

A Study on

Advancement of Estimating the Emission from Ships

through Connection and Utilization of Big Data

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※ This study is based on the work of Ahn YS et al. (2021) "A Study on Advancement of Estimating the Emission from Ships through Connection and Utilization of Big Data", Korea Maritime Institute















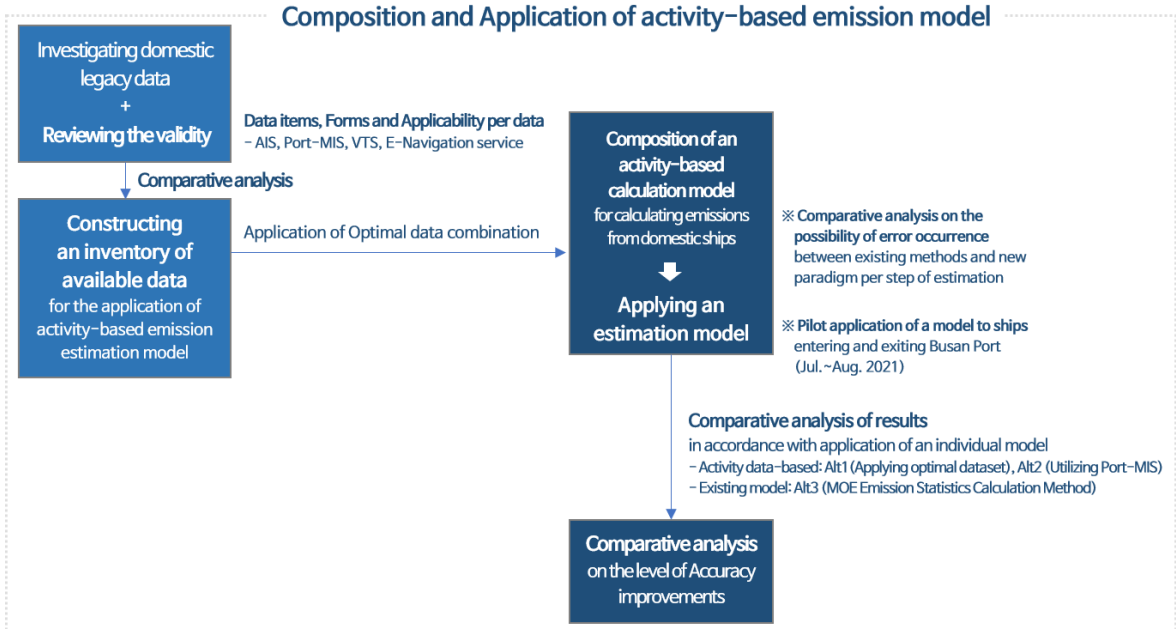
Overview

Purpose

- Through reviewing the availability and validity of domestic key data related to shipping and ports,
  create a 'Data Inventory' for candidate material data that can be linked and used not only in the calculation of ship's national and regional emissions but also in the calculation of ship's emissions in ports

- Composition and application of **Bottom-up emission estimation model based on the Activity-based method**
  - It acts as an important technical basis
    that enables real-time calculation and utilization by **reflecting the ship's activities more densely and accurately in space and time**.
  - In the case of real-time collection and application of material data using wired/wireless networks and sensing technology,
    real-time analysis and prediction using material data and data of emission calculation result in the concept of big data as well as real-time emission calculation.

  → the utilization of high demand and high value is dramatically improved.



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Features

▪ Breaking away from the existing calculation paradigm,
the **Paradigm of the ship emission calculation system is newly presented as a bottom-up methodology based on smart connectivity**
to dramatically improve the accuracy of the emission calculation result

※ Plan to provide technical and policy basis for smart intelligent analysis-prediction platform in the future

▪ Application of the bottom-up methodology to **densify the reporting-collection-calculation cycle(time grid) and location(spatial grid) based on the specifications(ships and engines, etc.) of each ship**
subject to emission calculation and big data-based activity data

- In-depth review and application of ship and engine specification information and activity data collection, availability and validity of periodic data, and the possibility of big data
  so that the emission of target ships can be calculated by country, region, and individual port.
- To construct and apply the optimal calculation model,
  the material data for acquiring the ship's activity data is not limited to AIS.

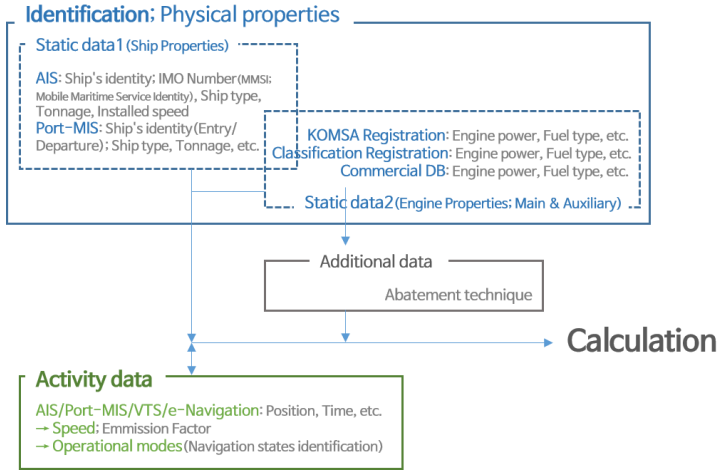
→ Instead, **the optimal data combination is derived and applied after examining the availability** of related domestic institutional data such as PORT-MIS, VTS, and e-Navigation services.

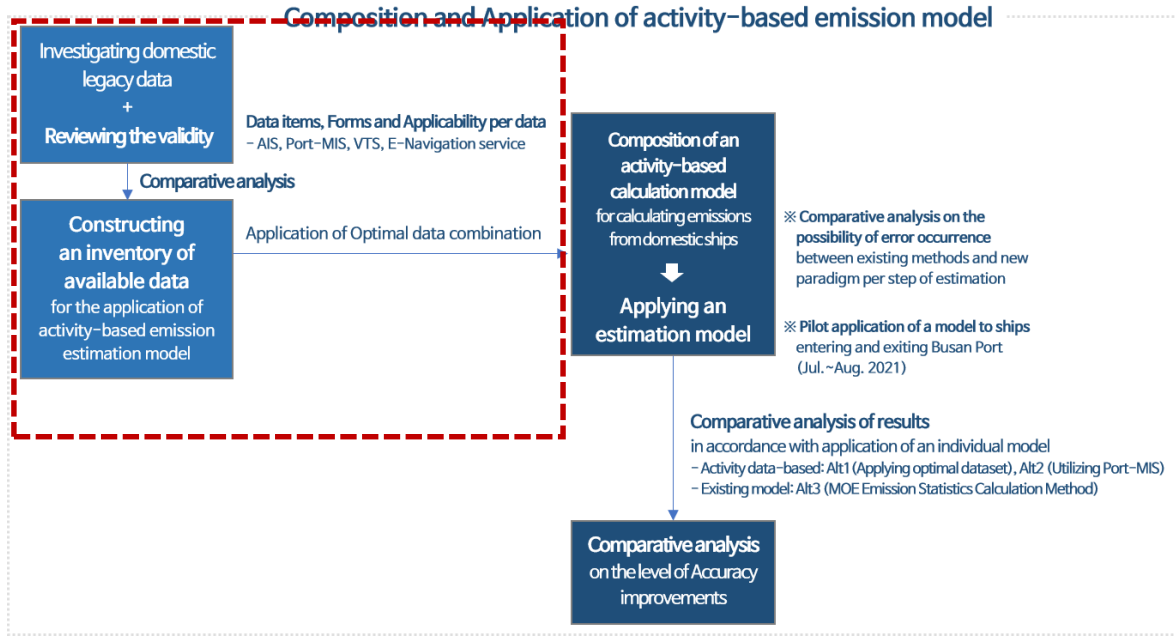
Data inventory of candidate source data

■ The Inventory of available data for the application of an Activity-based estimation model

Selection and Preparation of candidate data

- Based on the survey and review results of domestic shipping and port-related periodic data,
  the Applicability and Limitations to the Activity data-based bottom-up emission estimation model are summarized.
  - Among the data related to ship operation and entry/exit provided by the individual DB, **items of direct and indirect data required for the calculation of ship emissions are selected** and organized.
  - Classified into static data and dynamic data according to the nature of the data, and the applicability, related characteristics, and limitations to the activity data-based bottom-up emission estimation model based on the previously reviewed validation results are organized.





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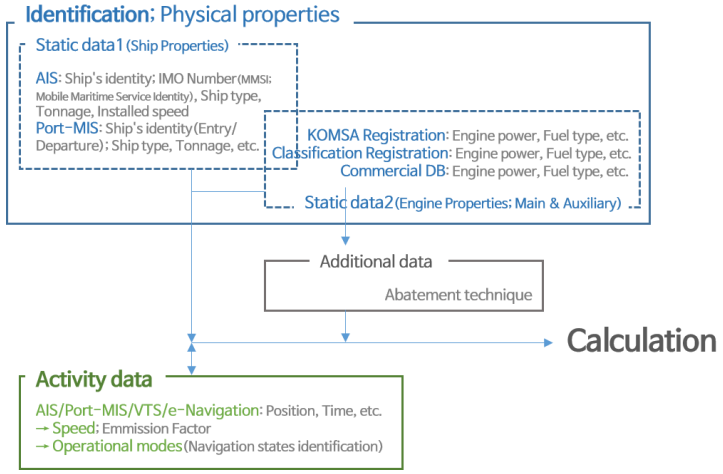


PORT-MIS (Port Management Information System)

Information item	Content and form	Type	Utilization	Classification
Call sign	Call number of the ship	DB	○	Static
Number of control	Number of control during a target period	DB	△	Dynamic
Voyage No. for arrival report	Number of report during a target period	DB	△	Dynamic
Time and Date	Time, date of report	DB	△	Dynamic
Traffic system	ID number of traffic system for communications	DB	△	Dynamic
Barge flag	Check the presence of barge	DB	○	Static
Remark	Remark	DB	-	-
Classification	Control classification	DB	○	Dynamic
Outer/Inner Port	Classification of Outer/Inner/Intra-port	DB	○	Static
Name	Name of a ship	DB	○	Static
Nationality	Nationality of a ship	DB	○	Static
Gross tonnage	Gross tonnage of a ship	DB	○	Static
Ship type	Type of a ship	DB	○	Static
Owner/Agent	Owner/Agent of a target ship	DB	-	-
Time of Arrival/Departure	Time of Arrival/Departure	DB	○	Dynamic
Location of Arrival	Location of arrival (name of port etc.)	DB	○	Dynamic
Port of prior departure	Port of prior departure	DB	△	Dynamic
Destination	Destination	DB	△	Dynamic
Time of Entry/Exit	Time of entry/exit of control area	DB	○	Dynamic
Location of Entry/Exit Passage	Location of entry/exit passing control area	DB	○	Dynamic

Footnote: ○: Preferential activity data able to directly utilize, △: able to utilize for estimation data when preferential activity data is unavailable
Source: Prepared by the author

[Result of validity review: PORT-MIS]

Applicability	Limitations
Useful when **'estimating the emission from ships within ports'** ※ Need to estimate missing time and location in case of applying into a real-time estimation model and unable to make correct estimation	Unable to provide other than specified time and place of report
	Special purpose ships within ports are not included to subject for report
Useful **as a complementary DB** when estimation is made based on activity-based data ※ Providing description information such as Identification of a ship and license, registration information	Not providing descriptions of engine and relevant information

Data inventory of candidate source data

■ The inventory of available data for the application of an activity-based estimation model

AIS (Automatic Identification System)

Information item	Type	Utilization	Classification
Ship name	DB	○	Static
IMO Number	DB	○	Static
MMSI Number	DB	○	Static
Call sign	DB	○	Static
Date and Time of Traffic	DB	○	Dynamic
Location	DB	○	Dynamic
Bow Direction	DB	△	Dynamic
Ship Speed	DB	○	Dynamic

Footnote: ○: Preferential activity data able to directly utilize, △: able to utilize for estimation data when preferential activity data is unavailable
Source: Prepared by the author

[Result of validity review: AIS]

Applicability	Limitations
Very Useful when **applying to an activity-based bottom up emission estimation model** for ships ※ Providing activity-based data such as location and speed per time of a ship ※ **The interval between transmitting and receiving periods is short enough** to estimate the emission at dense spatial-temporal grids.	When applying to a real-time based estimation model for real-time intelligent emission control, **missing time and location between transmitting and receiving periods should be presumed**.
	Not providing and collecting activity-based data of unequipped ships
	Not offering ship descriptions and relevant information ※ Need to connect port descriptions by PORT-MIS and administrative information related to entering and exiting ports through identification and matching of ships
	Not providing engine descriptions and relevant information ※ Need to connect ship inspection institutes (Korean Register etc.) through identification and matching of ships

VTS (Vessel Traffic System)

- **Integrated collection and use of current relevant data related to ship activities**
  - **Can be used as a highly accurate data tool** to precisely understand the activities of individual ships
- **However, the current VTS limits the connection** and use of other than closed networks for purposes other than maritime traffic control for security reasons
  - Therefore, this study is not considering a technical method of outputting it or linking it externally in the form of data.

Data inventory of candidate source data

■ The inventory of available data for the application of an activity-based estimation model

e-Navigation Service (DSP of Korea e-Navigation Service)

Information item	Type	Utilization	Classification
Latest LTE-M location inquiry	DB	○	Dynamic
Latest Mobile location inquiry	DB	○	Dynamic
Inquiry of ship description information	DB	○	Static
AIS ship track inquiry	Function	○	Dynamic
Port guideline request	Asynchronous	-	
Ship movement forecasting service request	Asynchronous	△	Dynamic
Marine safety information request of external networks	Asynchronous	-	
Sea route request	Asynchronous	△	Dynamic
Sea route confirmation	Asynchronous	△	Dynamic
Sea route end	Asynchronous	△	Dynamic
Density service request	Asynchronous	-	
Emergency report information	DB	-	
Pilot card inquiry	DB	-	
Vulnerability analysis inquiry	DB	-	
Navigation warning inquiry (collision)	DB	-	
Navigation warning inquiry (stranding)	DB	-	
V-Pass track inquiry	Function	○	Dynamic
Sensor information inquiry	DB	△	Dynamic
Ship fire inquiry	DB	-	
Ship stability inquiry	DB	-	

Footnote: ○: Preferential activity data able to directly utilize, △: able to utilize for estimation data when preferential activity data is unavailable
Source: Prepared by the author; MOF (Date of search: 12th of Oct, 2021)

[Result of validity review: e-Navigation service]

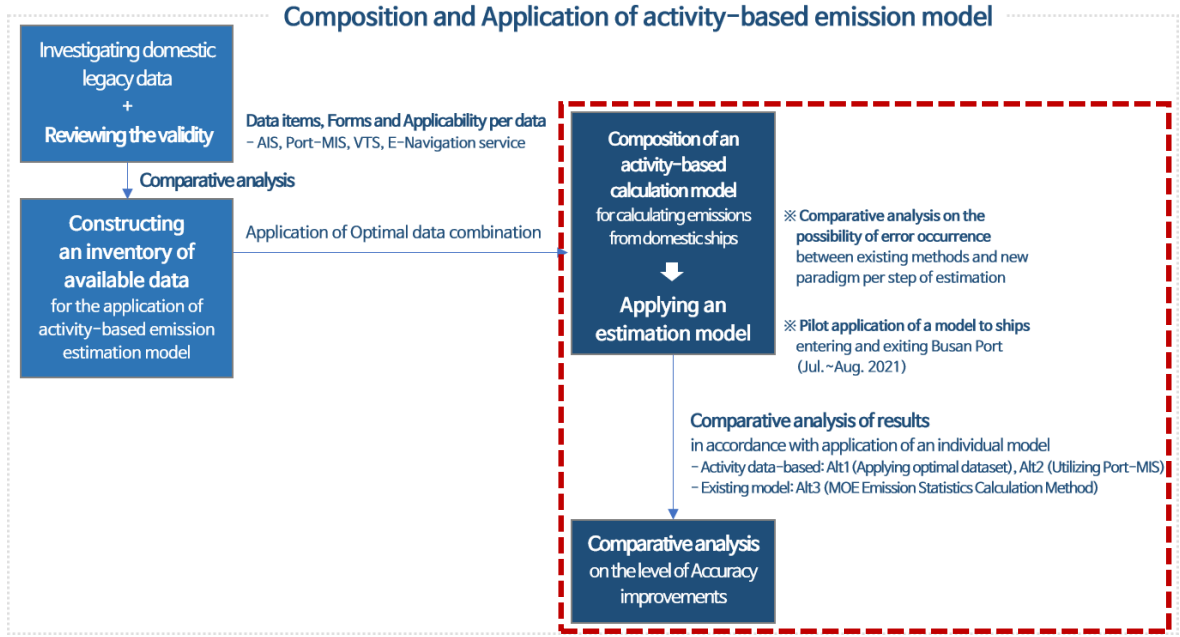
Applicability	Limitations
An optimal DB when applying to a 'real-time' estimation model for real-time intelligent emission control ※ **Providing real-time activity-based data** such as location per time of a ship and speed ※ **Minimizing the delay by utilizing LTE-M** network: able to estimate the emission in real-time	Currently operating a pilot project, and need to construct a DB without missing target ships and regions
	Not providing engine descriptions and relevant information ※ Need to connect ship inspection institutes (Korean Register etc.) through identification and matching of ships

Organization and application of an activity-based emission estimation model

Algorithm of the model

- **The data processing execution stage of this model is divided into a total of 6 stages as follows.**

① **Identification** of ship
② **Collection** of static and dynamic information
③ **Data selection** and determination (including classification of ship types/classes, fuel oil, etc.)
④ **Organize required data** for each emission source (main engine, auxiliary engine, boiler) in the ship
⑤ **Energy amount estimation and emission factor selection**
⑥ **Emission calculation** and aggregation



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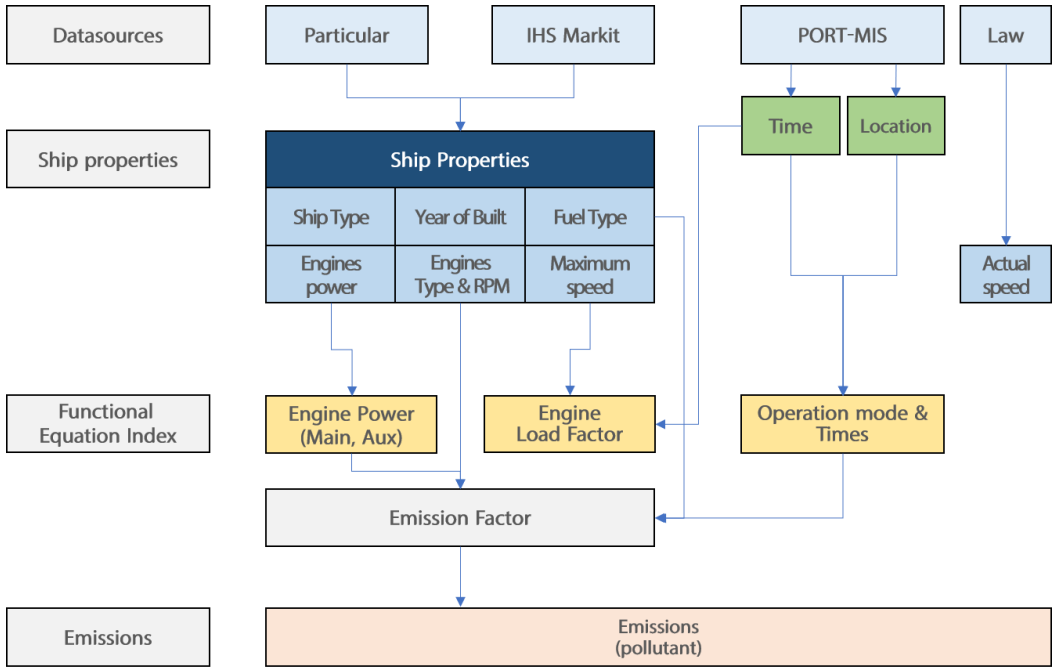
[Major factors and data-process in AIS-based Emission estimation model]



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Required data

Static information

IHS Fairplay (Engine manufacturer, regional authority, ship owner)

Internal DB

Identification	Ship description, characteristics	Features of main engine	Features of auxiliary engine	Others
Maritime Mobile Service Identity (MMSI)	Year of construction	Sulfur content of main engine fuel oil	Sulfur content of auxiliary engine fuel oil	Seawater density
IMO number	Length	Reduction technology applied to main engine	Reduction technology applied to auxiliary engine	Angular velocity of propellers
Ship name	Width	Specific Fuel Oil Consumption (SFOC) of Main engine	Specific Fuel Oil Consumption (SFOC) of auxiliary engine	Propeller rpm
Ship type	Draft	Main engine model	No. of auxiliary engine	-
-	Gross tonnage	Stroke type of main engine	Output of installed auxiliary engine	-
-	Weight tonnage	Main engine rpm	Fuel type	-
-	Design speed	No. of main engine	-	-
-	No. of cabins	Output of installed main engine	-	-
-	Hull type	Fuel type	-	-
-	Wetted surface area	Calculated emission factors	-	-
-	Length between perpendicular	-	-	-

+

Dynamic information

AIS System

Instantaneous speed	Location	Ship type

Source: Prepared by the author

Organization and application of an activity-based emission estimation model

Estimation of the emission

- **The space-time unit grid is divided** based on the position report point and transmission/reception period of the AIS data, and **the energy amount per section is estimated** by estimating and summing the energy amount per unit grid.

$$E_{Trip,i,j,m} = \sum_{p}[T_{p,s}\sum_{c}(P_c \times LF_{c,s} \times EF_{c,i,j,m,p})]$$

E_{Trip}: Amount of pollutants emitted from a ship (tons)
T: Shipping time (hr)
P: Engine output (kW)
LF: Engine load factor (%)
EF: Emission factor (g/kWh)
c: Source of emission within a ship (main engine, auxiliary engine, boiler)
i: Atmosphere pollution matter (8 air pollutants including NOx, NMVOC, PM)
m: Type of fuel (Burker Fuel Oil, Marine Diesel Oil, Marine Gas Oil)
j: Type of engine (Gas turbine, low-, mid-, high speed diesel engine, steam turbine)
p: Type of operation (cruising, berth, anchoring)
s: Classification by grid

Source: Prepared by the author

- **The engine load ratio for each unit grid or** section of an individual ship is estimated using **the 'propeller law'**

$$LF_{s,p,c} = (AS_{s,p,c}/MS)^3$$

LF: Load Factor(%)
AS: Actual Speed(knots)
MS: Maximum Speed(knots)
c: Source of emission within a ship (main engine, auxiliary engine)
p: Type of operation (cruising, berth, anchoring)
s: Classification by grid

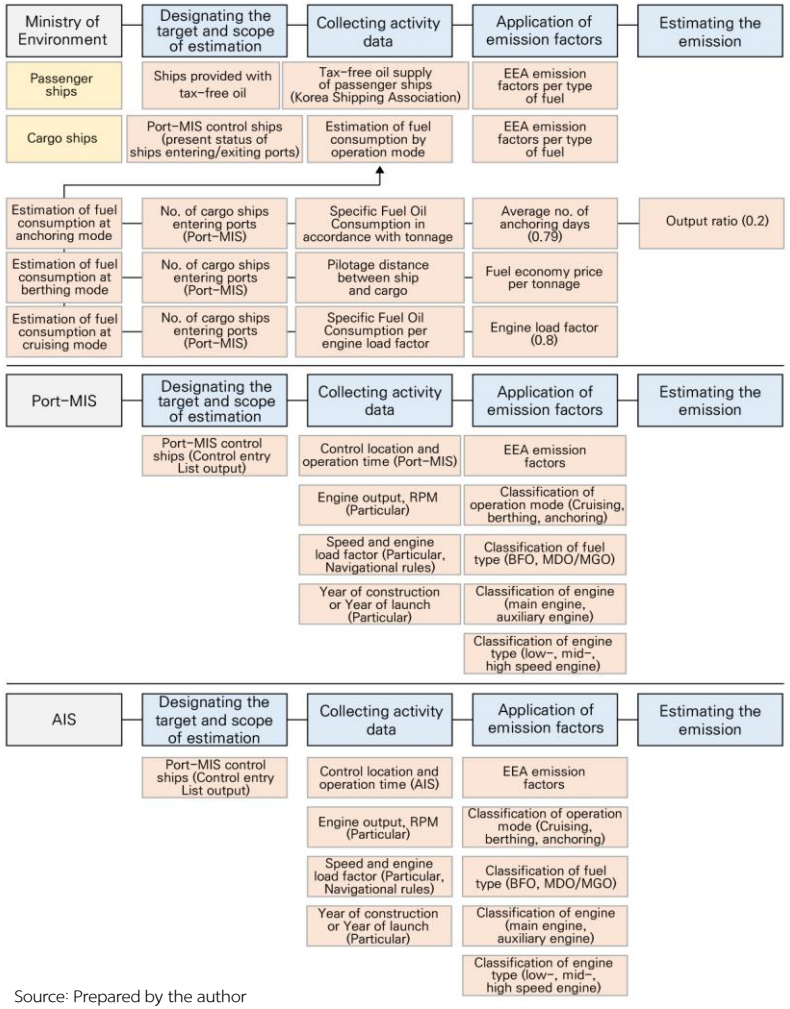
Source: US EPA(2009), pp.2-11~2-12.

- **EEA Tier 3 emission factors** are applied according to the conditions that each ship meets for the following classifications
  - **By operation type** (cruising, anchoring, berth)
  - **By fuel type** (BFO, MDO/ MGO)
  - **By emission source** (main engine, auxiliary engine) **and engine type** (gas turbine, low-speed, medium-speed, high-speed diesel engine, steam turbine, etc.),
  - **By pollutant**

Comparative analysis between 3 models and verification for accuracy improvements

■ Comparison and analysis of major factors in each calculation stage

[Comparison and analysis of major factors by stage of the three emission calculation models]



Source: Prepared by the author

Target and scope of estimating the emission

Classification	Content
Existing MOE methods Manual IV	• Scope of estimating the emission: After producing the national/1 year statistics, and allocating per region/month • Target: passenger ships, cargo ships, fishing vessels, leisure vessels - Passenger ships: Coastal passenger (excluding ocean-going passenger ships) - Cargo ships: cargo vessels entering/exiting domestic trade ports - Fishing boats: vessels using tax-free oil - Leisure vessels: registered leisure vessels
PORT-MIS activity-based bottom-up model	• Scope of estimating the emission: Limited application of specific temporal and spatial scope/entirety within port limit is available • Target: Port-MIS control ships
AIS activity-based bottom-up model	• Scope of estimating the emission: Application of specific temporal and spatial scope/entirety within AIS transmitting and receiving areas is available • Target: Ships in AIS vessel traffic

Reflecting the activity characteristics of individual ships

Classification	Content
Existing MOE methods Manual IV	• An optimizing model for producing 1 year/national macro statistics, hence, relatively easy to collect the data and estimate the emission • Difficult to accurately divide specific temporal/spatial scope and difficult to allocate the emission • Difficult to reflect actual activities of individual vessels
PORT-MIS activity-based bottom-up model	• Able to calculate the emissions including record of ships entering and exiting ports and reflecting movement information (7 traffic items) within port limits • Available for the division of specific temporal and spatial scope as well as emission allocation, although limited • Available for limited application of reflecting actual activities of individual ships
AIS activity-based bottom-up model	• Able to estimate the emissions by accurately reflecting real movement information (location, time and speed etc.) utilizing activity data transmitted and collected through AIS • Able to estimate the emissions according to a variety of demand following policy and research demand as well as accurately divide specific temporal and spatial scope • Capable of reflecting actual activities of individual ships in high resolution

Comparative analysis between 3 models and verification for accuracy improvements

■ Comparison and analysis of major factors in each calculation stage

Resolution of activity data

Classification	Content
Existing MOE methods Manual IV	● The Current method uniformly estimates and applies patterns and activities per group of ships, inappropriate for reflecting actual activities. - Average No. of anchoring days: the result of sampling survey on 560 ships at Ulsan port in 2001 (0.79) - Engine load factor per type of operation: Assuming anchoring (20%), cruising (80%)
PORT-MIS activity-based bottom-up model	● Difficult to reflect the pattern of activities between control points, however, favorable for roughly representing long periodic sections utilizing limited information - Able to identify anchoring of individual ships as well as time and location (ports) per point of limited activities utilizing control records - Engine load factor per type of operation: Able to estimate engine load factor based on the maximum speed of ship's description, while assuming maximum speed within a port as real speed
AIS activity-based bottom-up model	● Able to accurately reflect activities between AIS traffic points of individual ships ※ The denser the interval between traffic periods is set, the more accurate the representation of activities is. - Able to identify and utilize the location and time of all activities of individual ships utilizing control records - Engine load factor per type of operation: Extracting the real speed between communication locations is available, hence, able to estimate the engine load factor by type of operation utilizing real speed and maximum speed on a ship's description

Application of emission factors

Classification	Content
Existing MOE methods (Manual IV)	● Applying emission factors at the level of EEA-Tier 1 conceptually
PORT-MIS activity-based bottom-up model	● Partially applying emission factors at the level of EEA-Tier 3 conceptually
AIS activity-based bottom-up model	● Applying emission factors at the level of EEA-Tier 3 conceptually ● Still applicable when reflecting more precise conditions than EEA-Tier3 level later

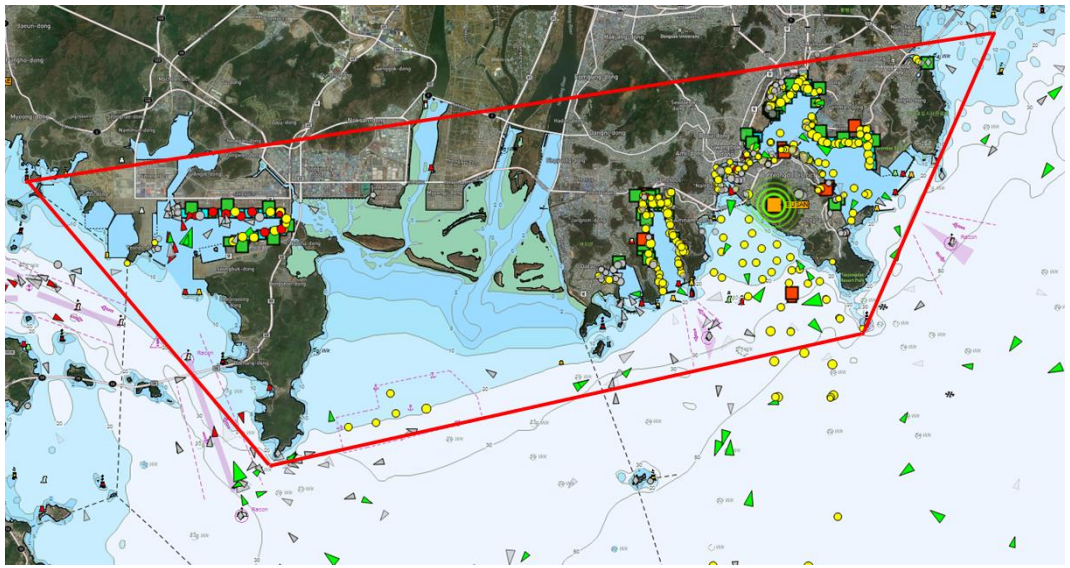
Comparative analysis between 3 models and verification for accuracy improvements

■ Application of Emission estimation model based on activity data

- Emissions are calculated **by applying a total of three models**, including the **proposed model of this study**(the AIS data-based model) and **the existing methods** (the PORT-MIS data-based model, the method of the MOE)
- Set **the same calculation target and range to compare** the results of applying the three models

Emission calculation boundary range

[Range of Emissions Calculation(Port boundary of Busan Port)]



- **The spatial boundary range of the emission calculation** is set based on the port boundary of Busan Port and the maritime area within the port.

Emission calculation target

- **To set the estimation target applicable to the three models,**
  - Using the control communication status data of PORT-MIS, this study checked the information of **ships entering and departing from Busan Port or moving within the port from July 12, 2021, to August 12, 2021 (30 days in total)**
  - Among them, **a total of 1,245 ships** that can check AIS communication information were selected for emission calculation.

Comparative analysis between 3 models and verification for accuracy improvements

■ Comparative analysis of Emission estimation results

Operation type: Cruising

[Result of estimating the emission per model (Cruising)]

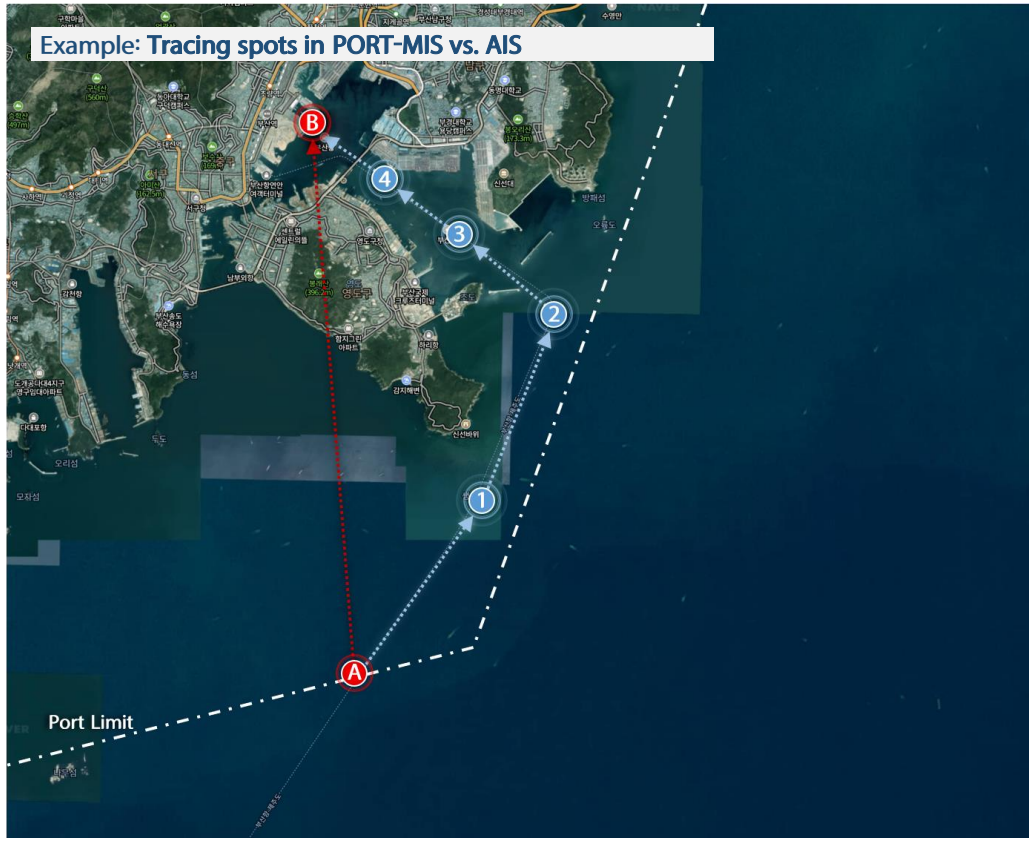
(Unit: ton)

Classification	NOx	VOC	TSP	PM_{10}	$PM_{2.5}$	SOx	CO	NH_3
PORT-MIS activity-based bottom-up model	155.562	4.776	7.714	7.714	7.714	48.325	17.880	0.003
AIS activity- based bottom- up model	519.048	16.782	27.307	27.307	27.307	170.323	63.019	0.020
Diff. in PORT-MIS model Compared with AIS model	-70.0%	-71.5%	-71.8%	-71.8%	-71.8%	-71.6%	-71.6%	-85.0%

▪ Analysis

- Emission calculation results by the PORT-MIS data-based model were all **underestimated by around 70% compared** to the AIS data-based model.

→ Since the movement between control points is basically assumed as a straight line, **AIS data with a tighter interval between control points more accurately reflects the actual activity** of the ship



- AIS data reflect ship activity and **path(A-1-2-3-4-B) with a relatively dense time-space grid**
- The PORT-MIS data-based model classifies the operation time and operation type by the difference in the control time between two control communication points.

→ The straight section of A-B is recognized as **a speed slower than the actual speed**

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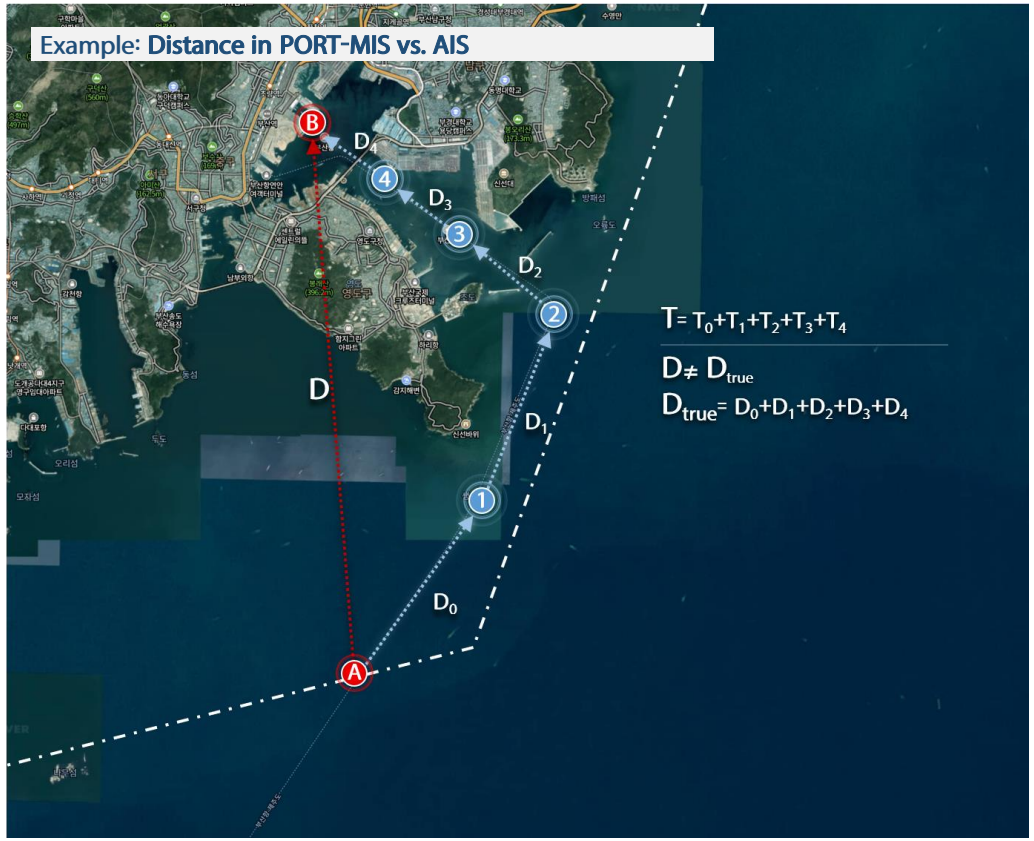


- AIS data reflect ship activity and **path(A-1-2-3-4-B) with a relatively dense time-space grid**
- The PORT-MIS data-based model classifies the operation time and operation type by the difference in the control time between two control communication points.

→ The straight section of A-B is recognized as **a speed slower than the actual speed**

Comparative analysis between 3 models and verification for accuracy improvements

■ Comparative analysis of Emission estimation results

Operation type: Cruising

[Result of estimating the emission per model (Cruising)]

(Unit: ton)

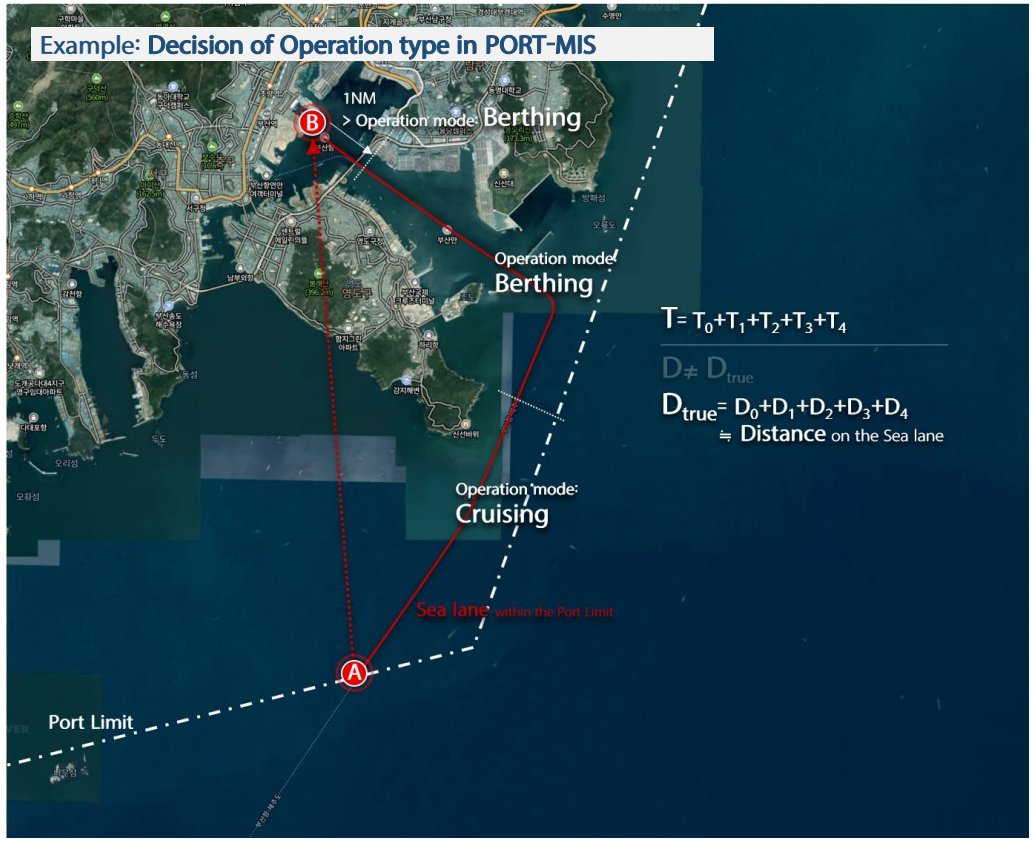
Classification	NOx	VOC	TSP	PM_{10}	$PM_{2.5}$	SOx	CO	NH_3
PORT-MIS activity-based bottom-up model	155.562	4.776	7.714	7.714	7.714	48.325	17.880	0.003
AIS activity- based bottom- up model	519.048	16.782	27.307	27.307	27.307	170.323	63.019	0.020
Diff. in PORT-MIS model Compared with AIS model	-70.0%	-71.5%	-71.8%	-71.8%	-71.8%	-71.6%	-71.6%	-85.0%

▪ Analysis

- Emission calculation results by the PORT-MIS data-based model were all **underestimated by around 70% compared** to the AIS data-based model.

→ Since the movement between control points is basically assumed as a straight line, **AIS data with a tighter interval between control points more accurately reflects the actual activity** of the ship

→ In the AIS model, if the ship's ground speed is more than 5 knots, it is classified as 'Cruising' according to the IMO standard; However, even though it was an actual 'cruising' movement, it is possible that it was classified as a 'berthing' type in the PORT-MIS model.



- In the PORT-MIS data-based model, dynamic information(location, speed) of a ship cannot be known, so 'moving in port' and 'berthing' are classified according to changes in communication facilities (control point).
- For movement within the port, the distance **within 1 nautical mile of the route is classified as 'berthing'**, and half of the other sections are classified as 'berthing' and the other half as 'cruising'.

Comparative analysis between 3 models and verification for accuracy improvements

■ Comparative analysis of Emission estimation results

Operation type: Cruising

[Result of estimating the emission per model (Cruising)]

(Unit: ton)

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- In the AIS data-based model, **based on the collected ground speed, the operation type is classified** as follows. Less than 3 knots are 'anchoring'
  More than 3 knots and less than 5 knots are 'berthing'
  More than 5 knots 'cruising'

Comparative analysis between 3 models and verification for accuracy improvements

■ Comparative analysis of Emission estimation results

Operation type: Cruising

[Result of estimating the emission per model (Cruising)]

(Unit: ton)

Classification	NOx	VOC	TSP	PM_{10}	$PM_{2.5}$	SOx	CO	NH_3
PORT-MIS activity-based bottom-up model	155.562	4.776	7.714	7.714	7.714	48.325	17.880	0.003
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  More than 3 knots and less than 5 knots are 'berthing'
  More than 5 knots 'cruising'

Comparative analysis between 3 models and verification for accuracy improvements

■ Comparative analysis of Emission estimation results

Operation type: Cruising

[Result of estimating the emission per model (Cruising)]

(Unit: ton)

Classification	NOx	VOC	TSP	PM_{10}	$PM_{2.5}$	SOx	CO	NH_3
PORT-MIS activity-based bottom-up model	155.562	4.776	7.714	7.714	7.714	48.325	17.880	0.003
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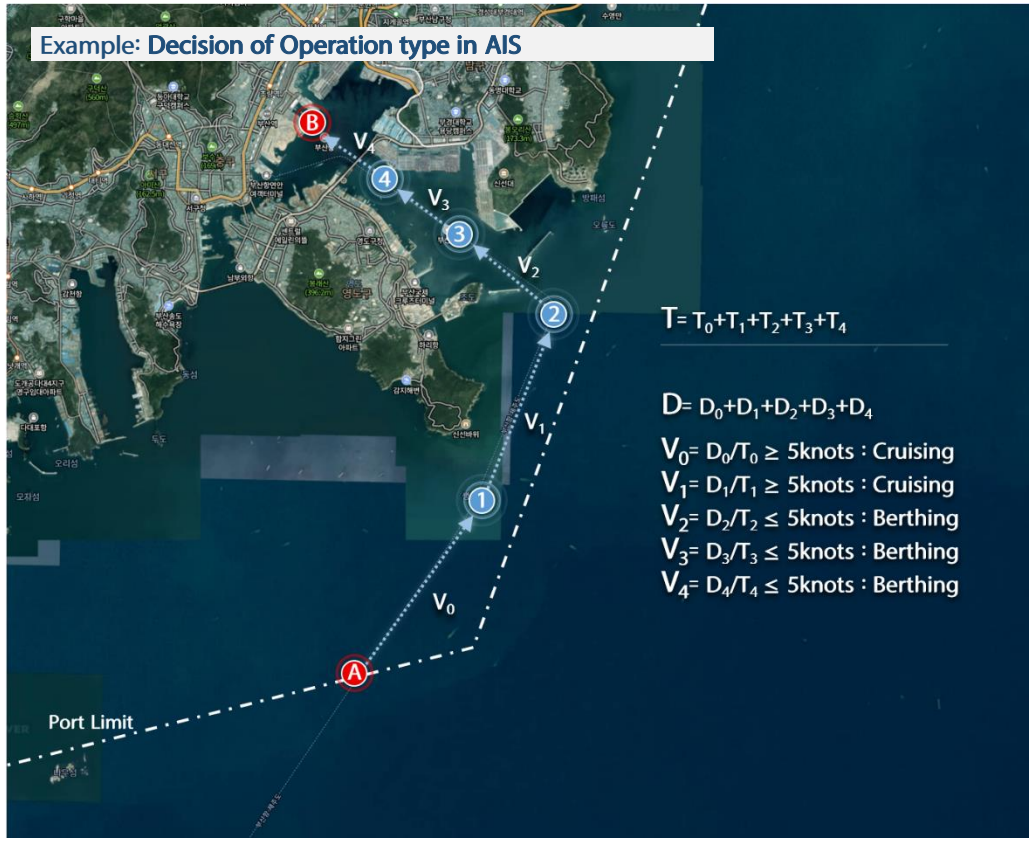

- In the AIS data-based model, **based on the collected ground speed, the operation type is classified** as follows. Less than 3 knots are 'anchoring'
  More than 3 knots and less than 5 knots are 'berthing'
  More than 5 knots 'cruising'

Comparative analysis between 3 models and verification for accuracy improvements

■ Comparative analysis of Emission estimation results

Operation type: Berthing

[Result of estimating the emission per model (Berthing)]

(Unit: ton)

Classification	NOx	VOC	TSP	PM_{10}	$PM_{2.5}$	SOx	CO	NH_3
Existing MOE methods (Manual Ⅳ)	111.203	3.786	8.694	8.694	7.853	28.046	10.377	0.010
PORT-MIS activity-based bottom-up model	178.495	18.563	29.979	29.979	29.973	68.979	25.003	0.012
AIS activity-based bottom-up model	75.906	7.883	12.756	12.756	12.751	30.166	10.781	0.006
Diff. in PORT-MIS model Compared with AIS model	+135.2%	+135.5%	+135.0%	+135.0%	+135.1%	+128.7%	+131.9%	+100.0%

- **Analysis**
  - Emission calculation results by the PORT-MIS data-based model were all **overestimated by 100 to 135% compared** to the AIS data-based model.
  → The actual activity in the form of 'Cruising' within the harbor might be classified and calculated as 'Berthing' in the PORT-MIS model.

Operation type: Anchoring

[Result of estimating the emission per model (Anchoring)]

(Unit: ton)

Classification	NOx	VOC	TSP	PM_{10}	$PM_{2.5}$	SOx	CO	NH_3
Existing MOE methods (Manual Ⅳ)	944.342	32.153	73.833	73.833	66.687	238.170	88.123	0.083
PORT-MIS activity-based bottom-up model	394.919	12.390	24.292	24.292	24.048	180.648	44.747	0.170
AIS activity-based bottom-up model	433.673	13.506	26.493	26.493	26.233	195.780	48.940	0.186
Diff. in MOE methods Compared with AIS model	+117.8%	+138.1%	+178.7%	+178.7%	+154.2%	+21.7%	+80.1%	-55.4%
Diff. in PORT-MIS model Compared with AIS model	-8.9%	-8.3%	-8.3%	-8.3%	-8.3%	-7.7%	-8.6%	-8.6%

- **Analysis**
  - In the case of applying the method of the MOE, **the same activity data**(average number of days at anchor and engine load factor) **is applied to all ships in the process of estimating fuel consumption during anchorage.**
  → The results of the calculation using the existing method of the MOE(Emission Calculation Method Manual IV) are **overwhelmingly large.**
  - Assuming that the calculation result by the AIS data-based model is very close to the true value, the emission at 'Anchoring' by the existing method is **overestimated by around 55~179% compared** to the result of the bottom-up model using Port-MIS and AIS data.
  (In the case of NH3, it is underestimated by 55.4%)

Thank you

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Email

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