2002) and Barros and Hilmola (2007). Also, the interested readers should refer to Eom and Kim (2006) for the recent applications of DSS to logistics disciplines.

3. The framework of DSS

The framework of a decision support system (DSS) is depicted in Fig. 2 This framework aims to develop viable multimodal transportation strategies for route facilitation. Within the DSS framework suggested by Sprague and Carlson (1982) and Dotoli *et al.* (2003), the proposed DSS is comprised of three components:

- Database management enhancing the access of accurate, timely data necessary for model development
- Model base management system developing a computerized Fuzzy-AHP model to prioritize alternatives and investigate the characteristics of international multimodal routes
- Dialogue generation and management software generating a series of ‘if-then’ or ‘what-if’ rules for the changes of variables such as cost data, traffic data, reliability data and security data and so on

The proposed DSS can be used by policy makers for multimodal transportation route facilitation so as to develop cooperation strategies with associated countries with concrete data. The proposed DSS will help them to make strategic decisions as to which physical barriers on a route to be tackled, which institutional limitations to be resolved and which

cost factors to be adjusted. The proposed DSS will be tested and validated with sample data gathered from Korean forwarders in section four. Unlike a standalone model which relies on the accuracy of available data for its efficiency, the proposed DSS allows for interfaces between databases and models and subsequently handles what-if scenarios in the case that model parameter values changed over time. The detailed descriptions of the proposed DSS are.

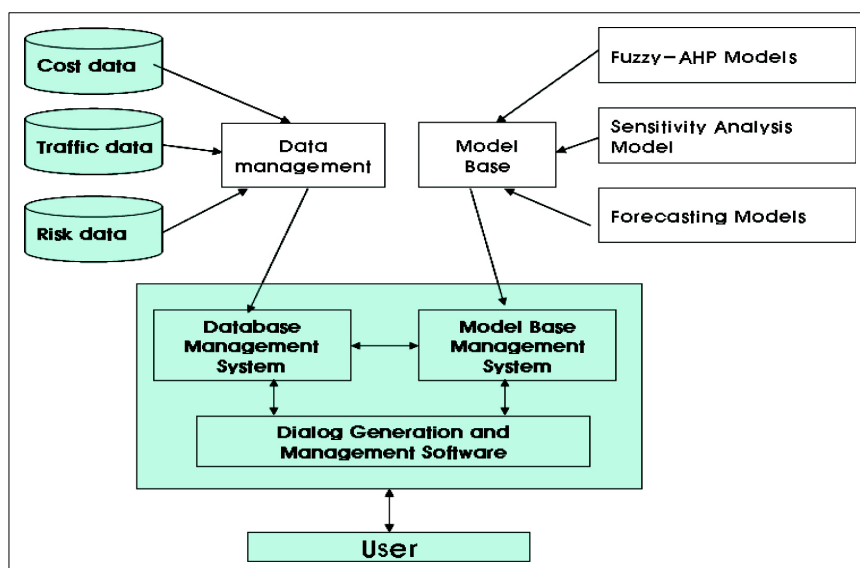


Figure 2. Architecture of decision support system for multimodal transport network

3.1 Database management system

To enhance data quality and avoid data redundancy, it is necessary to develop a database that contains two data sources: governmental and non-governmental. The database management system (DMS) is designed to supplement standard operating systems by allowing greater integration of data, complex file structure, quick retrieval and changes and better data security (Turban and Aronson, 2001). Governmental sources include regulatory guidelines and reports issued by federal and public transportation authorities and non-governmental sources include public data files such as published literature, websites and CD-ROMs and so on.

International multimodal transport corridors serve foreign trade between two or multiple countries, which have national and domestic routes. In this regard, international routes are competing with each other based on their overall performance. Most commercial players, in principle, make decisions on selecting a specific route according to the transport time, costs, volume of trade, on time delivery, supply chain security and so on. Thus,

it is necessary for policy makers to understand in detail the key factors which affect the selection of routes for facilitation. The data categories in this study that are relevant to multimodal transportation analysis can be defined as traffic time, transport costs, on time delivery and supply chain security.

3.1.1 Cost data

Cost is one of the primary concerns of multimodal transportation selection. These costs include navigating fees, trans-anchoring fees, mooring/unmooring fees, harbor fees, groundage fees, demurrage fees, terminal handling charges, freight rates, freight surcharges, port charges, loading/unloading, transshipment costs, insurance costs, in-transit inventory carrying costs, taxes and customs duties. The more the cost data are broken down in detail, the better the analysis can be made.

3.1.2 Traffic data

Important concerns of multimodal transportation operations include proximity to inland river-ports, break-bulk terminals, paved roads, major road arteries, access to forwarders and common carriers, transit risks, ocean-carrier/barge/rail/truck schedules, ocean-carrier/barge/rail/truck transit time, loading/unloading time, shipment transfer time, carrier reliability, choke points and government traffic regulations and rules. In addition, the volume of trade is significant with respect to the discount of shipping charges from mass transport and the balance of inbound and outbound volume.

3.1.3 Reliability data

On time delivery can be affected by the availability of equipment, the coordination of sequential activity, labor productivity, level of equipment modernization, etc.

3.1.4 Security data

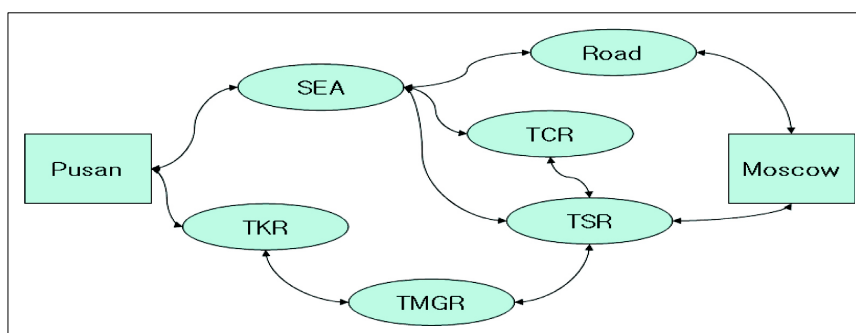
Supply chain security is measured by standardization of documents, efficiency of security checks, utilization of EDI systems, political risks, transit damage and conflict resolution of procedures, etc.

Table 1. Key factors for the network facilitation

Cost data	Traffic data	Reliability data	Security data
• Navigating fees • Trans-anchoring fee • Mooring/unmooring fee • Harbor fee • Groundage fee • Demurrage fee • Terminal handling charge • Freight rate • Freight surcharge • Port charge • Loading/unloading • Transshipment cost • Insurance cost • In-transit inventory carrying cost Taxes	• Proximity to ports • Border crossing time • Break-bulk terminals • Paved roads • Major road arteries • Access to forwarders and common carriers • ocean-carrier/barge/rail/truck schedules • ocean-carrier/barge/rail/truck transit time • Loading/unloading time • Shipment transfer time • Carrier reliability • Government traffic regulations and rules • Volume of trade	• Availability of equipment • Coordination of sequential activity • Labor productivity • Level of equipment Modernization	• Transit risks • Political risk • Transit damage • Conflict resolution procedure • Standardization of documents • Efficiency of security checks • Utilization of EDI system

3.2 Model management system

As a core of the model base within the DSS framework, the Fuzzy-AHP (FA) model is developed that considers multiple objective aspects of the multimodal transportation planning. The FA model is supported by the forecasting model that predicts any changes in the size of shipment between the port of entry and destinations, cost changes, infrastructure development, etc. in order to capture future updated information. The proposed FA model will determine which route should be selected to minimize the total transportation cost, transit time and transit risk, while maximizing the delivery reliability. This decision includes the consideration of either direct or indirect shipment via a transfer point and the optimal combination of the intermodal mix (Fig. 3).

**Figure 3.** Various routing options between Busan and Moscow

Since the use of a cheaper mode of transportation requires a longer transit time, the goal of minimizing transportation costs inherently conflicts with the goal of minimizing transit time. The presence of these conflicting goals requires FA model that makes an optimal trade-off between cost, time, reliability and security. In general, FA is referred to as a multiple-criteria scoring method that was designed to synthesize the priorities of decision alternatives with each decision criterion into an overall priority score of each decision alternative (Saaty, 1980). Accordingly, FA helps the transportation planner not only to identify the best intermodal selection and routing option among various transportation alternatives, but to also to assess the pros and cons of each transportation alternative with respect to four conflicting decision-making criteria:

- The cost
- The time
- The reliability
- The security

In addition, FA permits the policy planner to investigate the sensitivity of the chosen transportation alternatives to changes in strategic importance of decision-making criteria. Furthermore, FA can enhance the transportation planner's ability to make tradeoffs among various quantitative and qualitative attributes (Saaty, 1988). The application of FA to multimodal transportation planning involves four major steps (Wind and Saaty, 1980; Zahedi, 1989):

- Step 1: Break down the process of selecting the most desirable multimodal transportation routes into a manageable set of criteria and alternatives and then structure these into a hierarchical form.
- Step 2: Estimate the relative weights of the decision criteria based on the transportation planner's perceived importance of those criteria.
- Step 3: Estimate the fuzzy numbers of the criteria in each route based on the information from government or non-government sources by the use of fuzzy concept.
- Step 4: Make computations of priority scores among the decision criteria and alternatives according to their given relative priorities. Then, determine ranks of the alternatives and identify the best transportation alternative. Finally based on the benchmarking analysis, provide strategic recommendations for the performance improvement of target routes.

3.2.1 Step 1

In step 1, the manageable set of criteria and alternatives are selected and then these are structured into a hierarchical form for evaluating multimodal transport alternatives,

structured into four levels (Fig. 4). Since this hierarchical representation makes the complexity of analysis simplified through decomposition, it aids the transportation planner in understanding the interactions among transportation criteria. As shown in Fig. 4, the top level of a hierarchy represents the ultimate goal of determining the best multimodal transport option. At the second level of a hierarchy, the four distinctive decision criteria are placed which are generally considered important in evaluating the transportation alternatives. At the third level, the second level criteria were further broken down for more detailed analysis based on the transport planner's intention, as sub-criteria. At the fourth level, the third level criteria were connected to the bottom level of the hierarchy represented by multimodal routes under evaluation.

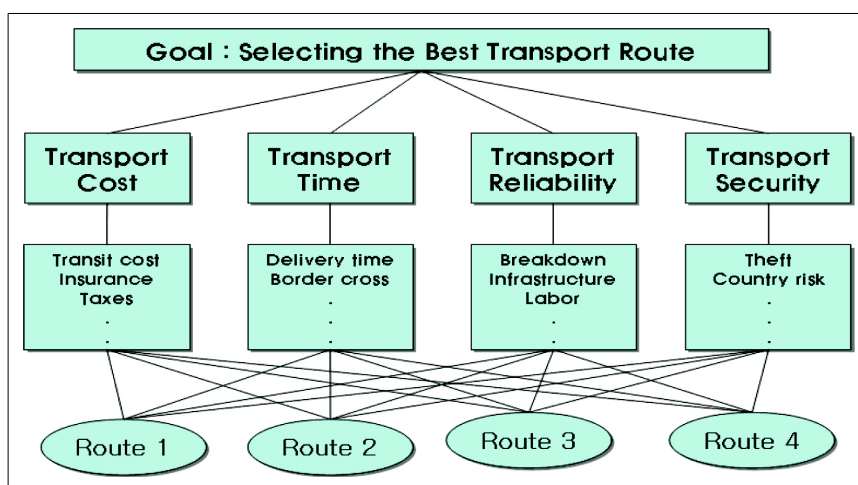


Figure 4. Hierarchy of selecting the best transport route

3.2.2 Step 2

Given the hierarchy of the problem, we need to estimate the relative weights of the decision criteria based on the transportation planner's perceived importance of those criteria. In this process, the sum of all the criteria belonging to the direct parent of the problem in the same hierarchy level must equal 100% or 1 so that each criterion has an absolute value between zero and one. For example, a transport time with priority 0.2 has twice the weight in reaching the goal as the transport cost with priority 0.1. As a result, an overall priority set, W_j , is computed for quantifying the relative importance of each criterion by multiplying the second level weight to the third level weight where j is an index for a criterion in the third level decision criteria. It is also true that W_j varies depending upon the transport strategies at hand. The transport planner then has the transport reliability in some business situations and can be the highest priority compared to other factors and vice versa.

3.2.3 Step 3

The sub-criteria estimation of each alternative was investigated in this step. The concept of fuzzy sets was applied. In fact, an international multimodal transport route passes through a number of cities in different countries so that it is hard to get qualified data along the route since they have their own transport regulations, infrastructure conditions, configurations of logistics systems and so on. Therefore, there is a limitation of data acquisition and a high uncertainty on data quality. In pursuit of such consideration, the concept of fuzzy sets⁶ was used to calculate the sub-criteria estimation that is represented as the type of a triangular membership function. The triangular membership function in this study can be defined as (a, b, c) or $\mu_G(x)$ with a fuzzy set G where a and c are lower bound and upper bound respectively. In addition, b is a real number with fuzzy quantity between a and c (e.g. $b = \{x | a \leq x \leq c \text{ and } x \in G\}$). Fig. 5 represents the graphical description of $\mu_G(x)$ which increases from a to b and then decreases up to c . For example, if a person has information on the transport risk to a particular route, it is very hard for him or her to quantify the information. In this case, the information can be scaled easily as a fuzzy number like $(4, 8, 9)$ using the interval scale of 0 and 10 (e.g. the higher the worse), which means the level of transport risk lies between 4 and 9 but the effect of the transport risk is considerably serious because the average number of eight is located near ten.

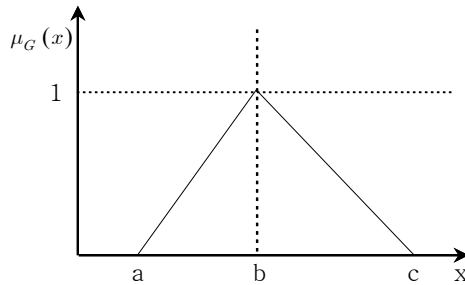


Figure 5. Triangular membership function

3.2.4 Step 4

In order to compute the priority scores of each alternative, it is first required to calculate the centers of gravity of fuzzy numbers of criteria obtained from Step 3. The center of a gravity of a fuzzy number is defined as G_j^i where j is an index for the criterion of the third level criteria mentioned in Step 2 and is an index for an alternative. Then, G_j^i is calculated as follows:

⁶ Zadeh, L.A (1965), Fuzzy sets, *Information and Control* 8:338~353.

$$G_j^i = c_j^i - \sqrt{\frac{(c_j^i - a_j^i)(c_j^i - b_j^i)}{2}} \text{ or } a_j^i - \sqrt{\frac{(c_j^i - a_j^i)(b_j^i - a_j^i)}{2}}$$

For example, when the second criterion of the first alternative is (0.074, 0.230, 0.487), its center of gravity is 0.256.

$$G_{2j}^1 = 0.487 - \sqrt{\frac{(0.487 - 0.174)(0.487 - 0.230)}{2}}$$

Therefore, the overall priority score of an alternative, $Score^i$, is obtained from the formula

$\sum_j W_j \times G_j^i$ and then the alternatives are ranked according to the priority scores. Finally the best transportation alternative is identified.

3.3 Dialogue generation and management software

At best, the model is an abstraction of real-world situations. Consequently, it cannot capture reality without running it more than once (Dyer and Mulvey, 1983). Thus, the model should enable policy planners to evaluate ‘what-if’ scenarios associated with changes in the transportation strategy (e.g., a shift from cost savings to prompt delivery services or vice versa), accessibility to transportation infrastructure (e.g., inland transportation hubs, terminals, rail sidings) and government regulations and rules. In other words, the model’s robustness needs to be tested by examining its sensitivity to contingency planning. Thus, the outcomes of a model can be different according to the changes in the relative importance of transport time and cost, whereas it is insensitive to changes in the relative importance of delivery reliability and transit risk.

4. Fuzzy-AHP DSS application and results

4.1 Model application

The proposed Fuzzy-AHP DSS is applied to an international multimodal network linking Busan in Korea to Moscow in Russia in which there are four possible routes (Table 2). Route 1 is a popular corridor at present where cargo are shipped from Busan to Vostochny by way of sea route and then are transported to Moscow through TSR. The distance is 10,280 km from Busan to Moscow. Route 2 is a route of using both TCR and TSR in which cargoes are shipped from Busan to Liayungang in China and then are transported from Liayungang to Moscow via Zhengzhou, Alasankou, Druzhba. Transship-

ment is required at the Alashankou/Druzhba border crossing. Route 3 is connecting from the Korean Peninsula to Moscow by railway. This route runs from Busan to Moscow, connecting the Gyungui Line, TMGR, TSR via Sinuiju, Shenyang, Beijing, Brenhot, ZamynUud, Ulanbaatar. Transshipment works are required at the Erenhot/ ZamynUud border crossing. Route 4 is one of the sea routes where cargo is shipped from Busan to the port of St. Petersburg and then transported to Moscow by road. Therefore, the success of routes for international trade will depend on whether it would be economically or efficiently competitive with other routes available such as maritime shipping and combined marine-railways. In addition, each route consists of two or more countries and they have different standards of logistics and transportation systems based on their economic development.

Table 2. Possible routes from Busan to Moscow

Mode	Route	Distance (km)	Transshipment
Route 1 : Sea+TSR	Busan-Vostochny-Moscow	9,833	None
Route 2 : Sea+TCR+TSR	Busan-Liayungang-Zhengzhou-Alasankou-Druzhba-TSR-Moscow	9,200	Alashankou/Druzhba
Route 3 : TKR+TMGR+TSR	Busan-Sinuiju-Shenyang-Beijing-Erenhot-ZamynUud-Ulanbaatar-TSR-Moscow	9,000	Erenhot/ZamynUud
Route 4 : Sea+Road	Busan-St.Petersburg-Moscow	23,000	None

In order to identify key factors of network facilitation in a particular route for getting competitive, we first construct a hierarchical form for evaluating multimodal transport alternatives, which was structured into four levels (Fig. 4). The top level of a hierarchy is set as finding the best alternative; the second level consists of the four distinctive decision criteria such as cost, time, reliability and security; the third level sub-criteria is set with nine factors such as transit costs, insurance costs, transit time, border crossing, equipment breakdown, infrastructure level, labor productivity, theft and country risk (Table 3); the fourth level consists of the four alternatives mentioned above. Given the hierarchical structure, we need to investigate the relative weights of criteria for which DSS searches the required information from the module of a database management system (Fig. 2). Unlike a standalone model, the database management system can provide more accurate information about evaluation criteria such as costs, times, reliability and security with updated sources from government or non-government organizations. Then, a policy planner interacts with the database management system by the use of dialogue generation and management software. In doing so, he or she can finalize the relative weight of decision criteria (Table 3).

Table 3. Relative weights of decision criteria

Criteria	Weight	Sub-criteria	Weight	Combined weight
Cost	0.286	Transit cost	0.90	0.257
		Insurance	0.10	0.029
Time	0.357	Transit time	0.80	0.286
		Border crossing	0.20	0.071
Reliability	0.214	Equipment breakdown	0.30	0.064
		Infrastructure level	0.40	0.086
		Labor productivity	0.30	0.064
Security	0.143	Theft	0.70	0.100
		Country risk	0.30	0.043

After setting up the relative weights, a policy planner needs to decide the performance of each route according to the sub-criteria. A particular international route generally passes a number of cities in the different countries so that it is hard to get qualified data due to the limitation of data availability and reliability. To overcome the difficulty, the concept of fuzzy sets is applied in this study in which the triangular membership function is adopted and then the fuzzy numbers are also extracted by the use of the database management system and dialogue generation and management software. By doing so, Table 4 is the summary of the fuzzy numbers and their gravity centers in each route (Section 3.2).

Table 4. Fuzzy number and gravity center of each route

j	Criteria	W_j	Route1		Route2		Route3		Route4	
			Fuzzy No.	G_j	Fuzzy No.	G_j	Fuzzy No.	G_j	Fuzzy No.	G_j
			(a, b, c)		(a, b, c)		(a, b, c)		(a, b, c)	
1	Transit cost	0.257	(0.70,0.72,0.73)	0.718	(0.71,0.74,0.77)	0.744	(0.67,0.69,0.72)	0.692	(0.95,0.97,1.00)	0.974
2	Insurance	0.029	(0.70,0.71,0.73)	0.714	(0.86,0.89,0.92)	0.888	(0.93,0.94,1.00)	0.964	(0.94,0.97,0.99)	0.969
3	Transit time	0.286	(0.51,0.57,0.62)	0.568	(0.62,0.68,0.73)	0.676	(0.54,0.60,0.65)	0.595	(0.89,0.95,1.00)	0.946
4	Border crossing	0.071	(0.14,0.29,0.43)	0.286	(0.43,0.57,0.86)	0.610	(0.29,0.71,1.00)	0.681	(0.143,0.29,0.43)	0.286
5	Equipment breakdown	0.064	(0.29,0.43,0.57)	0.429	(0.57,0.71,0.86)	0.714	(0.71,0.86,1.00)	0.857	(0.29,0.43,0.57)	0.429
6	Infrastructure level	0.086	(0.43,0.50,0.60)	0.507	(0.50,0.60,0.75)	0.613	(0.60,0.75,1.00)	0.776	(0.38,0.43,0.50)	0.433
7	Labor productivity	0.064	(0.43,0.50,0.60)	0.507	(0.50,0.60,0.75)	0.613	(0.60,0.75,1.00)	0.776	(0.43,0.50,0.60)	0.507
8	Theft	0.100	(0.29,0.43,0.57)	0.429	(0.43,0.57,0.71)	0.571	(0.57,0.71,1.00)	0.753	(0.29,0.43,0.57)	0.429
9	Country risk	0.043	(0.25,0.38,0.50)	0.375	(0.75,0.86,1.00)	0.875	(0.50,0.75,1.0)	0.750	(0.25,0.38,0.50)	0.375

In the end, we need to calculate the overall priority score of each alternative. It is important to check the characteristics of sub-criteria which means that for some criteria the higher the better but in other cases the lower the better. For example, the lower the transit cost, the better the alternative, but the higher the labor productive, the better the alternative. In order to unify such conflict factors of the criteria, it is useful to take the

reciprocal of the fuzzy numbers with respect to a single standard. In this case, we set the objective function as to minimize the overall score so that the rule of evaluation is that the lower the overall score, the better the alternative. Table 5 shows the performance of alternatives according to the criteria.

Table 5. The overall performance of alternatives

Criteria	Route1	Route2	Route3	Route4	Benchmark
Transit cost	0.18	0.19	0.18	0.25	Route 1, 3
Insurance	0.02	0.03	0.03	0.03	Route 1
Transit time	0.16	0.19	0.17	0.27	Route 1
Border crossing time	0.02	0.04	0.05	0.02	Route 1, 4
Equipment breakdown	0.03	0.05	0.06	0.03	Route 1, 4
Infrastructure level*	0.04	0.05	0.07	0.04	Route 1, 4
Labor productivity*	0.03	0.04	0.05	0.03	Route 1, 4
Theft	0.04	0.06	0.08	0.04	Route 1, 4
Country risk	0.02	0.04	0.03	0.02	Route 1, 4
Total	0.55	0.69	0.70	0.73	
Rank	1	2	3	4	

* The scores of infrastructure level and labor productivity are transformed into the lower the better standards

4.2 Results

The outcomes of model application shown in Table 5 indicate Route 1 that combines the intermodal mix of the ocean carrier and the railways is very competitive at present with the overall score of 0.55. Alternate Route 2 is the second most favorable option with an overall priority score of 0.69. Route 3 is followed by Route 2 which generates an overall priority score of 0.70. Among the four alternate routes, Route 4 is the least favorable route with on overall priority 0.73. The superiority of Route 1 over other alternatives shows that the priority scores of criteria are higher than those of alternative routes. On the other hand, Route 4 is less competitive in transit time and cost since cargo is shipped from the port of Busan to the port of St. Petersburg and then delivered by road. Road transport is very expensive and ocean transport is low cost.

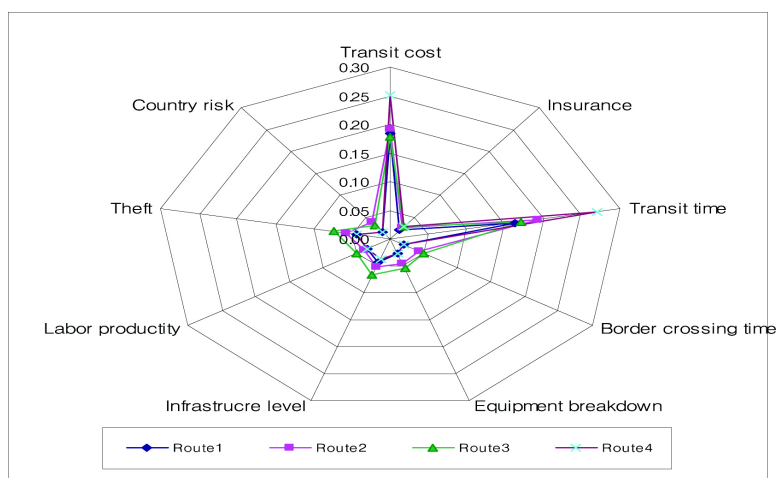


Figure 6. The graphical description of comparisons of the routes

The cargo in Route 1 is shipped from the port of Busan in S. Korea and sent to the port of Far East Russia and then transshipped by TSR up to Moscow. The competitive advantages of Route 1 partly can be explained by the fact that it has been used for a long time by numerous shippers and carriers so that the efficiency of the logistics systems is effectively improved. That is why Route 1 shows the highest scores in all the criteria, but the policy makers of the two countries need to continuously pay attention to the criterion of transit cost. The reason is that the gap of cost factors compared with other routes is relatively small so it is necessary for the two countries to cooperate to reduce the unnecessary cost in order to remain competitive.

The second rank is Route 2 where cargo is shipped by sea at the port of Busan and then arrives at Lianyungang port in China for the transshipment by the TCR up to the border of China-Russia (Alasnnkou-Druzhha). At the border, transshipment operations of cargo are required due to the different size of rail gauge and then delivered to Moscow. This corridor involves three countries such as Korea, China and Russia so that the efforts of coordination operations are important to improve the overall performance of the corridor with respect to interconnections, interoperability and legal framework. The outcomes of DSS show that there are high gap differences in the criteria of border crossing times, equipment breakdown, infrastructure levels, labor productivity, theft, country risk and so on. This indicates that the policy makers of three countries need to make efforts to cooperate for facilitating this route. First of all, the lack of efficiency in transit customs clearance should be overcome. In fact, many commercial players point out some weak points of Route 2. These are that the wagon supply in China is not sufficient to meet the need of logistics companies and the weight limitation of trains at TCR.

The third rank is Route 3 where cargo is shipped by railway connecting South

Korea, North Korea, Mongolia and Russia so that four countries are involved in moving cargo through the corridor. In this corridor, the transshipment operations are required at the border of China-Mongolia (Eranshot-Zamin Uud) through Beijing due to the different size of rail gauge. At Ulanbaatar, cargo is transported by the use of TMGR up to the border of Mongolia-Russia and then delivered by TSR to Moscow. Route 3 and Route 4 have similar overall scores with 0.69 and 0.70 respectively. Although the transit costs and time and country risks of Route 3 are more competitive than Route 2, other criteria of Route 3 such as border crossing time, equipment breakdown, infrastructure, labor productivity and theft are less competitive. The economic standards of the countries involved in Route 3 vary from country to country. This can affect the overall performance of the corridor due to the lack of interconnections, interoperability and legal framework while delivering cargo from origin to destination.

Table 6. The gaps between Route 2 and Route 3

Criteria	Route2	Route3	Gap(Route2 – Route3)
Transit cost	0.19	0.18	0.01
Insurance	0.03	0.03	0
Transit time	0.19	0.17	0.02
Border crossing time	0.04	0.05	-0.01
Equipment breakdown	0.05	0.06	-0.01
Infrastructure level*	0.05	0.07	-0.02
Labor productivity*	0.04	0.05	-0.01
Theft	0.06	0.08	-0.02
Country risk	0.04	0.03	0.01
Total	0.69	0.70	-0.01

In fact, commercial players have expressed that Route 3 has some issues to be improved for the efficient movement of cargo. First, there is delay at the border between Mongolia and Russia. Commercial players felt that the transshipment system in Mongolia lagged behind compared to international standards. In particular, they think that Mongolian transport companies don't have enough experience or knowledge in up to date logistics operations. Second, the availability of wagons in China and Mongolia is not sufficient to meet the needs of logistics companies. Third, the dispatch schedule which allocates wagons to railways is not predictable in China especially in peak seasons like Christmas. Fourth, while transferring cargo at Zamin Uud in Mongolia, frequent breakdowns of transshipment equipment takes place due to outdated machinery. This indicates that the improvement of these weak factors would allow Route 3 to have a competitive portion so that the policy makers of the four countries need to cooperate to make this happen.

5. Conclusions

The efficient, reliable and cost-effective services of international transportation and logistics systems facilitate smooth movement of cargo so that the economic development of associated countries is secured. With respect to the usage of international routes in a particular region, they are competing with alternate routes based on their overall performance. Since the economic standards of the countries along a particular international corridor vary from country to country, this can affect the overall performance of the corridor due to the lack of interconnections, interoperability and legal framework while delivering cargo. In fact, the facilitation of a particular international route largely depends upon the decisions of commercial players who generally select an optimal multimodal transport route with respect to economic principles. In this regard, it is crucial for the policy makers of associated countries in an international route to understand what commercial players want and what kinds of barriers commercial players are facing for the corridor facilitation. However, in order to investigate the characteristics of a particular route, it is required to have an analysis tool that can handle a large amount of data from multiple countries concerning not only physical and institutional factors but also the reliability of data. Thus, this study proposes a decision-aid tool within a decision support system (DSS) using Fuzzy-AHP for systemic analysis, which can assist countries in developing strategic policy decision making for the facilitation of international intermodal transport routes linking different countries.

The proposed decision support system is comprised of three components that are database management, model base management system with Fuzzy-AHP and dialogue generation and management software. The database management is to enhance the access of necessary data. For example, the input data for the model are physical and institutional factors. On the physical side, these are inadequate existing infrastructure such as poor rail and road access to ports, poor coordination of loading and unloading activities and different rail gauges resulting in costly methods of moving cargos from one country to another and so on. On the institutional side, conflicting customs and immigration procedures resulting in delays and prevention of cargos movement from one country to another, institutional blockage to the free flow of transit vehicles and cargo in the hinterland and a lack of coordination between different levels of government, etc. should be considered. A model base management system is developed to prioritize alternatives and investigate the characteristics of routes. The dialogue generation management software handles a series of 'if-then' or 'what-if' rules for the changes of variables.

The proposed Fuzzy-AHP DSS is applied to the case example of an international multimodal network linking Busan in Korea to Moscow in Russia in which four possible routes are considered. Route 1 is a popular corridor at present by which cargo is shipped from Busan to Vostochny by way of sea route and then are transported to Moscow through

TSR. The distance is 10,280 km from Busan to Moscow. Route 2 is a route of using both TCR and TSR. On Route 2 cargo is shipped from Busan to Liayungang in China and then transported from Liayungang to Moscow via Zhengzhou, Alashankou, Druzhiba. Transshipment is required at the Alashankou/ Druzhiba border crossing. Route 3 is connecting from the Korean Peninsula to Moscow by railway. This route runs from Busan to Moscow, connecting Gyungui Line, TMGR, TSR via Sinuiju, Shenyang, Beijing, Brenhot, ZamynUud, Ulanbaatar. Transshipment works are required at the Erenhot/ZamynUud border crossing. Route 4 is one of the sea routes where cargo is shipped from Busan to the port of St. Petersburg and then transported to Moscow by road.

As a result, the outcomes indicate that Route 1 is the most competitive route but for further facilitation, it is necessary for the two countries to cooperate to reduce the unnecessary cost in order to remain competitive; second ranked is Route 2 where three countries such as South Korea, China and Russia are involved. Facilitating the route is to have the efforts of coordination operations in the reduction of border crossing times, equipment breakdown, theft, country risks, as well as the improvement of infrastructure level and labor productivity; the third rank is Route 3 where South Korea, North Korea, Mongolia and Russia are involved. The cooperation efforts are placed at the border between Mongolia and Russia for removing delays, the improvement of Mongolia's logistics systems, the availability of wagons in China and Mongolia, the systems of dispatching and scheduling of wagons and the reduction of frequent breakdowns of transshipment equipment. Therefore, the proposed model can assist policy makers of the associated countries to develop cooperation strategies of route facilitation based on the mutual benefits with the outcomes of analysis. Finally, the proposed DSS can be extended for future work: i) The DSS can be expanded to include the knowledge base so that it can be evolved into an intelligent DSS that can learn from a series of model experiments and sensitivity analyses with changing parameters, ii) The theme of future research is to include dynamic design of the multimodal transport network which reflects the time-sensitivity of cost and risk parameters over a multiple planning horizon.

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TAC assessment for single species and multiple gear fisheries with an application to the Korean hairtail fishery

Jong-Oh Nam^{*}, Jeong-Gon Ryu^{**}, John M. Gates^{***} and Jung-Sam Lee^{**}

ABSTRACT

This paper describes a Total Allowable Catch assessment model for a single species and multiple gear types as an improvement on TAC assessment based on a single species and a single gear type. A case study is included for a hairtail species caught mainly by the Korean pair trawl and large otter trawl gears. We use a surplus production model based on the exponential growth model to estimate biological reference points. Fishing effort for the two gears is standardized and used in a general linear model. The Fox bioeconomic model is then used to estimate economic reference points. In the Korean hairtail fishery, the TAC assessment model for a single species and multiple gear types yielded values for each reference point that were more conservative.

Key words: TAC assessment system, general linear model, standardized fishing effort, maximum sustainable yield, maximum economic yield, net revenue of ABC

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1. Introduction

Fisheries across the world are often composed of multiple or single species and multiple gear types ($S \times G$ or $1 \times G$) rather than a single species and a single gear type (1×1). Nevertheless, the common Total Allowable Catch (TAC) assessment is based on the 1×1 case (Zhang, Kim and Yoon, 1992; National Fisheries Research and Development Institute (NFRDI), 2004), excluding other gear types that catch the given single species. However, this 1×1 case is rare in fisheries. As a result, the TAC, as conventionally calculated, can be overestimated or underestimated. Additionally, a 1×1 assessment model does not consider the allocation of Acceptable Biological Catch (ABC)¹ between multiple gear types, because it considers only one gear type.

In general, the 1×1 assessment model has two versions. The first version considers only catches of a single species caught by a single gear. When only catch and effort data are available, Maximum Sustainable Yield (MSY) can be estimated by a surplus production model.² Then, an ABC no greater than MSY can be estimated by the ABC determination system. Here, in general, ABC of the single species and the single gear equals TAC. The second version considers total catch of a species caught by all gear types, but fishing effort is based on one representative gear type among the all gear types. Reference points can also be estimated by a surplus production model with the same data limitations noted above, but the estimated ABC, in general, is proportionally distributed to each gear type based on gear and gear-specific catch rates (often smoothed by averaging).³ Thus, an ABC of a single species and multiple gears should be greater than a TAC of a single species distributed by gear type. However, these approaches exclude fishing efforts or catches by other gear types involved in catching the given single species. This exclusion can affect TAC estimation. To overcome the above-mentioned limitations of a 1×1 assessment model, this paper proposes an alternative procedure.⁴

Section 2 of this paper defines terminology and premises of an estimation method for multiple gear types that harvest hairtail. Section 3 states the theory of our proposed alternative TAC assessment for a multiple gear fishery. We assume application to pair

1 ABC is generally used to set the upper limit of the annual TAC. It is calculated by applying the estimated (or proxy) harvest rate to the estimated exploitable stock biomass (The Pacific Fishery Management Council and National Marine Fisheries Service 2006).

2 Surplus production models are basic tools used to establish safe harvest levels for a given gear type when only catch and effort data are available. They are also called “lumped parameter” models because they abstract from age class structure and many other biological determinants of birth, growth senescence and death. While these determinants are important, many cannot be controlled by a typical fisheries agency, nor can they be forecast from typical catch-effort fisheries data.

3 In Korea, the catch rate is averaged for the latest 3 years of hairtail caught by each fishing gear.

4 The current Korean stock assessment approach uses several assessment methods depending on the quality and quantity of data. The several assessment methods generally involve the Beverton-Holt yield per recruit model, the biomass-based cohort analysis and the surplus production model. Due to data limitations, this paper uses only on the surplus production model.

and large otter trawls in the Korean fishery for hairtail. Section 4 provides data analysis and results estimated for the proposed alternative TAC assessment model and also compares the results for the 1×1 and our proposed assessment models. Section 5 contains concluding remarks about implications and limitations for our proposed TAC assessment model.

2. Terminology and premises

A common characteristic of Korean fisheries is that either a single gear is used to catch multiple species or multiple gear types are used to catch a single species (Lee, 1991; Seo and Zhang, 2001). Hairtail is a typical single species-multiple gear case; the multiple gear types, include pair trawls, stow nets and large otter trawls (Ministry of Maritime Affairs and Fisheries (MOMAF), 2006).

One approach to TAC assessment in $1 \times G$ cases is to standardize all fishing effort associated with catches of the given single species caught by multiple gear types (Lee, 1991; Quinn and Deriso, 1999; Seo and Zhang, 2001). This approach may be more workable than the two versions of the 1×1 assessment model in single species and multiple (or mixed) fisheries. An idea for TAC assessment in $1 \times G$ cases with limited data is to incorporate the catch and fishing effort of other gears used to harvest a chosen single species. Such effort is excluded in 1×1 assessment model. The TAC results may also approximate reality more closely than those of the 1×1 assessment model. However, due to data limitations, this paper only provides a 1×2 case involving hairtail caught by pair and large otter trawls. This case may nonetheless be helpful in describing and explaining the TAC assessment model of the $1 \times G$ cases.

Premises used in the 1×2 assessment model are as follows. First, there is an economic interaction between the two gears, because the more pair trawls catch of the limited hairtail stock, the less hairtail remains for large otter trawls to catch. Second, only catches of hairtail by the two trawl gear types are considered. Third, the fishing costs for each gear type are different.

3. Theoretical approaches of TAC assessment model

3.1 *Standardization of fishing effort*

About 50% of the hairtail in Korean waters is caught by pair and large otter trawls (MOMAF, 2006). Since units of fishing effort for these gear types differ, the units need to be standardized. This standardization can provide reference point estimates that are more

relevant than those of the 1×1 assessment model. The general model of catch per unit effort (CPUE) is:

$$\hat{CPUE} = CPUE_r \prod_i \prod_j P_{ij}^{X_{ij}} e^{\varepsilon} \quad (1)$$

where $CPUE_r$ is the reference $CPUE$ at one level of each of the factors. Subscript i refers to the factors and subscript j refers to the levels of each factor. P_{ij} represents the relative fishing power for the j^{th} level of the i^{th} factor. For the reference level of each factor, P_{ij} is set to 1. A superscript dummy variable X_{ij} is equal to 1 when a datum refers to the j^{th} level of the i^{th} factor and 0 otherwise. ε is a normal random variable with mean 0 and constant variance, σ^2 . A natural logarithmic transformation of equation (1) results in a GLM⁵

$$\ln \hat{CPUE} = \ln CPUE_r + \sum_i \sum_j X_{ij} \ln P_{ij} + \varepsilon \quad (2.1)$$

or,

$$Y = \beta_0 + \sum_k \beta_k X_k + \varepsilon, \quad \{k\} = \{i\} \cup \{j\} \quad (2.2)$$

where the subscript k subsumes i and j . The Y- intercept β_0 is the reference natural log CPUE and the parameters $\{\beta_k\}$ are natural logarithms of the power coefficients (Lee, 1991; Quinn and Deriso, 1999; Seo and Zhang, 2001).

The standardized natural log CPUE ($\ln \hat{CPUE}$) can be estimated by explanatory variables: $\ln CPUE$ and X_{ij} . The standardized $\hat{CPUE}$ can be estimated by exponentiating the $\ln \hat{CPUE}$. A standardized fishing effort ($\hat{E}_{pt}$ or $\hat{E}_{lt}$) of hairtail caught by each gear can be calculated by the equation (3):

$$C_{T_t} = C_{pt_t} + C_{lt_t}, \quad \hat{E}_{T_t} = \hat{E}_{pt_t} + \hat{E}_{lt_t}, \\ \hat{CPUE}_{\hat{E}_{T_t}} = \hat{CPUE}_{\hat{E}_{pt_t}} + \hat{CPUE}_{\hat{E}_{lt_t}}; \quad \hat{E}_{pt_t} = \frac{C_{pt_t}}{\hat{CPUE}_{\hat{E}_{pt_t}}} \quad \text{and} \quad \hat{E}_{lt_t} = \frac{C_{lt_t}}{\hat{CPUE}_{\hat{E}_{lt_t}}} \quad (3)$$

where C_{T_t} is total annual catch of hairtail by pair and large otter trawls. C_{pt_t} and C_{lt_t} are annual catch of hairtail by pair and large otter trawls, respectively. $\hat{E}_{T_t}$ is total annual standardized fishing effort summed across annual standardized fishing effort ($\hat{E}_{pt_t}$ and $\hat{E}_{lt_t}$) of the two gears. $\hat{E}_{pt_t}$ and $\hat{E}_{lt_t}$ are annual standardized fishing effort of hairtail caught by pair and large otter trawls, respectively. $\hat{CPUE}_{\hat{E}_{T_t}}$ is total annual standardized $CPUE$ of

5 GLM considers consistency in trends over various combinations of factors. Another use of the GLM is in forecasting missing values of CPUE for some combination of factors. The missing data can be estimated from the predictive equation. For the GLM model, see Gavaris (1980) and Quinn and Deriso (1999).

hairtail caught by the two gear types. $\hat{CPUE}_{pt}$ and $\hat{CPUE}_{lt}$ are the annual standardized CPUE for hairtail caught by pair and large otter trawls, respectively. For all variables, the subscript t references the data year.

Given C_{T_t} and $\hat{E}_{T_t}$, an MSY of a yield curve for hairtail can be estimated by a surplus production model. Here, whether we use the Fox or Schaefer model, the results are determined by the empirical relationship between $\hat{E}_{T_t}$ and $\hat{CPUE}_{T_t}$. The MSY of the 1×2 case can be allocated as MSY_{pt} and MSY_{lt} by equation (4).

$$MSY_{pt} = C_{MSY_{pt}} = C_{MSY} \left(\frac{\hat{E}_{pt}}{\hat{E}_{pt} + \hat{E}_{lt}} \right) \text{ and } MSY_{lt} = C_{MSY_{lt}} = C_{MSY} \left(\frac{\hat{E}_{lt}}{\hat{E}_{pt} + \hat{E}_{lt}} \right) \quad (4)$$

where $\frac{\hat{E}_{pt}}{\hat{E}_{pt} + \hat{E}_{lt}}$ or $\frac{\hat{E}_{lt}}{\hat{E}_{pt} + \hat{E}_{lt}}$ is the rate of standardized fishing effort for each gear type. $C_{MSY_{pt}}$ or $C_{MSY_{lt}}$ represents the MSY of hairtail caught by each gear type when aggregate MSY is partitioned based on past effort and catch data (Lee, 1991; Seo and Zhang, 2001).

3.2 Fox model: MSY and ABC estimations

3.2.1 Fox yield curve induced by Gompertz growth function

The Fox yield (asymmetric) curve based on the Gompertz growth function has been used as an alternative to the Schaefer (symmetric) curve based on the logistic growth function (Fox, 1970). The Fox yield curve has three premises.⁶ Given its premises, the Fox yield curve can be expressed by the Gompertz growth function:

$$C_{e_t} = CPUE_{\infty} \exp\left(-\frac{q}{r} \hat{E}_{T_t}\right) \cdot \hat{E}_{T_t} \quad (5)$$

where C_{e_t} is the annual sustainable yield of hairtail caught by the two gear types at year t . $CPUE_{\infty}$ is the initial CPUE that would occur if the stock were at an unexploited level ($CPUE_{\infty} = q \cdot k : k$ is the carrying capacity of the environment). q is the catchability coefficient. r is the intrinsic growth rate.

⁶ Three premises with Fox yield curve are as follows: i) the sustainable yield is equal to the growth of the population, ii) CPUE is proportional to the stock biomass and iii) the sustainable yield is equal to fishing effort times the mean CPUE.

3.2.2 Effort Averaging Method (EAM)

To estimate the $CPUE_{\infty} = q \cdot k$ and q/r necessary to derive equation (5), we need to use the EAM. The EAM uses $\hat{CPUE}_{T_i}$ and $\hat{E}_{T_i}$ estimated by the GLM. The EAM equation is:

$$\ln \hat{CPUE}_{T_i} = \ln(qk) - (q/r) \hat{E}_{T_i} \quad (6)$$

Consequently, the Fox yield curve in the 1×2 case can be stated as $CPUE_{\infty} = q \cdot k$ and q/r .

3.2.3 MSY estimation

E_{MSY} that maximizes yield in equation (5) can be given by the first order condition:

$$\begin{aligned} \frac{\partial C_{e_i}}{\partial \hat{E}_{T_i}} &= \frac{\partial \left(CPUE_{\infty} \exp\left(-\frac{q}{r} \hat{E}_{T_i}\right) \cdot \hat{E}_{T_i} \right)}{\partial \hat{E}_{T_i}} = 0 \\ &= -\frac{q}{r} CPUE_{\infty} \exp\left(-\frac{q}{r} \hat{E}_{T_i}\right) \cdot \hat{E}_{T_i} + CPUE_{\infty} \exp\left(-\frac{q}{r} \hat{E}_{T_i}\right) \end{aligned} \quad (7)$$

Dividing both sides of equation (7) by $\frac{q}{r} CPUE_{\infty} \exp\left(-\frac{q}{r} \hat{E}_{T_i}\right)$ and solving the resulting equation for $\hat{E}_{T_i}$ gives:

$$\hat{E}_{T_i} = E_{MSY} = \frac{r}{q} \quad (8)$$

By substituting E_{MSY} for $\hat{E}_{T_i}$ in equation (5), MSY can be estimated by equation (9):

$$C_e = MSY = C_{MSY} = \frac{CPUE_{\infty} r}{q \exp(1)} \quad (9)$$

3.2.4 ABC estimation

Table 1 shows the Korean tier ABC determination system for setting TAC (NMFS, 2004).⁷ ABC of the 1×2 case can be calculated by the estimated CPUE and the estimated

⁷ Zhang and Lee (2001) constructed the Korean tier ABC determination system for setting TAC. Critical points (e.g. B_X% and F_X%) within the 5 Tiers have been partially changed by the decision makers. We use the latest version (2004) of Korean tier ABC determination system for setting TAC.

MSY based on tier 4 information. The ABC determination system lists, at each of 5 tiers, the quality and quantity of information required for the available stock assessment methods. The method chosen for a particular fish stock, in general, depends on available data information provided to each tier.

Table 1. Korean tier ABC determination system for setting TAC

Tiers	Information Available Levels
* Tier 1	Information available : Reliable estimates of B, F, B_{MSY} , f_{MSY} , $F_{X\%}$ and M 1a) Stock status : $B/B_{MSY} > 1$ $F_{ABC} \leq \text{low value out of } f_{MSY} \text{ or } F_{35\%}$ 1b) Stock status : $\alpha < B/B_{MSY} \leq 1$ $F_{ABC} \leq \text{low value out of either } f_{MSY} \times (B/B_{MSY} - \alpha) / (1 - \alpha) \text{ or } F_{35\%}$ 1c) Stock status : $B/B_{MSY} < \alpha$: $F_{ABC} = 0$
* Tier 2	Information available : Current B, $B_{X\%}$, $F_{X\%}$, M 2a) Stock status : $B/B_{35\%} > 1$ $F_{ABC} \leq F_{35\%}$ 2b) Stock status : $\alpha < B/B_{35\%} \leq 1$ $F_{ABC} \leq F_{35\%} \times (B/B_{35\%} - \alpha) / (1 - \alpha)$ 2c) Stock status : $B/B_{35\%} \leq \alpha$: $F_{ABC} = 0$
* Tier 3	Information available : Current B, $F_{0.1}$, M $F_{ABC} \leq F_{0.1}$
* Tier 4	Information available : Time-series catch (Y) and effort (or CPUE) data 4a) Stock status : $CPUE/CPUE_{MSY} > 1$ $ABC \leq MSY$ 4b) Stock status : $\alpha < CPUE/CPUE_{MSY} \leq 1$ $ABC \leq MSY \times (CPUE/CPUE_{MSY} - \alpha) / (1 - \alpha)$ 4c) Stock status : $CPUE/CPUE_{MSY} \leq \alpha$: $ABC = 0$
* Tier 5	Information available : Reliable catch history Y $ABC \leq 0.75 \times Y_{AM}$ (average catch over an appropriate time period)
1) Equation used to determine ABC in tiers 1~3 :	
$ABC = \frac{BF_{ABC}}{M + F_{ABC}} (1 - e^{-(M + F_{ABC})})$ where, B : biomass, M : instantaneous coefficient of natural mortality, F_{ABC} : instantaneous coefficient of fishing mortality determined by the data available and the stock status	
2) In tiers 1, 2 and 4, $\alpha = 0.05$	

Note: recent years usually represent latest 3 years.

Source: NFRDI. 2004. Stock assessment and fishery evaluation report of year 2005 tac-based fisheries management in the adjacent Korean water, National Fisheries Research And Development Institute, Yae Moon Press.

3.3 Fox bioeconomic model: Maximum Economic Yield (MEY) and NR estimations

3.3.1 MEY estimation

To estimate MEY, we need net revenue (NR). The NR can be estimated by subtracting total cost (TC) from total revenue (TR). NR is:

$$NR_t = P \left[CPUE_{\infty} \exp\left(-\frac{q}{r} \hat{E}_{T_t}\right) \cdot \hat{E}_{T_t} \right] - TC_t \quad (10.1)$$

$$= P \left[CPUE_{\infty} \exp\left(-\frac{q}{r} \hat{E}_{T_t}\right) \cdot \hat{E}_{T_t} \right] - \alpha m \hat{E}_{T_t} \quad (10.2)$$

where NR_t is the annual net revenue, P is the average market-sale price (won/kg) of hairtail used by the two gear types.⁸ TC_t is the annual total cost. As before, the subscript t on variables references the year. α is the weighted average unit cost (won/haul) of the two gear types.⁹ m is the annual weighted average rate of hairtail landed value caught by each gear type.¹⁰ TR_t is estimated by P multiplied by catch in equation (5).

The levels of effort (E) that produce MEY and E_{MEY} can be found by using the first order condition for profit maximization:

$$\begin{aligned} \frac{\partial NR_t}{\partial \hat{E}_{T_t}} &= \frac{\partial \left(P \left(CPUE_{\infty} \exp\left(-\frac{q}{r} \hat{E}_{T_t}\right) \cdot \hat{E}_{T_t} \right) - \alpha m \hat{E}_{T_t} \right)}{\partial \hat{E}_{T_t}} = 0 \\ &= P \left[-\frac{q}{r} CPUE_{\infty} \exp\left(-\frac{q}{r} \hat{E}_{T_t}\right) \cdot \hat{E}_{T_t} + CPUE_{\infty} \exp\left(-\frac{q}{r} \hat{E}_{T_t}\right) \right] - \alpha m \end{aligned} \quad (11)$$

Unlike the E_{MEY} equation of the Gordon-Schaefer model, E_{MEY} of the Fox model cannot be easily expressed in closed form. At best, the relation can be expressed as follows:

-
- 8 P represents the year 2000 value of (hairtail) market-sale price when the base year 2000 is normalized to be 100. The price is based on consumer price index of Korean commercial fish over 10 years (1995~2004).
- 9 α is the year 2000 value of (hairtail) unit cost when the base year 2000 is normalized to be 100. The value is based on the producer price index of Korean commercial fish over 10 years (1995~2004). Also, the α can be estimated by the annual number of days at sea, the number of hauls per day, the number of ships, the total cost per ship and the producer price index. The unit cost (α)=[annual total cost per ship (won/ship)/(annual number of days at sea $\times$ number of hauls per day)] $\times$ producer price index.
- 10 m can be estimated by dividing total landed values of all species caught by a chosen gear type to total landed values of hairtail caught by the gear type. The reason for using hairtail production is so that one needs only the fishing cost of hairtail caught by the chosen gear type. In particular, since the production has a positive relationship between landed value and fishing labor charge, the rate of hairtail landed value was used as an alternative measure of fishing cost.

$$\ln(E_{MEY}) - 2\left(\frac{q}{r}\right)E_{MEY} = \ln\left(\frac{\alpha rm}{CPUE_{\infty} qp}\right) \quad (12)$$

By substituting E_{MEY} for $\hat{E}_{T_i}$ into equation (10.2), NR can be maximized by equation (13):

$$NR|_{\hat{E}_{T_i}=E_{MEY}} = P \left[(CPUE_{\infty} \exp(-\frac{q}{r}E_{MEY}) \cdot E_{MEY}) - \alpha m E_{MEY} \right] \quad (13)$$

Particular solutions can be obtained numerically.

3.3.2 NR Estimation at the Level of ABC

TR at the level of ABC can be estimated by equation (14).

$$\begin{aligned} TR_{ABCpt} &= P_{pt} \cdot C_{ABCpt} = P_{pt} \cdot C_{ABC} \left(\frac{\hat{E}_{pt}}{\hat{E}_{pt} + \hat{E}_{lt}} \right), \\ TR_{ABClt} &= P_{lt} \cdot C_{ABClt} = P_{lt} \cdot C_{ABC} \left(\frac{\hat{E}_{lt}}{\hat{E}_{pt} + \hat{E}_{lt}} \right) \end{aligned} \quad (14)$$

where TR_{ABCpt} is the total revenue of hairtail caught by pair trawls at the level of ABC, P_{pt} is the annual average market-sale price of hairtail caught by pair trawls and C_{ABC} is the ABC of hairtail caught by the two gear types. TR_{ABClt} can be solved by the same method as above.

TC_{ABCpt} or TC_{ABClt} is the annual total cost at ABC level of hairtail caught by each gear. TC_{ABC} can be estimated by a , m and the annual number of hauls ($\hat{E}_{ABC}$).

$$TC_{ABCpt} = a_{pt} \cdot m_{pt} \cdot \hat{E}_{ABC} \left(\frac{\hat{E}_{pt}}{\hat{E}_{pt} + \hat{E}_{lt}} \right) \quad \text{and} \quad TC_{ABClt} = a_{lt} \cdot m_{lt} \cdot \hat{E}_{ABC} \left(\frac{\hat{E}_{pt}}{\hat{E}_{pt} + \hat{E}_{lt}} \right) \quad (15)$$

NR_{pt} or NR_{lt} at the level of ABC can be estimated by equations (16.1) and (16.2). NR_{ABCpt} and NR_{ABClt} are:

$$NR_{ABCpt} = P_{pt} C_{ABC} \left(\frac{\hat{E}_{pt}}{\hat{E}_{pt} + \hat{E}_{lt}} \right) - a_{pt} \cdot m_{pt} \cdot \hat{E}_{ABC} \left(\frac{\hat{E}_{pt}}{\hat{E}_{pt} + \hat{E}_{lt}} \right) \quad (16.1)$$

$$NR_{ABClt} = P_{lt} C_{ABC} \left(\frac{\hat{E}_{lt}}{\hat{E}_{pt} + \hat{E}_{lt}} \right) - a_{lt} \cdot m_{lt} \cdot \hat{E}_{ABC} \left(\frac{\hat{E}_{pt}}{\hat{E}_{pt} + \hat{E}_{lt}} \right) \quad (16.2)$$

$C_{ABC_{pt}}$ and $C_{ABC_{lt}}$ can be estimated by multiplying the rate of fishing effort of each gear type to $C_{ABC} \cdot \hat{E}_{ABC_{pt}}$ and $\hat{E}_{ABC_{lt}}$ can be also estimated by multiplying the rate of fishing effort of each gear type to $\hat{E}_{ABC}$. Net revenue curves of hairtail caught by each gear type at the level of ABC within a proportional range between 0 and 1 of fishing effort can be drawn by assuming constant shares for each gear. The constant shares we have assumed are historically (data) based. A rights-based system that allows transferability would encourage economic efficiency, but may be politically controversial (Seo and Zhang, 2001).

4. Data analysis and results

4.1 Data analysis

4.1.1 Catches and catch rate of target species and target gear types

Hairtail is selected as a target species in part because it has a high commercial value and is heavily exploited. It has been caught by pair trawls, large otter trawls, stow nets, long lines, large purse seines, jigging and other gear types. In addition, it is not included as a species in the current Korean TAC, but will be in the near future.¹¹

The main fishing zones of the pair trawls, stow nets, large purse seines and jigging gear associated with hairtail are the southern area of the Yellow Sea (Huk-San Island, Il-Hyang-Cho, Socotra, Cheju Island etc.), the northern area of the East China Sea and the seas near Thushima Island. In addition, the large otter trawls, large purse seines and jigging gear which harvest hairtail have mainly been active in the seas around Cheju Island and Thushima Island (NFRDI, 2004).

Catches and catch rate of hairtail by gear type for the 10-year period 1995~2004 are based on Fisheries Statistic Data (MOMAF, 2006).

The two gear types in the hairtail fishery had high catch rates for the decade 1995~2004 (the most recent data available). Note that the average catch rate of stow nets (20.1%) is higher than that of large otter trawls (17.8%) as shown in Table 2, but we choose large otter trawls for our study. This is because the average catch rate of stow nets has dramatically decreased every year since 1997 in the 10-year period examined except 2004, when a vessel buy-back program was instituted for stow net vessels (MOMAF, 2003).

11 At present, the hairtail species is not included in the Korean TAC species, but the stock assessment for this species has been continually carried out by National Fisheries Research and Development Institute (NFRDI).

Table 2. Catches and catch rate of hairtail caught by each gear type (1995~2004)

(Unit: MT and %)

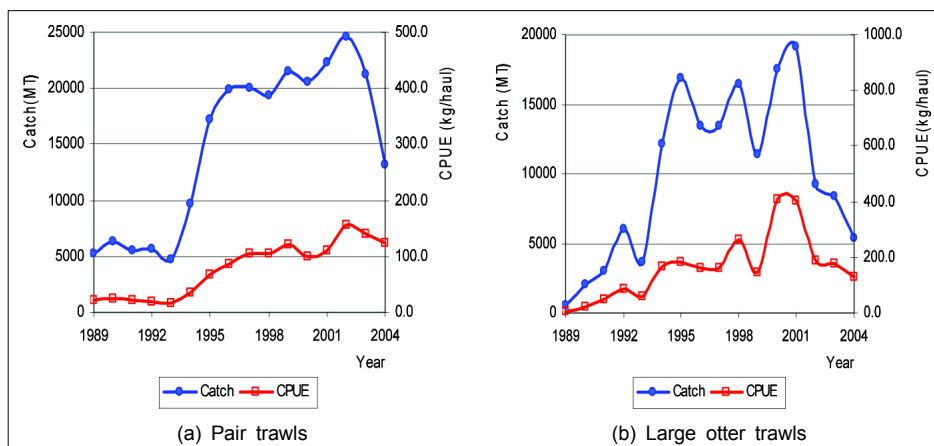
Year	Pair Trawl		Large Otter Trawl		Stow Net		Long Line		Large Purse Seine		Jigging		Others	
	Catch	Catch Rate	Catch	Catch Rate	Catch	Catch Rate	Catch	Catch Rate	Catch	Catch Rate	Catch	Catch Rate	Catch	Catch Rate
1995	17,173	18.2	16,875	17.8	41,062	43.4	5,091	5.4	3,966	4.2	7,694	8.1	2,735	2.9
1996	19,893	26.7	13,459	18.1	25,732	34.6	4,906	6.6	3,704	5	4,987	6.7	1,780	2.4
1997	19,988	29.8	13,493	20.1	19,537	29.1	4,591	6.8	2,907	4.3	4,379	6.5	2,275	3.4
1998	19,291	25.8	16,430	22	21,061	28.1	5,114	6.8	3,020	4	5,666	7.6	4,239	5.7
1999	21,443	33.3	11,449	17.8	9,516	14.8	4,683	7.3	4,867	7.6	7,081	11	5,395	8.4
2000	20,549	25.4	17,543	21.6	5,863	7.2	9,316	11.5	10,685	13.2	6,401	7.9	10,693	13.2
2001	22,317	27.9	19,136	24	5,318	6.7	12,422	15.5	9,642	12.1	6,946	8.7	4,117	5.2
2002	24,533	40.8	9,264	15.4	3,178	5.3	13,069	21.7	2,943	4.9	5,106	8.5	2,079	3.5
2003	21,182	33.7	8,358	13.3	4,839	7.7	9,603	15.3	5,932	9.4	2,266	3.6	10,681	17
2004	13,199	19.9	5,404	8.2	16,056	24.2	8,412	12.7	4,687	7.1	2,123	3.2	16,410	24.8
Average	19,957	28.1	13,141	17.8	15,216	20.1	7,721	10.96	5,235	7.18	5,265	7.18	6,040	8.65

Source: MOMAF. 2006. Fisheries statistic data. Ministry of Maritime Affairs and Fisheries.

<http://www.momaf.go.kr/info/statistics/>

4.1.2 Fishing effort and CPUE of hairtail

Fishing effort units used in this analysis are the annual number of hauls based on the annual total number of ships, the annual number of days at sea and the number



Source: MOMAF. 2006. Fisheries statistic data. Ministry of Maritime Affairs and Fisheries.

<http://www.momaf.go.kr/info/statistics/>

MOMAF. 2003. A study on the structural adjustment of offshore bottom trawl fisheries 1st year report. Ministry of Maritime Affairs and Fisheries.

MOMAF. 2006. A study on the structural adjustment of offshore bottom trawl fisheries 3rd year report. Ministry of Maritime Affairs and Fisheries.

Figure 1. Relationship between catches and CPUE of hairtail for each gear type (1989~2004)

of hauls per day. CPUE is estimated by the observed actual catches and number of hauls (Table 6).

In addition, the relationship between catches and the CPUE of hairtail caught by the pair trawl and the large otter trawl respectively demonstrates similar trends as shown in (Fig. 1).

4.1.3 Economic parameters estimates for hairtail

Table 3 shows all data information (e.g., the number of total ships, the number of annual days at sea, fishing cost per ship, rate of landed value and consumer and producer indexes, etc.) necessary to estimate economic parameters. As economic parameters, we use the fishing cost per ship, the market-sale price of hairtail, the unit cost and the rate of hairtail landed value of each gear type. Fishing cost per ship, market-sale price of hairtail and unit cost are average values, expressed in terms of year 2000 value (Table 4).¹²

Table 3. Total ships, days at sea, fishing cost per ship, market-sale price for target species and gear types

year	Pair Trawl						Large Otter Trawl						Consumer Index	Producer Index
	Total Ships (no.)	Annual Days at Sea (days)	Fishing Cost per Ship (10 ³ won/ship)	Market-Sale Price (won/kg)	Unit Cost (won/haul)	Rate of Landed Value (%)	Total Ships (no.)	Annual Days at Sea (days)	Fishing Cost per Ship (10 ³ won/ship)	Market-Sale Price (won/kg)	Unit Cost (won/haul)	Rate of Landed Value (%)	(Com. Fish)	(Com. Fish)
1995	357	257	1,071,174	1,780	1,503,102	0.115	95	249	1,002,920	1,481	1,017,615	0.201	71.25	74.1
1996	347	270	1,128,607	1,985	1,736,107	0.143	95	259	1,205,220	2,102	1,342,647	0.214	82.28	81.8
1997	337	253	1,187,095	2,022	2,110,961	0.133	94	242	1,307,337	1,545	1,433,588	0.150	101.97	87.0
1998	304	243	1,192,836	2,170	1,131,846	0.112	92	226	1,357,048	1,427	2,207,719	0.141	107.56	87.1
1999	287	253	1,493,639	1,271	1,617,393	0.144	90	258	1,536,137	963	2,753,414	0.076	104.9	95.9
2000	206	252	1,654,890	1,138	1,669,638	0.145	70	266	1,748,835	1,213	2,889,204	0.125	100.0	100.0
2001	201	301	1,792,789	1,669	1,792,687	0.196	62	292	1,918,267	1,176	2,511,338	0.141	100.6	102.0
2002	143	312	2,155,571	1,110	1,964,990	0.172	62	297	2,069,832	659	2,636,012	0.066	108.4	112.9
2003	131	280	2,438,981	1,300	2,113,408	0.233	60	220	1,852,050	659	2,354,806	0.051	106.7	111.3
2004	95	285	1,071,174	1,117	2,159,219	0.115	58	211	1,879,948	608	2,627,688	0.027	103.2	124.0

Source: National Federation of Fisheries Cooperatives (NFFCs). 1995~2004. Annual fisheries business statistic report.

MOMAF. 2006. Fisheries statistic data. Ministry of Maritime Affairs and Fisheries.

<http://www.momaf.go.kr/info/statistics/>

MOMAF. 2006. Fisheries and vessel statistic data. Ministry of Maritime Affairs and Fisheries.

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MOMAF. 2003. A study on the structural adjustment of offshore bottom trawl fisheries 1st year report. Ministry of Maritime Affairs and Fisheries.

MOMAF. 2006. A study on the structural adjustment of offshore bottom trawl fisheries 3rd year report. Ministry of Maritime Affairs and Fisheries.

¹² The annual fishing cost per ship represents the weighted average fishing cost per ship. It is expressed as the year 2000 value of the annual fishing cost per ship when the base year 2000 is normalized to be 100. The annual fishing efforts are the average of annual fishing hauls per ship from 1995 to 2004. The annual number of hauls per ship can be estimated by the annual number of days at sea and the number of hauls per day of ship due to knowing total number of ships.

Table 4. Economic parameters' estimates of hairtail caught by pair trawls and large otter trawls

Gear	Fishing Cost per Ship (thousand won/ship)	Fishing Efforts (hauls/ship)	Market-Sale Price (P: won/kg)	Unit Cost (α : won/haul)	Rate of Landed Value (m: %)
Pair Trawl	1,682,950	853	1,519	1,765,369	0.151
Large Otter Trawl	1,595,634	798	1,135	2,196,907	0.119
Average	1,639,292	-	1,327	1,981,138	0.135
Sum	-	1,651	-	-	-

Source: National Federation of Fisheries Cooperatives (NFFCs). 1995~2004. annual fisheries business statistic report.

MOMAF. 2006. Fisheries statistic data. Ministry of Maritime Affairs and Fisheries.

<http://www.momaf.go.kr/info/statistics/>

MOMAF. 2003. A study on the structural adjustment of offshore bottom trawl fisheries 1st year report. Ministry of Maritime Affairs and Fisheries.

MOMAF. 2006. A study on the structural adjustment of offshore bottom trawl fisheries 3rd year report. Ministry of Maritime Affairs and Fisheries.

4.2 Analysis results

4.2.1 Standardized fishing effort

This analysis is undertaken only with respect to two factors (year and gear) with 16 levels (1989~2004) of the year factor and 2 levels (pair trawl and large otter trawl)

Table 5. Coefficients' estimates and statistics

Factor level	Coef.	Est.	S. E	t Stat	P-value	P _{ij}
Ln (U)	β_0	2.845	0.361	7.890	0.000	17.2
1990	β_1	0.649	0.495	1.313	0.209	1.9
1991	β_2	0.977	0.495	1.976	0.067	2.7
1992	β_3	1.187	0.495	2.400	0.030	3.3
1993	β_4	0.931	0.495	1.882	0.079	2.5
1994	β_5	1.813	0.495	3.665	0.002	6.1
1995	β_6	2.176	0.495	4.398	0.001	8.8
1996	β_7	2.249	0.495	4.547	0.000	9.5
1997	β_8	2.344	0.495	4.739	0.000	10.4
1998	β_9	2.590	0.495	5.235	0.000	13.3
1999	β_{10}	2.364	0.495	4.780	0.000	10.6
2000	β_{11}	2.794	0.495	5.648	0.000	16.3
2001	β_{12}	2.833	0.495	5.727	0.000	17.0
2002	β_{13}	2.630	0.495	5.316	0.000	13.9
2003	β_{14}	2.539	0.495	5.132	0.000	12.7
2004	β_{15}	2.328	0.495	4.706	0.000	10.3
P _t	β_{16}	-0.647	0.175	-3.701	0.002	0.5

Note: factors considered are year (1989~2004) and gear (1,2).

p-value: 95% significant level ($p < 0.05$)

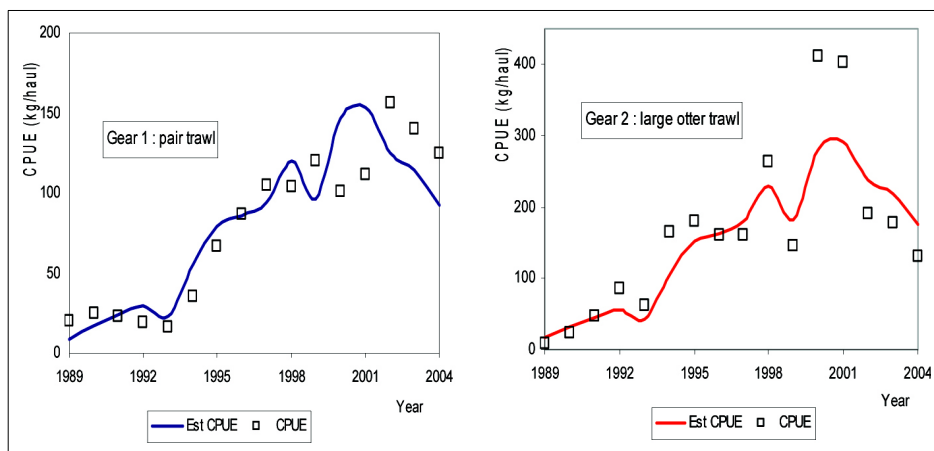


Figure 2. Observed and estimated CPUE of hairtail as function of year and gear type (1989~2004)

of the gear factor. The year variable is a qualitative one and indicates that not all years are the same. This may be indicative of the many other determinants that are omitted from a lumped parameter model. From a scientific perspective, their omission and replacement with qualitative variables is undesirable but reflects the status quo of data availability. For convenience, the reference CPUE is based on year 1989 data and the large otter trawl gear type.

The GLM run by the equation (2.2) fits the data well, with an R^2 of 0.876 and an F-statistic of 6.658 with 16 observations and 15 degrees of freedom ($p < 0.05$). Table 5 provides estimates of β coefficients, statistics, p-value and estimates of the relative fishing power coefficients associated with the GLM regression. All are highly significant for every year except years 90, 91 and 93. Estimates of year 91 and 93 are also significant within ($p < 0.1$). Estimates of the relative fishing power coefficients can be calculated by exponentiating the estimates of β coefficients.¹³ The reference CPUE of the large otter trawl obtained from the intercept is 17.2. CPUE differs somewhat from that of the reference year 1989 in all years except for years 2000 (16.3) and 2001 (17.0). The CPUE for the pair trawl averages 50% of the large otter trawl, a significant difference. This difference could be due to unequal catchability using each of the two gear types. This implies that fishing effort of the two gear types needs to be standardized in the GLM (Quinn and Deriso, 1999).

Fig. 2 shows the good fit of the model between both the observed actual CPUE and the standardized CPUE over 16 years, with the exception of actual CPUE in 2000 and 2001 for the large otter trawl. A reason for the relatively high increase in CPUE for

¹³ This non-linear transformation is biased downward in absolute terms, but the relative values of fishing power are not. Goldberger (1968) gives a first order approximation for non-linear bias which would be appropriate in forecasting the dependent variable.

the large otter trawl in 2000 and 2001 is that catches of hairtail by stow net were reduced in 2000~2003 due to a buy-back program for stow net vessels. However, the data are believed to be correct and observations for these two years have not been excluded.

From the observed actual catch and standardized $\hat{CPUE}_{T_i}$ yielded by the GLM, we obtain the standardized $\hat{E}_{T_i}$ of hairtail caught by the two gear types as shown in Table 6.

In addition, from equation (4), we can calculate the rate of standardized fishing effort of each gear distributed between the two gears. The average rate over 16 years (1989~2004) is 0.76 and 0.24, for each gear type, respectively (Table 7).

Table 6. The observed actual data and estimates of GLM (1989~2004)

Year	Observed Actual Data								GLM							
	Catches (MT)			CPUE (kg/haul)		Fishing Efforts (hauls)		PT	LT	Stan. CPUE (kg/haul)		Stan. Fishing Efforts (hauls)			Est. Stan. In CPUE (kg/haul)	Est. Stan. CPUE (kg/haul)
	PT	LT	PT+LT	PT	LT	PT	LT			PT	LT	PT	LT	PT+LT		
1989	5,175	521	5,696	20.3	7.6	254,953.5	68,330.0	9.0	17.2	574,925	30,301	605,226			2.24	9.41
1990	6,277	2,080	8,357	24.8	22.8	252,655.3	91,110.2	17.2	32.9	364,276	63,192	427,469			2.97	19.55
1991	5,551	3,060	8,611	22.7	48.1	244,293.8	63,634.2	23.9	45.7	232,095	66,979	299,074			3.36	28.79
1992	5,692	5,976	11,668	19.4	85.5	292,739.8	69,854.4	29.5	56.4	192,887	106,016	298,903			3.66	39.04
1993	4,662	3,638	8,300	16.1	61.7	288,939.0	58,922.3	22.8	43.6	204,144	83,397	287,541			3.36	28.87
1994	9,712	12,110	21,822	35.5	164.0	273,935.6	73,842.0	55.2	105.4	176,034	114,909	290,943			4.32	75.00
1995	17,173	16,875	34,048	66.6	180.2	257,851.4	93,628.2	79.3	151.4	216,635	111,442	328,076			4.64	103.78
1996	19,893	13,459	33,352	87.0	159.9	228,660.6	84,158.0	85.3	163.0	233,091	82,558	315,650			4.66	105.66
1997	19,988	13,493	33,481	104.7	160.6	190,952.5	83,992.5	93.8	179.2	213,036	75,286	288,321			4.75	116.12
1998	19,291	16,430	35,721	104.3	263.5	185,008.8	62,359.2	119.9	229.1	160,858	71,721	232,580			5.03	153.59
1999	21,443	11,449	32,892	120.4	145.3	178,038.9	78,768.5	95.7	182.9	223,992	62,609	286,600			4.74	114.77
2000	20,549	17,543	38,092	100.6	410.9	204,180.4	42,698.4	147.1	281.0	139,667	62,421	202,088			5.24	188.49
2001	22,317	19,136	41,453	111.0	402.5	201,011.4	47,541.7	153.0	292.2	145,908	65,496	211,404			5.28	196.08
2002	24,533	9,264	33,797	156.4	190.3	156,869.3	48,683.2	124.8	238.4	196,550	38,855	235,405			4.97	143.57
2003	21,182	8,358	29,540	140.1	177.1	151,180.7	47,189.9	114.0	217.7	185,842	38,389	224,230			4.88	131.74
2004	13,199	5,404	18,603	125.0	130.2	105,617.5	41,495.4	92.3	176.3	142,995	30,649	173,644			4.67	107.13

Note: PT is pair trawls and LT is large otter trawls

Source: MOMAF. 2006. Fisheries statistic data. Ministry of Maritime Affairs and Fisheries.

<http://www.momaf.go.kr/info/statistics/>

MOMAF. 2003. A study on the structural adjustment of off shore bottom trawl fisheries 1st year report. Ministry of Maritime Affairs and Fisheries.

MOMAF. 2006. A study on the structural adjustment of offshore bottom trawl fisheries 3rd year report. Ministry of Maritime Affairs and Fisheries.

Table 7. Average rate of fishing efforts of the two gears for hairtail (1989~2004)

(Unit: %)

Year	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Ave.
Effort Rate pt	0.95	0.85	0.78	0.65	0.71	0.61	0.66	0.74	0.74	0.69	0.78	0.69	0.69	0.83	0.83	0.82	0.76
Effort Rate lt	0.05	0.15	0.22	0.35	0.29	0.39	0.34	0.26	0.26	0.31	0.22	0.31	0.31	0.17	0.17	0.18	0.24

To evaluate the relationship between the standardized $\hat{E}_{T_i}$ and the standardized $\hat{CPUE}_{T_i}$ (Schaefer, 1954; Fox, 1970), we use SPSS 14.0, the Curve Estimation Method (CEM). Results of the CEM regression show, respectively, linear (0.493), logarithmic (0.547) and exponential (0.681) R^2 values and linear (13.6), logarithmic (16.89) and exponential (29.91) F statistics. Consequently, the analysis shows that the relationship is closer to being exponential than linear. Thus, we use the Fox model derived from the Gompertz growth function.

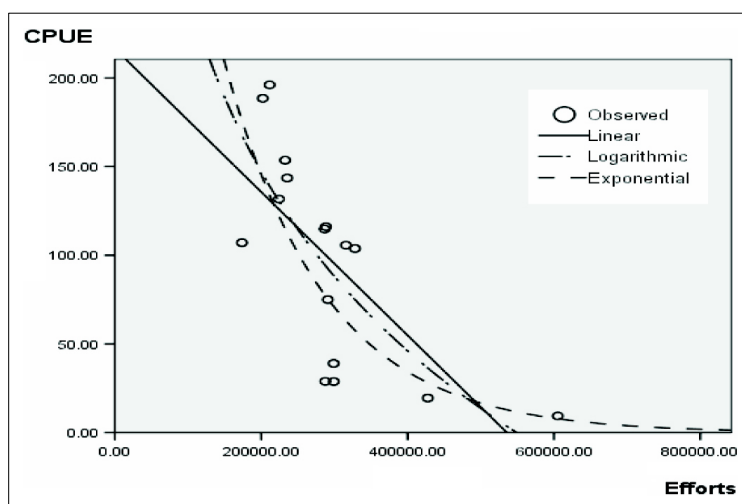


Figure 3. Relationship of estimated fishing effort (E) and estimated hairtail CPUE standardized for two gear types

4.2.2 EAM: estimations of $CPUE_{\infty}$ and q/r

The EAM in equation (6) estimates coefficients of $CPUE_{\infty}$ and $-q/r$. The coefficients of the two parameters are 615.91 and -7.22×10^{-6} , respectively. The EAM regression shows that R^2 is 0.68 and p-values are 2.86×10^{-10} and 8.30×10^{-5} ($p < 0.05$), respectively.

4.2.3 Estimates of MSY (C_{MSY}) and E_{MSY}

MSY (C_{MSY}) and E_{MSY} estimated by equations (8) and (9) are 31,383 metric tons (MT) and 138,504 hauls, respectively. From the average rate of standardized fishing effort (the pair trawl=0.76 and the large otter trawl=0.24) of each gear type, MSY and E_{MEY} of hairtail for each gear can be estimated: MSY (C_{MSY}) and E_{MEY} of hairtail caught by the pair trawls are 23,778 MT and 105,263 hauls. MSY and E_{MEY} of the large otter trawls are 7,605 MT and 33,241 hauls. Moreover, the results of the regression fixed between

the observed catches and the Fox yield curve with the same horizontal line of standardized fishing effort ($\hat{E}_r$) show that R^2 is 0.36. The p-value of the independent variable (observed catches) is 0.0112 ($p < 0.05$). The reason for the somewhat low R^2 may be the extremely high CPUE (410.9 and 402.5) of large otter trawls for hairtail in 2000 and 2001. Fig. 4 shows the fitted Fox yield curve based on observed actual catch and standardized fishing effort.

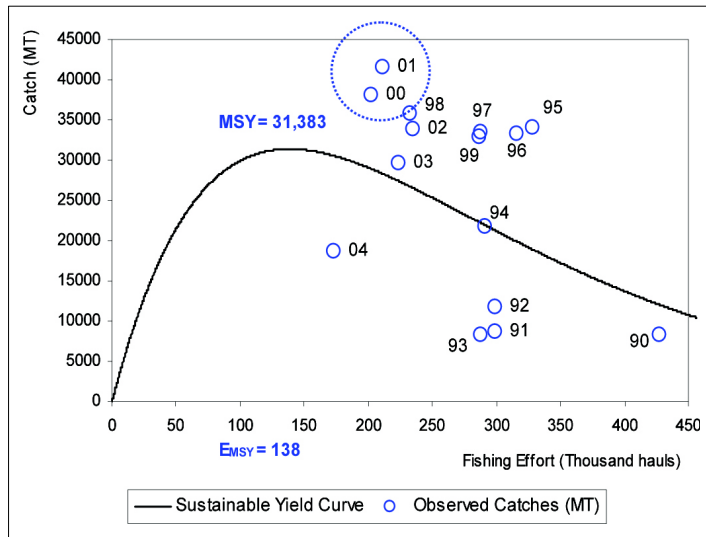


Figure 4. Sustainable yield curve, MSY and E_{MSY} for hairtail in the Korean pair trawl and the large otter trawl based on the Fox model

4.2.4 Estimates of ABC

The TAC for hairtail is related to time series catch and effort data. Since the CPUE: $CPUE_{MSY}$ ratio is between 0.05 and 1, the hairtail TAC falls under 4b) of Tier 4 in Table 1. The CPUE represents the average CPUE of the latest 3 years (2002~2004). This average CPUE is about 128 kg/haul as shown in Table 6. $CPUE_{MSY}$ can be estimated by MSY/E_{MSY} , so the $CPUE_{MSY}$ is about 227 kg/haul. Thus, the CPUE: $CPUE_{MSY}$ ratio is about 0.56.

By the Korean tier ABC determination equation [$=ABC \leq MSY \times (CPUE/CPUE_{MSY} - \alpha)/(1 - \alpha)$] at 4b) of Tier 4, the ABC of hairtail caught by the two gear types is about 15,283 MT. The large difference between MSY and ABC is due to a rapid decrease in recent CPUE (2002~2004). The level of ABC is about 49% of the level of MSY. Based on fishing effort rates for pair trawlers (0.76) and other trawlers (0.24), the ABC_{pt} of hairtail caught by pair trawlers is 11,615 MT; ABC_{lt} of hairtail caught by otter trawlers is 3,668 MT.

Fig. 4 shows that recent catches of hairtail by pair and large otter trawlers have been excessive. Fishing effort has been in excess of the level of fishing efforts at MSY and also recent catches since 1995 (with the exception of year 2004) have also exceeded sustainable yield. In addition, CPUE of hairtail caught by the two gear types has been steeply decreasing since 2001. As a result, even though inputs of fishing effort were only slightly reduced in 2004, the catch dramatically decreased. This result shows that hairtail stock is rapidly decreasing. Therefore, to protect the hairtail stock from overfishing and depletion, we suggest that it needs to be included in the list of Korean TAC target species.

4.2.5 Estimates of MEY and E_{MEY}

MEY and E_{MEY} of hairtail caught by the two gear types are estimated by equations (12) and (13) and the economic parameters of Table 4.¹⁴ The estimated MEY is about 25,184 MT and standardized fishing effort at the level of MEY is about 66 thousand hauls. NR at the level of MEY is approximately 15.9 billion won.¹⁵

Total operating ships (about 40 ships) of the two gear types at the level of MEY can be estimated by dividing annual average fishing effort (1,651 hauls) summed in Table 4 into the E_{MEY} (65,715 hauls). In addition, the total operating ships of each gear type at the level of MEY can be estimated by multiplying the average rate (0.76, 0.24) of fishing effort of each gear type in Table 7 by the total number of operating ships (about 40 ships), i.e., approximately 30 pair trawlers and 10 large otter trawlers.

The estimated MEY of hairtail caught by the two gear types is about 80% of the estimated MSY; the estimated E_{MEY} is about 47% of E_{MSY} . This means that, when E_{MSY} is reduced by 53% to reach E_{MEY} , the MEY, which is also a sustainable yield, falls by only 20%. Harvesting costs would presumably fall by 53%. In short, current fishing effort of the two gear types for hairtail is excessive. Realization of this cost reduction is absolutely dependent on coupling the TAC with a cost-effective rights based system.

Since the hairtail stock has recently been overfished as shown in Fig. 4, it is not possible for fishing effort at the level of MEY to achieve maximum net revenue due to the currently depleted state of stocks. In other words, given the depleted status of the resource, the fishing effort at the level of MEY can gradually recover the resource, but cannot achieve the maximum net revenue until the resource recovers to the steady state biomass associated with MEY. In addition, since pair trawlers and large otter trawlers have been used for catching other species, the revenues of ships of the two gear types that harvest species other than hairtail should also be taken into account.

Fig. 5 shows that the net revenue at MEY is higher than at MSY when the resource

14 To estimate MEY and E_{MEY} in equations (12) and (13), we use Maple 8 program and Excel Goal Seek program.

15 The current exchange value of 1 dollar is about 944 won (<http://www.keb.co.kr> 03/16/2007).

recovers. Hence, if the hairtail resource is allowed to recover, operating at MEY can be much more efficient than operating at the level of MSY in terms of fishing effort and net revenues.

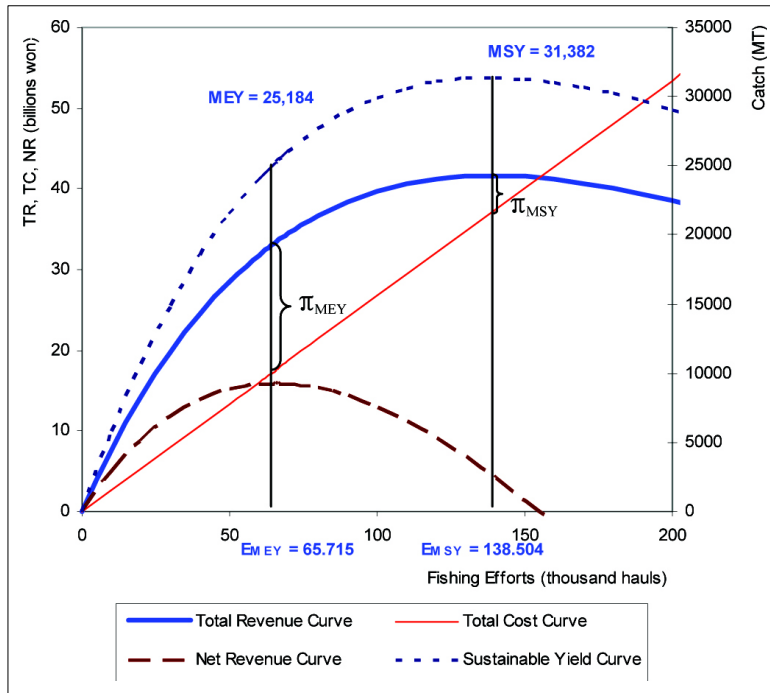


Figure 5. Total revenue, total cost and net revenue of the Korean pair trawler and large otter trawler harvesting hairtail: estimates based on the Fox bioeconomic model

4.2.6 Estimates of NR at the level of ABC

Hairtail net revenues of the two gears can be estimated by equations (16.1) and (16.2). At the current proportional levels ($pt=0.76$ and $lt=0.24$) of fishing efforts between the two gears, NR of pair trawlers is about 11.4 billion won and NR of large otter trawlers is about 2.2 billion won. Also, total NR of the two gear types is about 13.6 billion won. This result implies that pair trawlers input much more fishing effort than do large otter trawlers. As a result, pair trawlers have earned much more, in net revenue terms, than large otter trawlers. This result may be due to a lower unit operating cost and higher market-sale price of hairtail caught by pair trawlers (Table 4).¹⁶ Fig. 6 shows the empirical relationship between net revenue and fishing effort.

¹⁶ Indeed, price differences are sufficiently common in fisheries, that econometric models based on duality should examine the behavioral implications of heterogeneous prices. See, for example, Ty and Gates (1992).

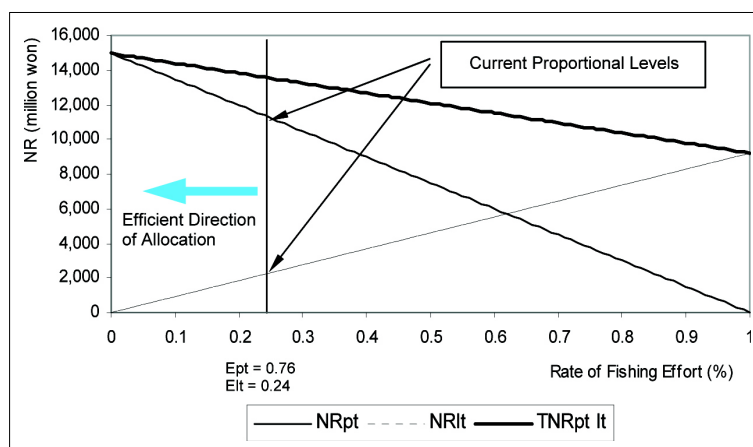


Figure 6. Relationship between net revenue and the rate of fishing efforts

4.2.7 1×1 Assessment model versus 1×2 assessment model

Table 8 shows the comparison between two versions of the 1×1 assessment model and an alternative 1×2 assessment model of the 1×G case. The two versions of the 1×1 case and the 1×2 model have significantly different estimates for reference points MSY, ABC and MEY. For example, the total MSY (31,383 MT) estimated by the 1×2 model is less than the total MSYs (36,972 MT and 38,849 MT) estimated by the two versions of the 1×1 case. In cases of individual fishing gear, the MSY (23,778 MT) of the pair trawlers estimated by the 1×2 model is less than the MSYs (29,129 MT and 27,941 MT) of the pair trawlers estimated by the two 1×1 versions. The MSY (7,605 MT) of the large otter trawlers estimated by the 1×2 model is also less than the MSYs (7,843 MT and 10,907 MT) of the large otter trawlers estimated by the two 1×1 versions. The total ABC (15,283 MT) estimated by the 1×2 model is less than the total ABCs (17,548 MT, 38,849 MT) estimated by the two 1×1 versions. With respect to type of fishing gear, the ABC (11,615 MT) of the pair trawlers estimated by the 1×2 model is less than the ABC (27,941 MT) of the pair trawlers estimated by the second version model of the 1×1 case. However, the ABC (11,615 MT) of the pair trawlers estimated by the 1×2 model is greater than the ABC (9,705 MT) of the pair trawlers estimated by the first version of the 1×1 case. The reason is that the $CPUE:CPUE_{MSY}$ ratio has a small proportion (0.37) due to the high $CPUE_{MSY}$ while the current CPUE is increasing. The ABC (3,668 MT) of the large otter trawlers estimated by the 1×2 model is also much less than the ABC (7,843 MT and 10,907 MT) of the large otter trawlers estimated by the two versions of the 1×1 case. Also, the total C_{MEY} (25,184 MT) estimated by the 1×2 model is less than the total C_{MEY} (31,542 MT) estimated by the first version of the 1×1 case.

These results indicate that the total MSY and ABC estimated by the two versions of the 1×1 case can be overestimated and also the hairtail fishery can be overfished as judged by the reference points (e.g., MSY, ABC) relative to recent effort and catch rates. The alternative (1×2) model of the 1×G case yielded values for each reference point that were more conservative.

Table 8. Comparison of MSY, ABC and MEY between the two versions of the 1×1 case and the 1×2 case

Reference Points	model	First Version of the 1×1 Case			Second Version of the 1×1 Case			The 1 × 2 Case		
		Pair Trawl	Large Otter Trawl	Total	Pair Trawl	Large Otter Trawl	Total	Pair Trawl	Large Otter Trawl	Total
MSY (MT)		29,129	7,843*	36,972	27,941*	10,907*	38,849*	23,778	7,605	31,383
ABC (MT)		9,705	7,843*	17,548	27,941*	10,907*	38,849*	11,615	3,668	15,283
C _{MEY} (MT)		27,161	4,381	31,542	-	-	-	-	-	25,184

Note: * all values are same, because CPUE/CPUE_{MSY} is greater than 1 and ABC equals TAC in 1×1 cases.

5. Conclusions

This paper has demonstrated that the common TAC assessment based on two versions of the 1×1 model case can generate biological and economical bias, when applied to more complex fisheries that involve multiple species and/or gear types. The results analyzed from a Korean case study also show that MSY, ABC, or MEY estimated by the two version models of the 1×1 model case is somewhat greater than the one estimated by the 1×2 model. More specifically, the 1×1 model overestimated the MSY by about 18 percent (1st version) and about 24 percent (2nd version), the ABC by about 15 percent (1st version) and about 254 percent (2nd version) and the MEY by about 15 percent (1st version). These results show that the 1×1 model can generate a decline in the stock of a certain species due to the bias of the analyzed result. In addition, for problems of TAC allocation which can occur as a result of competition for a certain species between vessels of different gear types, the 1×2 model shows that the TAC of each gear type at the ABC level is economically inefficient. Moreover, the 1×2 model suggests the direction of change (more pair trawler, fewer otter trawlers) in sectoral allocations, assuming that a more efficient gear mix is allowed to evolve.

There are several limitations of analysis on single species and multiple gear types. First, there is a lack of biological and technical information necessary to the analysis. In this analysis, due to data limitations, the surplus production model was used. Second, the 1×2 model mentioned as a case study can facilitate understanding of the analysis process, but the model has a limit in not considering other gear types commonly used for catching

hairtail. Thus, as an extension of the present analysis, a study needs to be done on a $1 \times G$ model that considers all gear types. The study should address whether or not the $1 \times G$ model is more conservative than the 1×1 model by using other methods (e.g., sensitivity analysis and theoretical comparative analysis, etc.). In addition, as a technical issue, when a $1 \times G$ model is applied, one must standardize fishing effort for different fishing gear types. By showing that such details matter, we hope this analysis will be a spur for acquisition of a more complete data series. It is also hoped that the paper may help in evolving a rights based system so that both resource conservation and efficient resource harvesting can be achieved. The TAC system alone is unlikely to achieve either.

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Data and Documentation. Data sources, models and estimation procedures are expected to be documented to permit replication by other researchers. Data used in the analyses should be made available to other researchers for replication purposes. Submission of appendices, model documentation and other supporting materials is encouraged to facilitate the review process.