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# Development of COI classification algorithm for chemical terrorism

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**Abstract**−This study focused on a novel approach for classifying hazardous chemicals to be used for chemical terrorism. We developed a novel algorithm to classify nationally customized chemicals of interest (COI) out of 325 COI in USA. The proposed COI classification algorithm aims to identify a key set of factors that reflect nation-wide uniqueness: intentional use, objectives, toxicity, related laws (CWC, ITF-25, CAA, etc.) and responsive counter-actions to terrorism. Although the U.S. has managed 325 COI to prevent terrorism, there are some nations in which the management and control of all the hazardous chemicals are beyond their capability. Based upon the outcome of this study the Ministry of the Environment of Korea has made appropriate revisions on relevant law. As a result, the Korean government has officially added a new set of 13 chemical species to the list of existing hazardous chemicals. This work is worthwhile to contribute to protecting the people's lives and property from possible chemical accidents including terror by chemicals.

Key words: Chemicals of Interest, Chemical Terrorism, Classification Algorithm, Hazardous Chemicals

## INTRODUCTION

### 1. Global Terrorism for Chemical Plants

International terrorism has become a serious concern in the modern world [1]. Prior to September 11, 2001 when terrorists attacked the World Trade Center in New York City, the risk assessment of chemical process industries (CPI) handling hazardous chemicals had focused on the analysis of risks related to technological accidents and natural disasters (unintentional acts). Deliberate acts by terrorists or disgruntled employees were not included in formal risk assessment. The events of 9/11 changed the scene dramatically [2].

The security of hazardous sites has now become a major concern to the CPI. Chemical plants like oil refineries, fertilizer plants, petrochemical plants, etc., that handle hazardous chemicals are prime targets for terrorists and criminals. Not only does the CPI store and transport hazardous chemicals in bulk, but the operating processes also take place under extreme conditions, with fast flowing chemicals and complex kinetics. Terrorists with sufficient knowledge of the chemical operations and layout of the plant may exploit these conditions, which may then lead to the release of toxins, fires and explosions, resulting in the loss of life both on- and off-site [3].

Hazardous chemicals that have serious effects on the environment, human life and the economy are likely to leak to the surrounding environment when fires and explosions occur. In advanced countries like the USA, management standards are well set up to be able to control hazardous chemicals and facilities according to their toxicity and processes. The purpose of these management standards is to ensure the safety of the country and to preserve people's lives and property by stipulating management standards regarding terrorism, terrorism prevention, rescue operations, and so on. These management standards make it possible to quickly respond to terrorism.

### 2. Management of Security System for Chemical Plants

Management standards related to hazardous chemicals in the USA comprise guidelines of the Center for Chemical Process Safety (CCPS), the Toxic Chemicals Control Act (TSCA), the Occupational Safety and Health Act (OSHA), Clean Air Act (CAA, established by EPA) and so on. In OSHA, Process Safety Management (PSM) has been added to manage hazardous chemicals. Process security management especially addresses any threats from terrorists and criminal acts against plants that may result in the release of hazardous chemicals [4]. Recent events have emphasized the need for such programs, and both government and industry take appropriate actions to remedy current shortfalls in process security [5-8].

Policies, procedures, instructions and documentation to manage process security for an organization must be implemented (e.g., policies for screening pre-employment and controlling accessibility; procedures for reporting incidents and threats and for responding to bomb threats and suspicious packages).

Accidental and natural events are addressed by the PSM and Risk Management Plan (RMP) required by government regulations, which are already adopted by many countries (e.g., OSHA PSM and EPA RMP) [9-11]. The OSHA of the USA was first declared as a federal level regulation. This became a starting point from which special laws were established to prevent major industrial accidents in the USA, and the PSM regulations were enacted in November, 1992. OSHA's PSM standard, 29 CFR 1910.119 [11] was promulgated in 1992 and EPA's RMP rule, 40 CFR Part 68 [12] became effective in 1999. In January 1995, Korea developed a PSM regulation

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system for preventing major industrial accidents with the amendments of Industrial Safety and Health Act, and then it was legalized in January 1st, 1996 [9].

**3. Management of Chemicals in Risk of Diversion for Terrorism**

Terrorism can be classified into hard target and soft target terrorism. Hard target is guarded under considerable security so that a terrorist attack leads to running a high risk of being intercepted with potentially lethal forces. Examples of hard targets are military bases, political organizations and high ranking politicians and heads of state such as presidents. A soft target is of little or no military protection or security and hence is an easy option for a terrorist attack. These include commercial shopping centers, power stations, chemical facilities and leisure facilities such as football grounds and sports stadiums.

Nowadays, terror targets are changing from hard to soft targets. In advanced countries, hazardous chemicals and their facilities are controlled by special management regulations that are flexible enough to vary per the characteristics of each chemical. Although Korea has regulations for managing chemical facilities, the applicability of the currently available regulations to the hazardous chemicals and processes is not effective in managing accidents involving hazardous chemicals or their release to the environment. To solve this problem, it is important to manage each chemical in accordance with its own characteristics. This work aims to develop a novel algorithm for classifying COI appropriate to Korea.

## RISK CHARACTERISTICS OF CHEMICALS

Risk characteristics have been classified by Global Harmonized System (GHS) and other Korean regulations such as Industrial Safety and Health Law (Ministry of Labour) and Management Law for Harmful Chemicals (Ministry of Environment). In this paper, the classification of risk characteristics is based on the National Fire Protection Association (NFPA) standard of the USA: fire and explosion, environment and human effect. The standard is established with an aim to identify hazardous chemicals and analyze probability of an accident and type of danger posed by hazardous chemicals. It is being globally used to identify risks posed by chemicals. The hazard identification system (e.g., a diamond-shaped table) is helpful when figuring out the inherent dangers of each chemical and when evaluating risks of emergency such as a leakage of hazardous chemical or fire. A risk identification standard for fire by hazardous chemicals can be divided into five grades, based on the categories of NFPA: highly flammable, high ignition, low ignition, caution and non-flammable. The identification standard for fire hazards used by the NFPA is briefly described in NFPA 921 [13]. The explosive characteristics of hazardous chemicals are classified in the above manner.

In this way, an analysis of explosion characteristics of hazardous chemicals is performed. The identification standard of explosion hazard in NFPA is briefly described in NFPA 921 [13]. Hazard class can be divided into five codes, such as very lethal, very explosive, explosive, attentive and not explosive.

Information on persistence and bio-concentration factor (BCF) of chemicals is provided by certified agencies such as EPA, NFPA and EU [14,15]. An assessment criterion on Persistence, bioaccumulation and toxicity (PBT) is based on the principle of Registration, Evaluation, Authorization and restriction of CHemicals (REACH) system certified by EU. Half-life data measured at medium is used to evaluate persistence of chemicals. A chemical would be assessed as being of persistence if a half-life of one of chemicals at medium is measured higher than its designated value. If BCF of a chemical is higher than 2,000, it would be assessed as being bio-accumulative. The log Kow is used in the absence of BCF value of a chemical (it would be assessed as being of bio-concentration if it is less than 4.5).

A standard of health hazard in NFPA is summarized in NFPA 99 [15]. The classification is based on the health hazard class available in NFPA hazardous chemicals. The hazard class can be divided into five codes: lethal, very hazardous, hazardous, attentive and not hazardous.

The classification of human-harmful chemicals is based on their carcinogenesis, mutagenicity and reproductive toxicity. An impact of hazardous chemicals on ecology is assessed using no observable effect concentration (NOEC) (it would be assessed ecologically toxic if long term NOEC is less than 0.01 mg/L).

## ALGORITHM FOR CLASSIFYING COI

**1. Illegally Used Chemicals of High Toxicity**

The algorithm begins with the identification of a specific set of chemicals that are in risk of theft and diversion as needed to be added to an existing list of accident risk chemicals. To do this, there are several factors of an underlying chemical to take into account: easiness of purchase and previously used example including physical and chemical properties, such as toxicity, vapor pressure. Chemical terrors, executed by either an individual or a group, have characteristics that they can be applied in various ways in order to make an effective achievement, depending on their types and purposes. In this work, the proposed approach to classifying COI is based on the classification of terror types through an analysis of recent terror trends. Fig. 1 presents a schematic diagram of the algorithm proposed to classify a new set of COI through reshuffling in combination with Department of Homeland Security (DHS) COI and existing 56 accident risk chemicals. As a start point, the existing 56 accident risk chemicals are excluded, at a start point of the algorithm, from the set of chemicals under consideration. The accident risk chemicals are taken into consideration after completing the identification of COI.

A set of COI in risk of diversion are extracted out of 325 DHS COI in accordance with the regulated chemical and toxicity standards. As represented in Fig. 1, a set of items screen out in each phase are as follows:

- **Phase 1.1:**

- Toxic chemicals intended to be used for military purpose or chemical terrorism.

- Toxic chemicals under control of Chemical Weapons Convention (CWC) plus raw materials of Lists 1, 2 and 3 the toxicity of which is $LCt50<0.5$ mg/*l* (exposed less than 8 hours), Dermal $LC50 \leq 50$ mg/kg and Oral $LC50 \leq 25$ mg/kg in the state of gas or liquid at normal temperature.

- Chemicals that are classified to be higher than medium risk among ITF-25 (NATO International Task Force-25) chemicals as well as the toxicity of which are less than $LCt50<0.5$ mg/*l* (exposed less

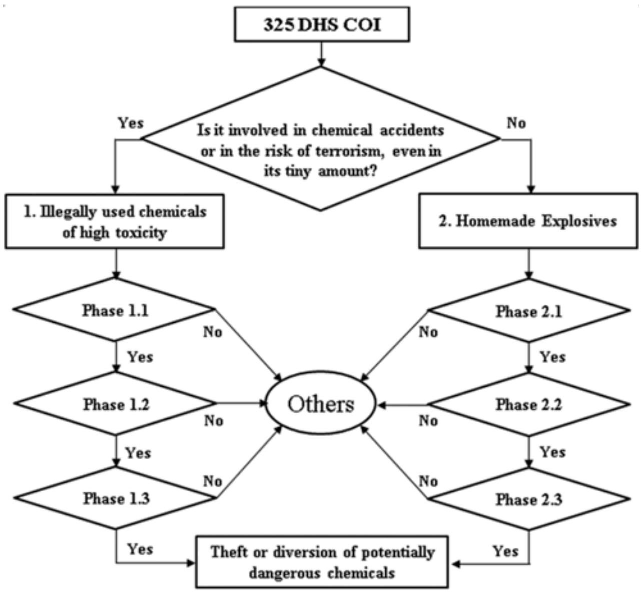


**Fig. 1. Schematic diagram of proposed algorithm for classifying COI.**

than 8 hours), Dermal LD50≤50 mg/kg and Oral LD50≤25 mg/kg.

- Nonflammable and non-volatile chemicals under control of Clean Air Act (CAA) or chemicals under control of Emergency Planning and Community Right-to-Know Act (EPCRA).

- Amongst all chemicals under control of Australian group, Standing Committee on Propagating Material and Ornamental Plants (SCPOP), and Petrochemical Industries Company (PIC), a set of chemicals that belong in the following ranges: LCt50<100 g*min/$m^3$, LCt50<0.5 mg/*l* (exposed less than 8 hours), and Dermal≤50 mg/kg and Oral LD50≤25 mg/kg.

• **Phase 1.2:**

- Chemicals that have ever been used either for chemical terrorism or have been involved in diversion.

- Chemicals whose steam pressure are higher than 1,000 mmHg, and less than 300 ppm of IDLH or less than 25 mg/kg of ORL-RAT LD50.

• **Phase 1.3:**

A set of high toxic chemicals that can be involved in diversion are screened out, based upon the following criteria.

- A set of highly toxic chemicals publicly available in large quantity, being less than 300 pm of its IDLH. These chemicals exist in the form of gas at normal temperature as its steam pressure is higher than 1,000 mmHg so that they can cause serious damages when exposed to people.

- A set of easily purchased and manufactured chemicals of high toxicity; IDLH less than 50 ppm. Their steam pressure is higher than 500 mmHg so that they can cause serious damages to people when involved in diversion.

- Chemicals that have ever been involved in diversion or large scale damages due to leak.

**2. Homemade Explosives**

Although homemade explosives are of low toxicity, those can be involved in diversion as bombs or chemical weapons. As represented in Fig. 1, a set of following items are screened out in each phase:

• **Phase 2.1:**

- A set of chemicals that are under control of Explosives (EXP)/ Improvised Explosive Device Precursor (IEDP) as being involved in the use of theft and illegal weapons.

• **Phase 2.2:**

- A set of highly explosive chemicals that are available in public or those that have ever been used for terrorism.

• **Phase 2.3:**

- A set of homemade explosives that have caused serious damages or involved in any terror attempts.

## APPLICATION OF COI ALGORITHM

The proposed COI algorithm is demonstrated through its application to Korea. The Korean government has its own criteria of risk chemicals to manage its national security against any chemical terror by relevant law [16]. However, the Korean government has no nationwide appropriate classification of risk chemicals, leading to inefficient and poor capability of national protection or response to accident and terror that might occur. The application of the proposed algorithm identifies additional 13 COI that are added to existing 56 chemicals that are under management by the Ministry of the Environment, Korea. The resulting 69 chemicals are classified into four categories: chemicals in risk of fire and explosion, toxic chemicals, frequently used chemicals and chemicals in risk of theft or diversion of potentially dangerous chemicals for chemical terrorism.

**1. Chemicals in Risk of Fire and Explosion**

31 accident risk chemicals that NFPA has classified into grade 3 and 4 in terms of reactivity, in this study, are classified into chemicals in risk of fire and explosion, comprising 27 fire risk chemicals in grades 3 and 4, one reactivity risk chemical in grades 3 and 4 and three chemicals in grade 3 in risk of fire and reactivity.

**2. Toxic Chemicals**

A classification of toxic chemicals is attempted based on environmental contamination and harmfulness to human beings. Two primary factors used to evaluate how much a chemical contributes to environmental contamination are bio-concentration factor (BCF) and persistence of chemicals. The classification of human-harmful chemicals is based on their oncognicity, mutagenicity and reproductive toxicity. In this study, the set of toxic chemicals consists of NFPA grade 4 chemicals, REACH cancer producing chemicals and mutation causing chemicals.

**3. Frequently Used Chemicals**

Chemicals that are frequently used in large volume of distribution in the domestic market are in high risk and required special control, as their use for terror gives rise to massive destructive damages.

**4. Chemicals in Risk of Theft or Diversion**

An application of the algorithm designed for the set of chemicals in risk of theft or diversion to existing 56 accidents risk chemicals yields two chemicals such as nitric acid and nitrobenzene. An addition of the two existing chemicals to newly identified 13 chemicals comes up with 15 chemicals in risk of theft or diversion. On the other hand, cyanogen chloride and sarin are added to the selection criteria even though they are distributed in negligible quantity because they have been used for terror for a long time and are of symbolic significance. A list of chemicals in risk of theft or diver-

**Table 1. Chemicals in risk of theft or diversion**

| No | Chemicals | CAS number | Min. concentration (%) | STQ (pound) |
|---|---|---|---|---|
| 1 | Nitric acid | 007697-37-2 | 68 | 400 |
| 2 | Nitrobenzen | 000098-95-3 | ACG | 100 |
| 3 | Nitric oxide | 010102-43-9 | 3.83 | 15 |
| 4 | O-Isopropyl methylphosphonofiuoridate (GB) | 000107-44-8 | - | - |
| 5 | Cyanogen chloride | 000506-77-4 | 2.67 | 100 |
| 6 | Nitromethane | 000075-52-5 | ACG | 400 |
| 7 | Ammonium nitrate | 006484-52-2 | ACG | 400 |
| 8 | Hexamine | 000100-97-0 | - | - |
| 9 | Hydrogen peroxide | 007722-84-1 | 35 | 400 |
| 10 | Potassium chlorate | 003811-04-9 | ACG | 400 |
| 11 | Potassium nitrate | 007757-79-1 | ACG | 400 |
| 12 | Potassium perchlorate | 007778-74-7 | ACG | 400 |
| 13 | Potassium permanganate | 007722-64-7 | ACG | 400 |
| 14 | Sodium chlorate | 007775-09-9 | ACG | 400 |
| 15 | Sodium nitrate | 007631-99-4 | ACG | 400 |

※ ACG=any commercial grade

sion is presented in Table 1.

## CONCLUSIONS

This work investigated risk characteristics of chemicals that are under control of the Korean government by relevant law as accident risk chemicals. To make a systematic attempt on the classification of those chemicals, a set of internationally certified standards for risk materials have been adopted such as the USA NFPA, EPA and EU REACH. In addition, to classify COI appropriate to Korea environment, a new algorithm for classifying COI was proposed in combination with the DHS COI in USA. The proposed algorithm was demonstrated with its application to Korean relevant law related to protection from terror and accidents. Lastly, the proposed algorithmic approach may be helpful for a country in planning to retain a set of its own national COI for terrorism. Based on the outcome of this study, the Ministry of the Environment of Korea has legislated a newly customized law for managing a set of chemicals in risk of terror and accidents.

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