한국방재학회논문집
제9권 1호 2009년 2월
pp. 73 ~ 79

Estimation of Sodium Hydroxide Waste Origin-Destination Matrices for Preventing Hazardous Material Transportation Disasters

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Abstract

Hazardous materials (HazMats) are substances that are flammable, explosive, toxic, or harmful, if released into the environment. Since the transportation of HazMats increases in many developed countries, HazMat transportation has the key function in the process of HazMat usage to trace information of production, storage, shipment, usage, and waste disposal. The Korean Ministry of Environment (KMOE) and the National Emergency Management Agency (NEMA) have developed many laws, regulations, and standards for hazardous materials. However, the Korean HazMat laws, regulations, and standards do not guarantee accurate information of HazMat origin-destination (O-D) shipments, though the HazMat O-D movement is the critical information in safety and security of HazMat transportation. The objectives of this research are: (1) to investigate emerging and recurrent issues in Korean HazMat transportation, and (2) to develop the estimation method of O-D matrices for hazardous materials under limited data sets. The sodium hydroxide waste shipment among forty candidate HazMats is selected as the sample research case. The growth-factor method is applied to estimate the 2005 O-D matrix of sodium-hydroxide waste shipment. The column-and-row factoring process is used to calibrate the estimated sodium-hydroxide O-D matrix. The result shows the applicability of the O-D estimation process for hazardous materials. The Sodium Hydroxide Waste Origin-Destination Matrix is obtained to trace routes and paths of the Sodium Hydroxide transportation.

Key words **:** Hazardous material transport, Origin-destination matrix, Sodium hydroxide waste, Regional freight movement, Growth-factor method, Column-and-row factoring process

요 지

유해물질은 만일 누출된다면 화재 · 폭발 · 독성 및 위해성이 있는 물질을 말한다. 많은 선진국에서 유해물질의 수송이 증가하고 있기 때문에 유해물질의 생산 · 저장 · 수송 · 사용 및 폐기에 대한 정확한 정보는 매우 중요하다. 유해물질의 수송은 유해물질의 사용과정에서 핵심적인 기능이라고 말할 수 있다. 정부는 유해물질에 대해 많은 법령과 규제, 기준들을 개발해 왔다. 그러나 한국의 법령, 규제, 기준들은 비록 유해물질의 이동이 유해물질 수송에 대한 안전과 방재차원에서 중요한 정보임에도 불구하고, 유해물질의 O-D수송에 대한 정확한 정보를 보장하고 있지 못한 실정이다. 본 연구의 목적은 한국의 유해물질 수송에 대해 새롭게 대두되거나 기존에 제기된 이슈들을 조사하고, 제한된 자료를 가진 상황에서 유해물질에 대한 O-D매트릭스를 예측하는 기법을 개발하는 것이다. 본 연구는 유해물질 수송사례에 대한 40개의 후보군 중에서 수산화나트륨 폐기물에 대한 수송이 사례연구로 선정하였다. 성장률법이 수산화나트륨 폐기물 수송의 2005년 O-D매트릭스를 추정하는데 적용되었다. 행렬보정기법이 추정된 수산화나트륨 O-D매트릭스를 보정하는데 사용되었다. 본 연구는 유해물질에 대한 O-D추정기법의 적용가능성을 제시하였다. 본 연구를 통해 도출된 수산화나트륨 폐기물 O-D 매트릭스는 수산화나트륨 수송의 수송로와 수송구간을 추적하는데 사용되어 진다.

핵심용어 : 유해물질 수송, O-D매트릭스, 수산화나트륨 폐기물, 지역화물이동, 성장률법, 행렬보정기법

1. Introduction

The shipment record of hazardous materials in transportation is critical information to the safety and security of our daily activities and freight movements. Hazardous materials are materials and/or substances that are flammable, explosive, or toxic or have other properties that would threaten human life, activity, health, the environment, or property if released or leaked. The U.S. Department of Transportation (U.S. DOT) regulates more than fifteen percent of the freight tonnage moved in the U.S. as HazMats under Hazardous Materials Regulations (Title 49 CFR Part 100-185). The HazMat shipments tend to increase as the

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national economy is advanced. Thus, it is very important to have accurate information in all stages of HazMat treatment process including production, storage, shipment, usage, and waste disposal.

Ensuring safety and security in HazMat transportation is necessary because many of these HazMats are vital to commerce and the daily activities in Korea. Therefore, the Korean Ministry of Environment (KMOE) and the National Emergency Management Agency (NEMA) have developed many laws, regulations, and standards for hazardous materials. However, the Korean HazMat laws, regulations, and standards do not guarantee accurate information of HazMat origin-destination (O-D) shipments, though the HazMat O-D movement is the critical information in safety and security of HazMat transportation. All parties responsible for the HazMat transportation require O-D information to support their decisions in government or business policies (TRB, 2005): Which routes, departure times and modes of transportation are safest, most secure, and pose the least risk to the environment? Which HazMats are suitable for which type of packaging? Which emergency management is most prudent given the nature of HazMats passing through our transportation systems? Which shipments merit extra security attention? Different HazMat types and sizes, origins and destinations, transportation modes and carriers, and shipment routes and times affect costs and risks of our transportation systems.

The objectives of this research are: (1) to investigate emerging and recurrent issues in Korean HazMat transportation, and (2) to develop the estimation method of O-D matrices for hazardous materials under limited data sets. The sodium hydroxide waste shipment among forty candidate HazMats is selected as the sample research case.

2. Mounting Needs for HazMat Transportation

2.1 HazMat Transportation

Hazardous materials in transportation include petroleum products such as gasoline, industrial and agricultural chemicals including pesticides, fertilizers, compressed gases or acids, explosives, wastes, and radioactive materials. U.S. DOT has identified more than 4,100 materials subject to regulation. KMOE defines 16 categories and 534 types of materials. NEMA identifies six categories and 64 types of materials. The Korean Ministry of Labor (KMOL) indicates sixteen categories and 698 types of materials. In addition, thousands of unnamed materials are annually introduced worldwide.

The information of only total HazMat tonnage outcome from regional administrations during the period of 1999 to 2006 is available in Korea. The total HazMat outcome of Korea is 324.0 thousand tons in 2004, and 331 thousand tons in 2005, representing 2.2 percent increase. According to U.S. DOT, about 817,000 shipments consisting of 5.4 million tons of HazMat are made daily in U.S., which would total nearly 300 million shipments and 2 billion tons of HazMat cargo per year. Each shipment is suspected to deliver approximately 6.61 tons of HazMats in average. This is equivalent to about 18 percent of total freight shipped at that time. The HazMat shipped in U.S. by mode during the period of 1997 to 1998 is shown in Table 1.

2.2 Shipment Types and Sizes: Trip Generation

HazMats are carried out as bulk package, parcels, or pipelines. The bulk package requires tank trucks, railroad tank cars, barge tankers, or intermodal tanks. Tank trucks deliver between 2,000 and 10,000 gallons. Railroad tank cars carry out between 10,000 and 34,500 gallons. Barge tankers hold several hundred thousand gallons. Intermodal tank containers deliver up to 6,500 gallons. Many potable tanks, bins, and drums carry out 119 gallons or 1,000 pounds of HazMat liquids and solids. Boxes, drums, cylinders, and other smaller containers are also used for small sizes of shipments.

2.3 Origins and Destinations: Trip Distribution

There is insufficient information for origins and destinations in Korean HazMat transportation. Korea has only shipment information of HazMat origins in sixteen regional administrations. U.S. has more detailed information for HazMat shipments, comparing with Korea. According to the U.S. Department of Commerce's Commodity flow Survey, more than 14,000 firms are identified as the manufacturers of HazMats (U.S. Census Bureau 2003; RSPA 2003). About 45,000 firms regularly send significant quantities of HazMats, and additional 30,000 companies occasionally ship HazMats (RSPA 2003). Oil refiners, chemical manufacturers, and gasoline distributors are performing shippers of large HazMat quantities. Gasoline stations and retailers, farms, filling stations, hospitals, paint stores, small manufacturers, and waste disposal companies are shippers of small HazMat quantities.

2.4 HazMat Carriers: Mode Choice

There are two types of carriers in HazMat transportation: specialized and occasional carriers. Specialized carriers include specialized tank truck operators, cargo trains in railroads, barge operators, and shipping lines that regularly move products with fixed schedules and routes, dedicated equipments and services,

Table 1. HazMats Shipped in U.S. by Mode during the Period of 1997～1998

Mode	Daily Shipments	Tons Shipped Daily	Ton-Miles Shipped Daily (millions)	Average Shipment Size (tons)	Percentage of Total Daily Shipments	Percentage of Tons Shipped Daily	Percentage of Ton-Miles Shipped
Truck	768,907	3,709,180	205	4.82	94	69	34
Rail	4,315	378,916	205	87.81	1	7	34
Water	335	1,272,925	187	3,799	0	24	31
Air	43,750	4,049	0.26	0.09	5	0	<0.01
Total	817,307	5,365,070	597	6.56	100	100	100

Source: RSPA 1998; Census Bureau 1999, Table 1, recited from TRB (2005).

and well-trained operators and interconnected monitoring centers. Occasional or periodic carriers would consider all kinds of transportation modes. On average, cargo trucks in roadways carry out the largest number of shipments. Ships or barges in waterways deliver the heaviest shipments. Railroads take care of shipments over the longest distances. Airlines move the most expensive shipments.

2.5 HazMat Shipment Routing and Times: Trip Assignment

HazMat carriers pass through several routes between origins and destinations with the combination of expressways, highways, arterials, and local roads. HazMat carriers may select the departure time HazMat shipment leaves its place of origin, and probably the arrival time at its final destination. HazMat carriers determine the duration of HazMat shipments and break times at transfer points.

2.6 Other Issues

Contemporary HazMat transportation considers other issues such as HazMat incident analysis and risk management, intermodal cooperation among HazMat transport modes, new technologies of HazMat-ITS or ubiquitous-HazMat management, and roles of public and private sectors in HazMat transportation.

3. Baseline Research for HazMat Production and Waste Movement

3.1 HazMat Production

Determining origin and destination demands is the first stage for estimating O-D matrices for HazMats. This research uses the 『2005 Chemical Production & Discharge (CPD) Survey Report』 published by KMOE. This CPD survey considers the total amounts of production and discharge of 223 chemicals collected from 2,741 sites of 32 business types. The geographical distribution of business sites and chemicals is provided in Table 2. The Kyonggi province surrounding the Seoul Metropolitan city dominates other regional administrations in terms of business site, chemicals, and ratio (business site per chemical). The traditionally industrial regions such as Daegu, Incheon, Kyongbuk, and Kyongnam have the large numbers of business site and ratio. Ulsan and Chungbuk are exceptional regions. As the representative industrial region of Korea, Ulsan's lower ratio is interpreted that Ulsan's business sites are matched with specifically designated chemicals. The Chungbuk region is suspected to have spill-over effects from the Seoul Metropolitan region.

The total production & use tonnage by industry in 2004 and 2005 is provided in Table 3. The total production & use tonnage of 223 chemicals at 2,741 business sites is 112,678 thousand tons in 2005. This number is 0.5 percent (510 thousand tons) smaller than the total tonnage of 113,188 thousand in 2004 because the total number of business sites is decreased by 151. The chemicals & chemical manufacturing dominates other industries with the share of about sixty-five percent. The top three industries occupy 91.9 percent of total production & use tonnage.

The total tonnages of top twenty chemicals in 2004 and 2005 are presented in Table 4. Xylene is the only chemical with the share of over ten percent in total. Six materials out of top ten chemicals are in increasing trend. Thirteen materials among the

Table 2. Geographical Distribution of Business Sites and Chemicals

Administ.	Busi. Site	Chem.	Ratio	Administ.	Busi. Site	Chem.	Ratio
Seoul	36	28	1.29	Kwangwon	36	28	1.29
Busan	148	65	2.28	Chungbuk	155	70	2.21
Daegu	219	67	3.27	Chungnam	178	109	1.63
Incheon	192	93	2.07	Jeonbuk	138	110	1.26
Kwangju	47	42	1.12	Jeonnam	90	107	0.84
Daejeon	63	55	1.15	Kyongbuk	255	93	2.74
Ulsan	166	131	1.27	Kyongnam	305	87	3.51
Kyonggi	709	154	4.60	Jeju	4	3	1.33
Total	2,741	223	12.29	※ The ratio average of 16 regions is 1.99.			

Table 3. Total Production & Use Tonnage by Industry in 2004 and 2005 (Unit: tons)

Industrial Classification		2004	2005	Trend
1	Chemicals & Chemical Manufacturing	74,020(65.4%)	73,085(64.9%)	↓
2	Coal, Petrolium and Nuclear Manufacturing	20,174(17.8%)	20,804(18.5%)	↑
3	1st Metal Industry	10,001(8.8%)	9,626(8.5%)	↓
4	Rubber & Plastic Manufacturing	1,986(1.8%)	2,019(1.8%)	↑
5	Travel, Warehouse & Transport Service	1,670(1.5%)	1,649(1.5%)	↓
6	Surface & Pipeline Transport	1,421(1.3%)	1,500(1.3%)	↑
7	Electric & Transformation Machinery	987(0.9%)	959(0.8%)	↓
-	Miscellaneous	2,929(2.5%)	3,036(2.7%)	↑
Total		113,188(100.0%)	112,678(100.0%)	↓

top twenty chemicals are in increasing trend. This trend explains that the significance of HazMat problems would grow up as the economy of Korea is advanced. The top twenty chemicals have the share of 77.8% in total production & use.

3.2 HazMat Waste Movement

Produced & used hazardous materials are shipped for waste disposal. 189 types of chemicals out of 223 chemicals are moved to waste disposal firms as HazMat wastes. The total tonnage of the wasted chemicals is 331 thousand tons in 2005, sharing 0.29 percent of the total production & use tonnage. Table 5 provides the total number of waste shipments, the total number of chemicals for waste movement, and the chemical with the largest amount of waste shipments in 2004 and 2005. Sodium-hydroxide is identified as the largest amount of chemical in terms of liquid waste movement in both years. Aluminum and aluminum compound are selected as the largest amount of chemical in solid waste movement in 2005, whereas zinc and zinc compound are the one in 2004. About 83.8 percent is treated by solid waste disposal firms in 2005. The share of liquid waste treatment firms is 16.2 percent in the same year. The total number of moved chemicals increased from 2004 to 2005 in both liquid and solid wastes. The total shipments by regional administration are shown in Table 6.

4. Case Study: O-D Estimation for Sodium Hydroxide Waste

4.1 Brief Description for Sodium Hydroxide

In doing this case study, we have chosen to select the sodium hydroxide as the sample research case, for several reasons. First, sodium hydroxide is the top liquid chemical in terms of waste shipment tonnage in 2004 and 2005. Liquid waste is usually more dangerous than solid, if released. Second, sodium hydrox-

Table 4. The Change of Total Production & Use Tonnage by Chemicals in 2004 and 2005 (Unit: tons, %)

Order	Materials	2004	2005	Trend
1	Xylene	11,985(10.6)	12,104(10.7)	↑
2	Ethylene	9,192(8.1)	9,518(8.4)	↑
3	Benzene	8,469(7.5)	8,882(7.9)	↑
4	Propylene	6,554(5.8)	7,135(6.3)	↑
5	Naphthalene	6,051(5.3)	6,294(5.6)	↑
6	Sulfuric acid	5,725(5.1)	5,644(5.0)	↓
7	Styrene	5,325(4.7)	4,787(4.3)	↓
8	Toluene	4,384(3.9)	4,216(3.7)	↓
9	Ethylbenzene	3,738(3.3)	3,721(3.3)	↓
10	Butadiene	2,629(2.3)	3,028(2.7)	↑
11	Vinylidene chloride	2,733(2.4)	2,890(2.6)	↑
12	Sodium hydroxide	2,828(2.5)	2,586(2.3)	↓
13	Copper and copper-compound	3,155(2.8)	2,570(2.3)	↓
14	Sulfur	2,110(1.9)	2,538(2.3)	↑
15	Ammonia	2,256(2.0)	2,296(2.0)	↑
16	n-hexane	2,052(1.8)	2,060(1.8)	↑
17	1,3-butadiene	1,914(1.7)	1,948(1.7)	↑
18	N,N-dimethyl formamide	1,511(1.3)	1,904(1.7)	↑
19	Hydrogen chloride	1,863(1.6)	1,864(1.7)	↑
20	Chloric acid	1,810(1.6)	1,712(1.5)	↓
-	Others	26,904(23.8)	24,981(22.2)	↓
-	Sum	113,188(100.0)	112,678(100.0)	↓

Table 5. Shipment, Chemical Type, and the Representative Chemical of Liquid & Solid Waste

Shipment	Year	Liquid Waste Movement	Solid Waste Movement
Quantity of Shipment (tons)	2004	55,656(17.2%)	268,330(82.8%)
	2005	53,806(16.2%)	277,319(83.8%)
# of Chemicals	2004	113	172
	2005	117	183
Representative Chemical (tons)	2004	Sodium hydroxide (37,670)	Zinc and compound (27,234)
	2005	Sodium hydroxide (33,809)	Aluminum and compound (49,636)

Table 6. Liquid and Solid Waste Movement by Regional Administration in 2005

(Unit: tons)

Order	Administration	Liquid Waste Shipment	Solid Waste Shipment	Quantity of Shipment
1	Kyonggi	8,702,131	75,995,736	84,697,367
2	Kyongbuk	1,078,904	47,233,410	48,312,314
3	Daegu	31,147,547	4,642,499	35,790,046
4	Ulsan	46,371	31,738,373	31,784,743
5	Chungnam	3,115,044	19,218,192	22,333,236
6	Jeonnam	112,762	19,630,822	19,743,584
7	Kyongnam	535,559	18,178,038	18,713,597
8	Chungbuk	3,842,346	12,417,988	16,260,333
9	Busan	3,251,240	11,729,085	14,980,324
10	Jeonbuk	401,392	13,370,787	13,772,179
11	Incheon	1,228,664	10,678,169	11,906,832
12	Kangwon	145,796	6,950,991	7,096,787
13	Daejeon	130,290	3,310,963	3,441,253
14	Kwangju	23,734	1,535,482	1,559,216
15	Seoul	43,955	646,866	690,822
16	Jeju	0	42,262	42,262
Sum		53,805,733	277,319,163	331,124,895

ide is the 11th chemical in 2004 and 12th in 2005 in terms of total production & use tonnage. Thus, the safety problem of sodium hydroxide shipment is prominent and persistent. Third, sodium hydroxide is the 10th chemical in hazardous material incidents of Korea by the Emergency Information Service Database of the Chemical Emergency Information Center, Inje University (Kim and Moore, 2008). According to Kim and Moore (2008), sodium-hydroxide shares 1.61 percent of total HazMat incidents of Korea. Thus, the safety issue of sodium-hydroxide waste shipments cannot be ignored based on the relatively high risk of sodium-hydroxide movement.

According to Wikipedia, sodium hydroxide (NaOH) is a white solid, and a strong alkaline solution when dissolved in a solvent such as water. It is known as lye, and caustic soda. Sodium hydroxide is used in many industries, mostly as a strong chemical base in the manufacture of pulp and paper, textiles, drinking water, soaps and detergents and as a drain cleaner. Worldwide production in 1998 was around 45 million tons. It is deliquescent and readily absorbs carbon dioxide from the air, so it should be stored in an airtight container. It is very soluble in water with liberation of heat. It also dissolves in ethanol and methanol, though it exhibits lower solubility in these solvents than potassium hydroxide. A sodium hydroxide solution will leave a yellow stain on fabric and paper.

U.S.DOT treats sodium hydroxide as one of the important hazardous materials by designating an identification number (ID No. 1823) and a guide number (Guide No. 154). According to the Emergency Response Guide (2004) published by U.S. DOT, sodium hydroxide is toxic. Inhalation, ingestion, or skin contact with sodium hydroxide may cause severe injury or death. And, contact with molten sodium hydroxide may cause severe burns to skin and eyes. Fire may produce irritating, corrosive and/or toxic gases. Runoff from fire control or dilution water may be corrosive and/or toxic and cause pollution. Sodium hydroxide itself does not burn, but may decompose upon heating to produce corrosive and/or toxic fumes. Contact with metals may evolve flammable hydrogen gas. Containers may explode when heated. Consequently, any skin contact should be avoided.

Sodium hydroxide shipments should be very carefully monitored. If released during transport, emergency responders such as fire fighters, policemen, or road maintenance service men should isolate spill or leak areas immediately for at least 25 to 50 meters in all directions. If tank, rail car or tank truck is involved in a fire, emergency responders must isolate for 800 meters in all directions. Initial evacuation for 800 meters in all directions is highly recommended. Water inside containers should not be touched unless wearing appropriate protective clothing. Emergency responders must prevent entry into waterways, sewers, basements or confined areas.

The Korean Ministry of Environment assigned CAS number 1310-73-2 to sodium hydroxide. United Nation provides an identification number of UN1824 for liquid, and that of UN1823 for solid. Sodium hydroxide also gets International Maritime Dangerous Goods (IMDG) Class 9 Level II and III for liquid, IMDG class 8 Level II for solid, International Civil Aviation Organization (ICAO) / International Air Transport Association (IATA) Class 8 Level II PAT809 Y809 CAO813 and Level III PAT819 Y819 CAO821 for liquid, and ICAO/IATA Class 8 Level II and Level III PAT814 Y814 CAO8163 for solid. Many Korean chemical companies such as LG Chem, Samsung Fine Chemicals, Hanwha Chemical, and DC Chemical produce sodium hydroxide as the leading business firms.

4.2 O-D Estimation for the Sodium Hydroxide Waste Case

There are a significant number of researchers who performed HazMat O-D related studies. Smith (1989) introduces computer-assisted hazardous material shipping that can be used for creating HazMat O-D matrices. Frank (2000) provides the working spatial decision support system (SDSS) for hazardous material trucking routing by using a desktop personal computer. Smith (2006) develops a preliminary system design for a national hazardous material truck tracking system. Others include Mirchandani, et. al. (1995), Gordon, et. al. (1999), Ellena, et. al. (2004), and Benze, et. al. (2007). There is no monitoring system supporting HazMat O-D generation. Thus, this research uses the growth-factor method and the column-and-row factoring method explained by Dickey (1983).

This research develops a stepwise procedure for estimating origin-destination matrices for hazardous materials with limited data sets. The conceptual framework for estimating an O-D matrix for the sodium hydroxide case is presented in Fig. 1. This procedure is composed of four steps: (1) estimation of total origin demands in regions, (2) isolation of target material quantities in production and shipment, (3) application of growth-factor method for an initial O-D matrix, and (4) calibration of the initial O-D matrix using column-and-row factoring method.

In the first step, we estimate total origin demands of sixteen

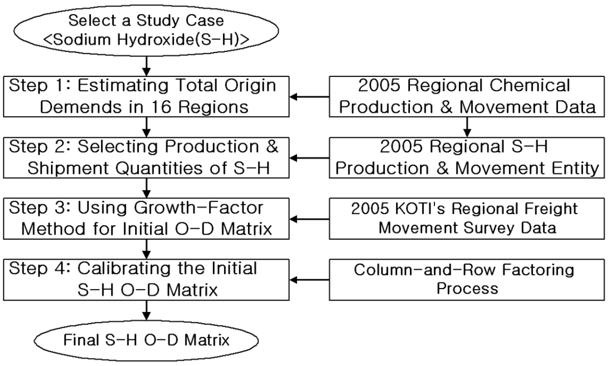

Fig. 1 Conceptual Framework for Estimating an O-D Matrix for Sodium Hydroxide

regions from the 『2005 Regional Chemical Production & Movement Date』 provided by KMOE. Regional production and shipment quantities of sodium hydroxide are selected from the total origin demands in the second step. Korea Transport Institute (KOTI) provides 34 origin-destination matrices of freight trucks and carriers from the 『2005 Inter-Regional Freight Movement Survey Data』. We uses "Freight O-D 19: chemicals and chemical products" O-D matrix as the baseline O-D matrix for HazMat O-D estimation. We compute element ratios of freight origin-destination matrix using the "chemicals and chemical products" O-D matrix of the 『2005 Inter-Regional Freight Movement Survey Data』. The initial sodium hydroxide O-D matrix with 16 × 16 cells is obtained by applying the element

Table 7. Estimated 2005 Sodium Hydroxide Origin-Destination Matrix (Unit: kg/year)

O-D	Seoul	Busan	Daegu	Incheon	Kwangju	Daejeon	Ulsan	Kyonggi	Kwangwon	Chungbuk	Chungnam
Seoul	3,125	28	39	516	30	103	79	2,342	163	201	649
Busan	38,492	512,763	35,593	565	5,617	1,672	563,507	16,727	969	2,628	7,812
Daegu	113,753	2,394,161	6,946,263	23,641	253,250	306,926	6,870,887	162,494	89,297	251,370	455,089
Incheon	12,025	144	172	15,031	124	914	325	13,915	534	1,659	2,782
Kwangju	37	223	108	10	3,081	87	360	56	5	44	317
Daejeon	15,579	5,691	15,815	2,904	10,456	52,532	16,241	23,482	3,382	26,655	44,552
Ulsan	325	913	215	25	18	50	15,606	442	19	39	50
Kyonggi	964,251	12,865	23,056	208,425	18,872	69,793	36,812	1,177,362	67,877	121,763	360,949
Kangwon	7,645	669	1,140	1,084	193	1,036	2,520	7,880	11,287	3,089	2,759
Chungbuk	150,824	22,074	51,962	24,952	20,806	105,484	57,110	214,709	49,268	175,297	185,426
Chungnam	8,223	649	1,420	1,870	1,800	4,524	1,734	12,407	876	4,663	74,070
Jeonbuk	19,809	4,610	4,802	1,103	20,351	14,537	6,733	8,972	772	6,201	32,271
Jeonnam	166	1,101	2,084	48	2,079	155	696	6,343	28	139	413
Kyongbuk	47,882	284,554	546,697	8,271	29,208	69,107	968,026	66,254	66,637	88,087	84,500
Kyongnam	183	16,859	4,168	51	1,005	332	23,368	287	89	265	782
Jeju	0	0	0	0	0	0	0	0	0	0	0
Sum	1,382,318	3,257,304	7,633,537	288,497	366,891	627,252	8,564,003	1,713,671	291,202	682,098	1,252,422

Table 7. Continued (Unit: kg/year)

O-D	Jeonbuk	Jeonnam	Kyongbuk	Kyongnam	Jeju	Sum
Seoul	130	232	126	24	0	7,788
Busan	5,545	171,693	60,602	173,440	0	1,597,624
Daegu	399,705	3,340,948	5,043,758	2,919,775	0	29,571,317
Incheon	606	615	652	123	0	49,624
Kwangju	777	8,464	112	349	0	14,030
Daejeon	44,789	48,552	29,159	11,699	0	351,488
Ulsan	94	170	771	439	0	19,176
Kyonggi	100,792	127,873	73,932	14,997	0	3,379,617
Kangwon	838	1,185	5,759	550	0	47,633
Chungbuk	88,712	105,035	145,848	29,768	0	1,427,275
Chungnam	7,520	7,271	2,931	1,154	0	131,110
Jeonbuk	86,107	104,386	7,567	8,380	0	326,600
Jeonnam	890	59,109	1,499	1,489	0	76,239
Kyongbuk	68,131	307,799	1,188,061	263,154	0	4,086,367
Kyongnam	985	23,939	4,049	16,193	0	92,555
Jeju	0	0	0	0	40,483	40,483
Sum	805,620	4,307,272	6,564,824	3,441,532	40,483	41,218,926

ratios to the production and movement quantities of sodium hydroxide using the growth-factor method in step 3. We finally calibrate the initial sodium hydroxide O-D matrix by applying the column-and-row factoring process in step 4. Table 7 presents the estimated sodium hydroxide O-D matrix in this research.

5. Conclusion

Hazardous material is any chemical that, if released into the environment, could be potentially harmful to the public's health or welfare. The shipment information of hazardous materials in transportation, especially origin-destination matrices, is critical to the safety and security of our daily activities and further national economy. This research explains emerging and recurrent issues such as shipment types and sizes, origins and destinations, carriers, shipment routing and times, risk management, intermodal cooperation, new technologies, and public and private roles in Korean HazMat transportation. The stepwise procedure is introduced for estimating 16×16 regional O-D matrices for HazMats. The applicability of the stepwise procedure is evaluated by estimating the 2005 sodium hydroxide O-D matrix. The 2005 sodium hydroxide O-D result of this research has many potential in studies of hazardous material transportation. It can be used to trace routes and paths of the sodium hydroxide transportation. Thus, we can develop many transportation disaster policies to prevent hazardous material incidents and reduce the disaster damage caused by the hazardous material incidents. The stepwise procedure of this research can produce other hazardous material O-D matrices that are used to make our society more safe and secure from the hazardous material incidents.

Further studies are suggested in applying other O-D estimation methods including gravity models. Trip generation, mode choice, and network assignment need to be analyzed for hazardous material shipments. Geographical distribution patterns of HazMat production and shipment need to be studied using statistical and GIS methods. Other hazardous materials are also recommended to be investigated for the safety and security of Korean HazMat freight movement.

Acknowledgments

This study is performed under the support of "Part IV: Technology Development of u-Transportation Operation Management" of "the 2007 National Transportation Technology Development Project (T406A1010001-06A010100510)" sponsored by the Ministry of Land Transport and Maritime Affairs.

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◎ 논문접수일 : 09년 1월 28일
◎ 심사의뢰일 : 09년 2월 4일
◎ 심사완료일 : 09년 2월 13일