CONSEQUENCE ANALYSIS, EMERGENCY RESPONSE AND PLANNING FOR AN INTEGRATED RISK MANAGEMENT SYSTEM: SYSTEM DESIGN AND IMPLEMENTATION

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In the multidisciplinary safety research with Korea Occupational Safety and Health Agency (KOSHA), we are developing, in the framework of a GIS-based, Integrated Risk Management System (IRMS), which is the wholly integrated system including Process information management, hazard identification, risk assessment, worst-case accident scenarios selection and emergency response planning. It is based on database system (of process information, layout, probability, etc.) and GIS of chemical plant complex in Korea, so its output can be expressed in both quantitatively and qualitatively and displayed on the digital map. In case of an emergency, escape routes for local residents and approach routes for fire engines and rescue teams are indicated for better control and management of the accident. In this paper, we emphasize the importance of integrated risk management by presenting on our experiences in designing and implementing the IRMS.

Keywords: Consequence Analysis, Integrated Risk Management System, Emergency Response Planning, Robust Accident Scenario Selection

INTRODUCTION

Despite on-going efforts with industrial accident prevention programs and improvements of occupational environments, according to an ILO report, about 2.5 million cases of accidents occur each year in the world involving about 335,000 casualties. Especially in the chemical industry, high concentration of sophisticated technical devices for handling, storage, shipping, and processing of many types of chemicals are used. These equipments have inherent dangers such as fire, explosion, leakage, etc. due to the nature of chemicals themselves. If such accidents happen, not only the workers engaged in the chemical industry but also the residents and the environment of surrounding area can be severely affected. Furthermore, the direct financial loss due to the damages to the equipments themselves can be serious. In addition, the situation could also affect the overall economy by affecting the supply of raw materials and other ways as a direct result of long equipment restoration period.

The Korean Government has been enforcing the Industrial Safety Management Act in accordance with the Industrial Safety and Hygiene Act since January 1996, in attempts to prevent major industrial accidents. Following the enforcement of this act, the safety of Korean petrochemical industries has shown a drastic improvement: significant reduction in fatality, injuries, near-misses, and emergency shutdowns of plants, and improved product quality and productivity as well. With this success and the implementation of Process Safety Management (PSM), which was introduced as a law in 1996, the Korea Occupational Safety and Health Agency (KOSHA) is building a GIS-based, Integrated Risk Management System (IRMS). There have been lots of research and studies on systematic finding of hazards, risk assessment, consequence analysis, mitigation measures, and emergency response concerning the characteristics of Korean industries, especially in hazard identification methodology. Integration of these safety technologies and techniques should elevate the overall safety control to a higher level.

In this multidisciplinary research with the KOSHA, our laboratory has been developing a new strategy for generation and selection of robust worst-case accident scenarios, to be used in the quantitative evaluation of risks at the plant sites, and designing and implementing the consequence analysis program. In this paper, we will discuss more on these two topics in the framework of IRMS. We will present on our experiences on designing and implementing these two programs and emphasize the importance of integrated risk management with discussions on the performance of the developed system.

IRMS: AN INTEGRATED SOLUTION

The IRMS is a tool for the prevention of major chemical accidents, which displays the risks on a map after calculating the risks quantitatively and identifying the risk level, and helps us to reduce potential risk and minimize possible losses[5]. The system has been designed to assimilate on-line and off-line data with geographical information with user-friendly access and interfaces. It consists of several main functions: display of petrochemical complex layout, display of equipment layout with related process information, zonation of the area in effective hazard with the estimation from the consequence analysis, and demographic analysis of the effected area, etc. It also provides risk contours using GIS technology. Figs. 1 and 2 show the structure and information flow of IRMS.

IRMS is composed of various integrated software elements. In terms of risk management, firstly potential hazards are found utilizing hazard analysis methods such as HAZOP and Checklist. For this, database which contains the previous accident information and the information of hazardous installations, such as capacity of equipment, hazardous material being handled, temperature, pressure and flammability, etc., is to be established. Secondly, we have to find the frequency and the size of consequence when the potential hazards are developed into actual incidents. For this we utilize ETA, FTA and consequence models enhanced by KOSHA. Thirdly, we calculate the risk which is a function of frequency and consequence ($R = F \times C$), and judge whether it is acceptable or not in comparison with the acceptable risk criteria.

The highlight of IRMS is to provide the risk contours using GIS technology. Data of hazardous installations and the result of consequence are also provided through computer screen. In this paper, we will present our part of work of major elements of IRMS such as accident scenario selection, GIS and consequence analysis.

REASONING ALGORITHM FOR ACCIDENT SCENARIO SELECTION

In this part of the study, we propose a new reasoning algorithm, through process partition and process component analysis, to improve the reliability of accident scenario selection[6]. Process elements are analyzed, and then the proposed strategy selects and generates the robust accident scenario of a worst case that is most likely to happen and should be foremost considered. The scenario reasoning scheme consists of three types of knowledge base and four reasoning algorithms (see Fig. 3): knowledge base (KB) of equipment property, material property, and process units; and four algorithms of macro decomposition, equipment screening, equipment behavior analysis, and accident scenario reasoning. Equipment property knowledge base is composed of equipment properties such as handling materials, operating condition, flow rate, safety devices, age, etc. (see Fig. 4). Material property knowledge base uses NFPA rating to describe toxicity, reactivity and flammability of process materials. Process unit knowledge base consists of topography and meteorological characteristics.

Accident scenarios are inferred according to the following steps: macro decomposition, micro decomposition using the equipment screening algorithm, equipment behaviour analysis, accident reasoning, and the effect analysis (see Fig. 5). In the macro decomposition, process units are selected according to their functions and the meteorological condition around the area. For the decomposition, the chemical plant is classified into the feed system, reaction system, separation system, storage system, and utility system. Meteorological characteristics and the surrounding condition are also considered: the main unit is defined, and meteorological characteristics and the topography of the selected unit are considered.

In the second step, we propose the Equipment Screening Algorithm (ESA) analyzing the process condition and selecting the process equipment with higher priority risk ranking. Equipment characteristics such as material property, flow rate, operating condition, capacity, safety devices, age, failure rate, accident history and repaired history are analyzed using ESA, which is a sequential reasoning method[4] (see Fig. 6). In case of material property, we use NFPA (National Fire Protection Association) code to confirm the flammability and toxicity; the criterion of this property is more than 3 NFPA rating. In the next stage, equipments of high flow rate or capacity or being operated in high pressure or temperature are determined. In the fourth stage, we decide whether the selected equipments have safety devices. In the final stage, we consider the age and accident history for individual equipment using the sequential screening method. The analyzed process elements are ranked and risk grades determined. According to the grades, risk assessment is performed. In the equipment analysis using the equipment behavior algorithm, the effect estimation for the selected equipment in the equipment-screening algorithm is accomplished: equipment with high severity is researched to find a detailed accident scenario. We use effect analysis method for the failure mode of the selected equipment to identify single equipment failure modes and each failure mode's potential effect on the system and the plant[1-3]. This mode describes how equipment fails and is determined by the system's response and cause to the equipment failure. In the scenario selection, we infer possible effects and the root cause depending on the failure mode of the equipment. Possible scenarios for each failure mode are so variable that risk rankings are assigned according to the potential hazard of material and the magnitude of the expected abnormal situation.

In the accident-reasoning algorithm, we infer the possible accident due to the equipment behavior and material property. For example, if the ultimate effect is valve breakage, we may infer that the possible accident is fire or explosion when material has a flammable property:

1) Valve leakage + toxic materials (Nh>2) ⇒ personnel injury
2) No inlet flow + pump ⇒ pump damage and malfunction
3) Downstream equipment breakage + flammable materials (Nf>3) ⇒ fire or explosion

CONSEQUENCE ANALYSIS AND QUANTITATIVE RISK ASSESSMENT

In this part of the system, extents of damage due to plume, overpressure or heat leaks are displayed on the digital map. In case of an emergency, escape routes for local residents and approach routes for fire engines and rescue teams are indicated for better control and management of the accident.

The whole system being developed consists of (1) database of material property and approximation algorithm for chemicals, (2) geographic information and 2D maps on the surrounding area, (3) meteorological data processing module, (4) quantitative risk calculation module, (5) real-time consequence analysis, (6) models on the release and dispersion of mixed chemicals, (7) dispersion models on chemicals showing unusual behavior, (8) dispersion models for complex geography, (9) models on the effect of buildings and constructions to the dispersion, (10) dispersions inside the confined areas like buildings, and (11) Probit function-based estimation on the effect and the effected area. Fig. 7 shows how these modules are integrated to give the result of consequence analysis.

In our presentation at the conference, we will present on our experiences in designing and implementing the consequence analysis system, with comparison to commercial packages, and emphasize the importance of integrated risk management and discuss about the performance of the developed system.

DEVELOPMENT STATUS OF IRMS

From 1999, the phase three has been under implementation that includes GIS of five petrochemical complexes. The system is intended to manage hazardous installations more systematically and effectively and to reduce the number of accidents significantly, further minimizing production losses in the plant. Various modules of IRMS, which have been developed simultaneously, are being integrated into one package system with extensive field tests. All the elements are supposed to be built and ready for integration by Summer 2002 and will go to field tests. Integration of the components as one system of IRMS will be finished in the second half of 2002.

CONCLUSION

If the IRMS being constructed through methods overviewed in this paper is implemented and used for the risk management of petroleum chemical complexes in Korea, a substantial amount of benefits are expected in many areas. In the technological area, the degree of safety can be raised by employing a fast, effective analysis and systematic risk management which are made possible by the combination of separate safety management and technological factors. In the economical point of view, this IRMS can also help to prevent the loss of lives and properties by helping to make a notable decrease in the occurrences of accidents. In addition, effective operations of installations are possible using the established database and system, thereby decreasing the production loss at plants. However, since there are rapid developments in the fields of sensors, communication and information technologies, this system needs to be continually updated and maintained so that an even more effective risk management system can be established.

ACKNOWLEDGEMENTS

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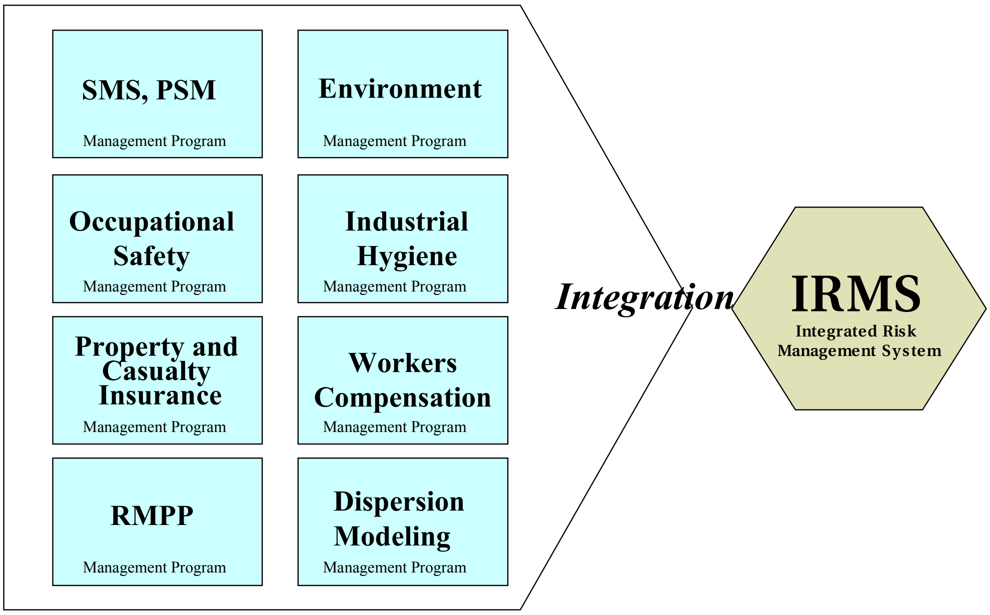


Fig. 1. Components consisting of the IRMS

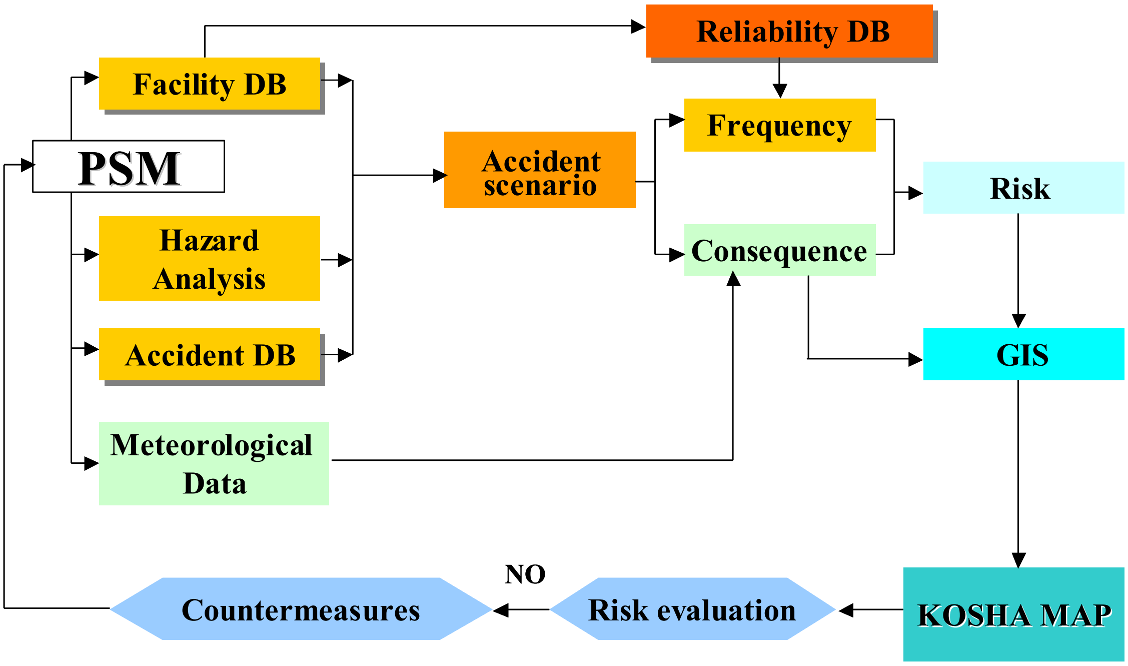


Fig. 2. Information flow in the IRMS

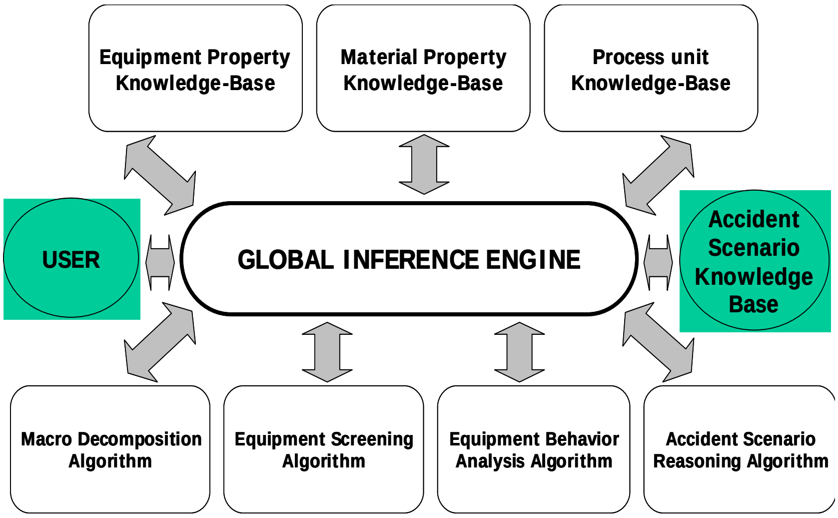
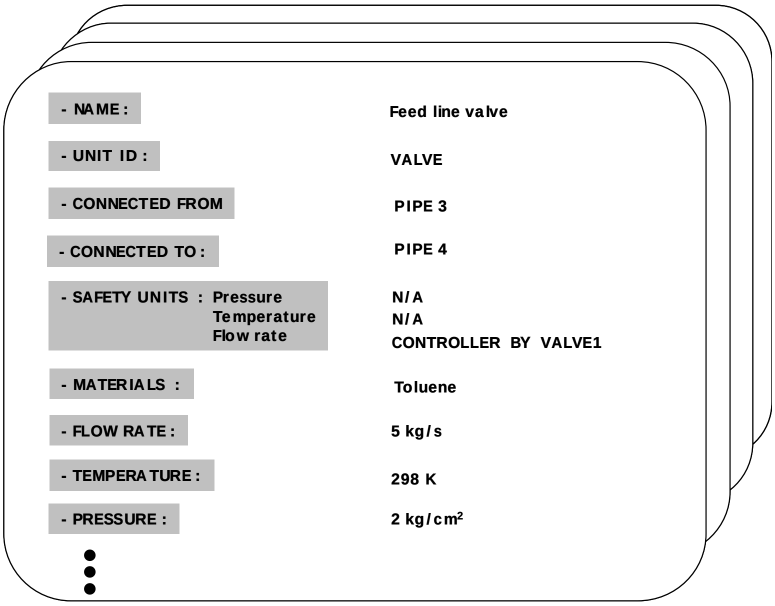


Fig. 3. Proposed framework for the accident scenario selection



- NAME :	Feed line valve
- UNIT ID :	VALVE
- CONNECTED FROM	PIPE 3
- CONNECTED TO :	PIPE 4
- SAFETY UNITS : Pressure Temperature Flow rate	N/A N/A CONTROLLER BY VALVE1
- MATERIALS :	Toluene
- FLOW RATE :	5 kg/s
- TEMPERATURE :	298 K
- PRESSURE :	2 kg/cm^2

⋮

Fig. 4. An example of equipment property KB

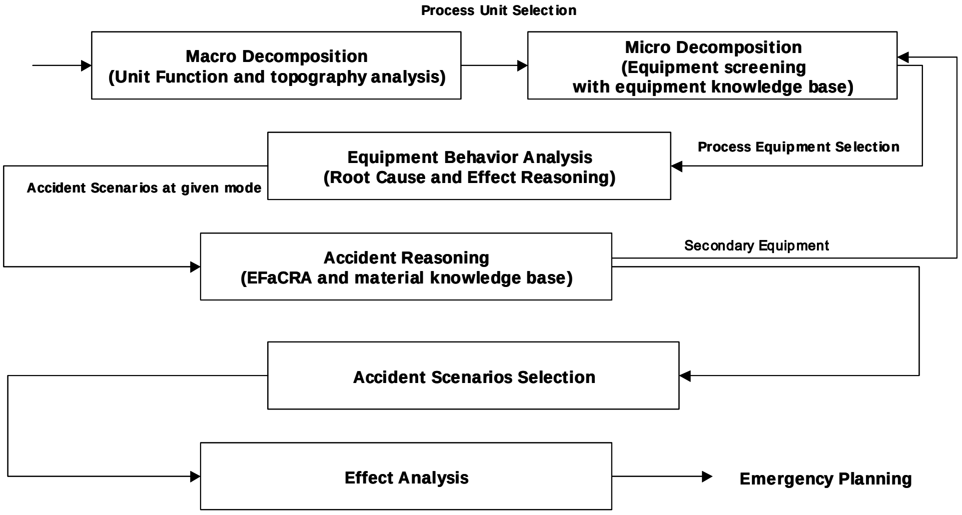


Fig. 5. Inference procedure of the proposed system

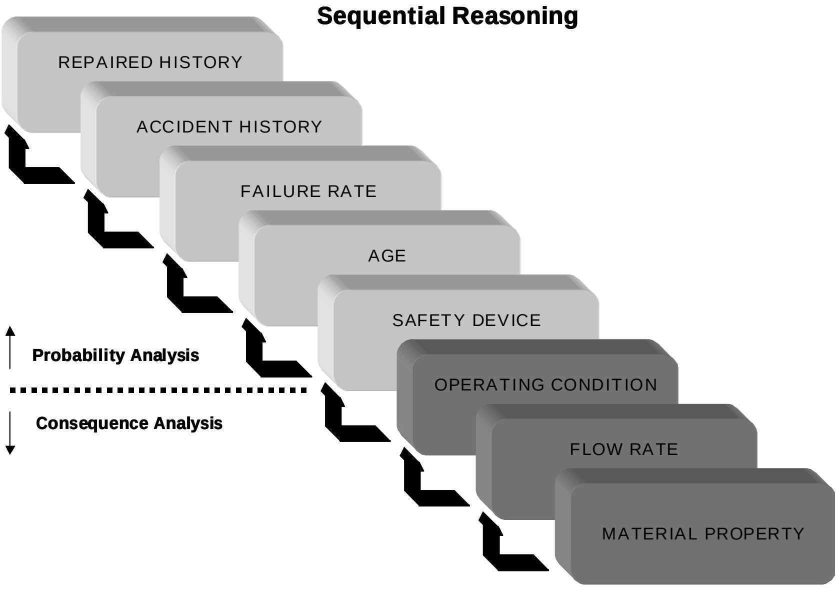


Fig. 6. Sequential reasoning of ESA

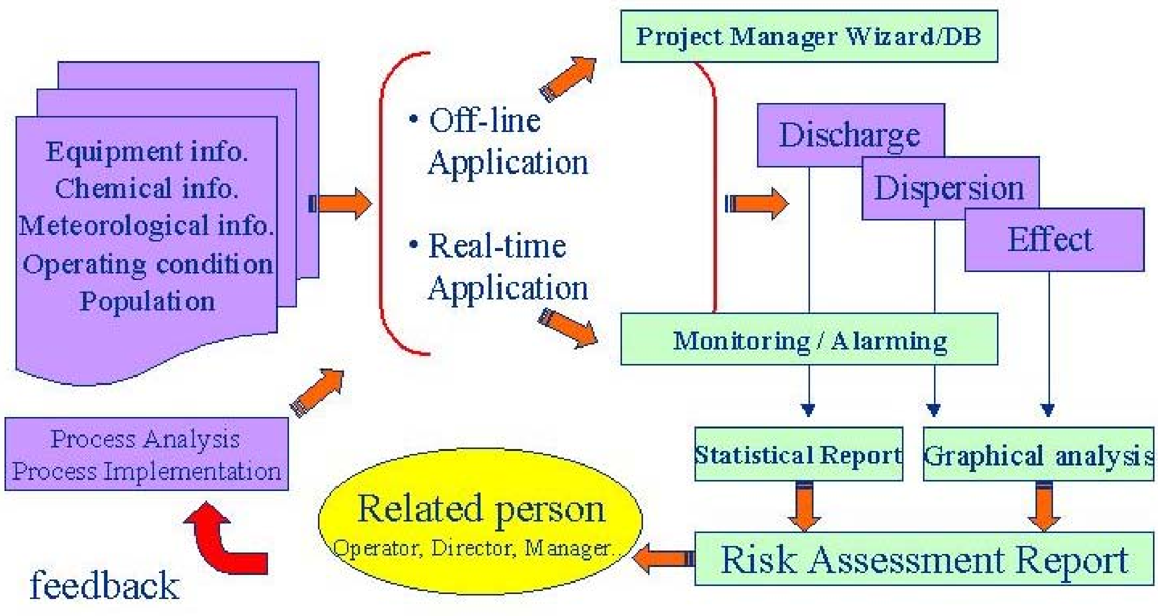


Fig. 7. Flowdigram of consequence analysis program