Environmental Monitoring System for Map Ta Phut Industrial Estate in Thailand

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Fujitsu has installed a volatile organic compounds (VOCs) monitoring and environmental information management system (VM-EIMS) for the Industrial Estate Authority of Thailand and Chulalongkorn University in Thailand. The system is intended to improve air quality in Map Ta Phut. It monitors 19 kinds of VOCs, 10 odor-causing compounds, and ozone. We improved the analysis function and the information publishing function of the system by introducing technological concepts such as "risk assessment" and "risk communication" for environmental risk management. The system can carry out advanced simulations for use in predicting the diffusion of air pollutants. In addition to installing the system, we conducted such technology transfer activities as holding technical training sessions to develop the environmental simulation skills of Thai researchers. The system can publish information on air quality (both measured and simulated) on the Web and receive information about the state of pollution in various areas from local residents. This paper describes Fujitsu's efforts and achievements related to this system.

1. Introduction

The period of industrialization that began in Thailand in the 1960s led to a period of rapid economic expansion beginning in the latter half of the 1980s. This expansion has been accompanied, however, by severe environmental problems. In 1996, it became evident that pollution in the Map Ta Phut Industrial Estate in Thailand's Rayong Province was becoming a problem as local residents began to complain of offensive odors. Since then, a variety of environmental problems have surfaced, and a survey conducted by the Ministry of Public Health in 2008 revealed that benzene in the urine of local residents exceeded the normal level. Benzene is a carcinogenic substance and a volatile organic compound (VOC), which means that it becomes gaseous at ordinary temperatures and pressures. It can be found in familiar, everyday products such as paint, gasoline, and adhesives, and its emissions are regulated at the national and local government levels.

Fujitsu had been in discussions with Thailand's National Science and Technology Development Agency (NSTDA) since July 2010 on ways to improve the air quality in Map Ta Phut and identified several possible solutions over the following year. To determine which solutions were most appropriate, Fujitsu surveyed the conditions in the field and conducted hearings at ministries and agencies in Thailand. As a result, it was decided in December 2011 that Fujitsu would implement a VOCs Monitoring and Environmental Information Management System (VM-EIMS) for the Industrial Estate Authority of Thailand (IEAT) and Chulalongkorn University (CU) as a collaborative research project sponsored by Japan's New Energy and Industrial Technology Development Organization (NEDO).

Although air quality was already being monitored in Rayong Province at the time of project launch, the atmospheric concentrations of some VOCs were still unacceptably high.[1] The NSTDA, IEAT and CU therefore agreed that a VM-EIMS was needed and presented Fujitsu with a set of system requirements.

This paper introduces the VM-EIMS constructed by Fujitsu in accordance with this request. Fujitsu developed this system by applying knowledge accumulated in Japan for dealing effectively with air pollution.

2. VM-EIMS overview

VOCs in the atmosphere generate oxidants through a chemical reaction caused by ultraviolet radiation. In this reaction, nitrogen oxide (NO_x) acts as a catalyst. The oxidant, or oxidizing agent, with the highest concentration in the atmosphere is ozone. VOC, NO_x, and ozone are all closely related, so it is necessary in atmospheric monitoring to comprehensively measure and evaluate these substances as opposed to monitoring the atmospheric concentration of any one of them.

2.1 Basic concept of atmospheric monitoring

Atmospheric monitoring can be classified into four activities in accordance with the processing done on the measurement data.

1) Measurement and collection

In this activity, a measurement station equipped with atmospheric sensors measures the concentrations of air pollutants. The diffusion of air pollutants is greatly affected by weather conditions, so the station also measures meteorological variables such as temperature, humidity, wind speed, wind direction, and solar radiation.

2) Monitoring

Standard values of air pollutants are determined by a regulatory system that includes the national government, local governments, and institutions operating atmospheric monitoring systems. The system then notifies relevant personnel and outside institutions whenever any of these standard values are exceeded.

3) Analysis

The time-series trends in measurement data are analyzed, measurement data are compared with geographical information, and the atmospheric environment is analyzed using scientific techniques. The effects of measures taken to comply with emission regulations are also evaluated using numerical analysis or other advanced techniques.

4) Publishing

Information on the generation and diffusion of air pollutants is published for use by residents, schools, hospitals, and local governments in the monitored area and surrounding communities.

2.2 System overview

An overview of the VM-EIMS is shown in **Figure 1**.

1) Air sensors

The substances targeted for air sensor monitoring are 19 types of VOCs, 10 types of malodorous substances, and ozone, as requested by the Thailand side. The procurement and deployment of the air sensor units and the network that connects them with the monitoring center are being handled on the IEAT and CU side. The types of air sensors used and the substances monitored are listed in **Table 1**.

2) Data collection subsystem

This subsystem consists of software for outputting a file of measurement data obtained by air sensors and software for periodically collecting measurement data using the file transfer protocol (FTP) initiated from the monitoring-center side.

3) Data monitoring subsystem

This subsystem receives measurement data from the data collection subsystem and manages measured values using a database. It also monitors measured values and sends out warning messages to monitoring personnel and outside institutions if standard values are exceeded. It includes the following functions especially for monitoring personnel:

- Display function for showing measured values, values exceeding standard values, changes in values over time, etc.
- Form-creation function for preparing periodic reports.

4) Data analysis subsystem

This subsystem receives measurement data from the data monitoring subsystem. It uses this data to quantify the dynamic processes in the diffusion of VOCs and ozone in the atmosphere. It also makes atmospheric diffusion forecasts by using the Weather Research and Forecasting (WRF) model, which is open source software developed and managed by user communities such as the National Centers for Environmental Prediction (NCEP) in the United States. Additionally, for chemical transport calculation, this subsystem uses the Community Multiscale Air Quality (CMAQ) model, which is also open source software developed and managed by user communities such as the U.S. Environmental Protection Agency (EPA). The results of atmospheric diffusion forecasts are output in a file using the Network Common Data Form (NetCDF)

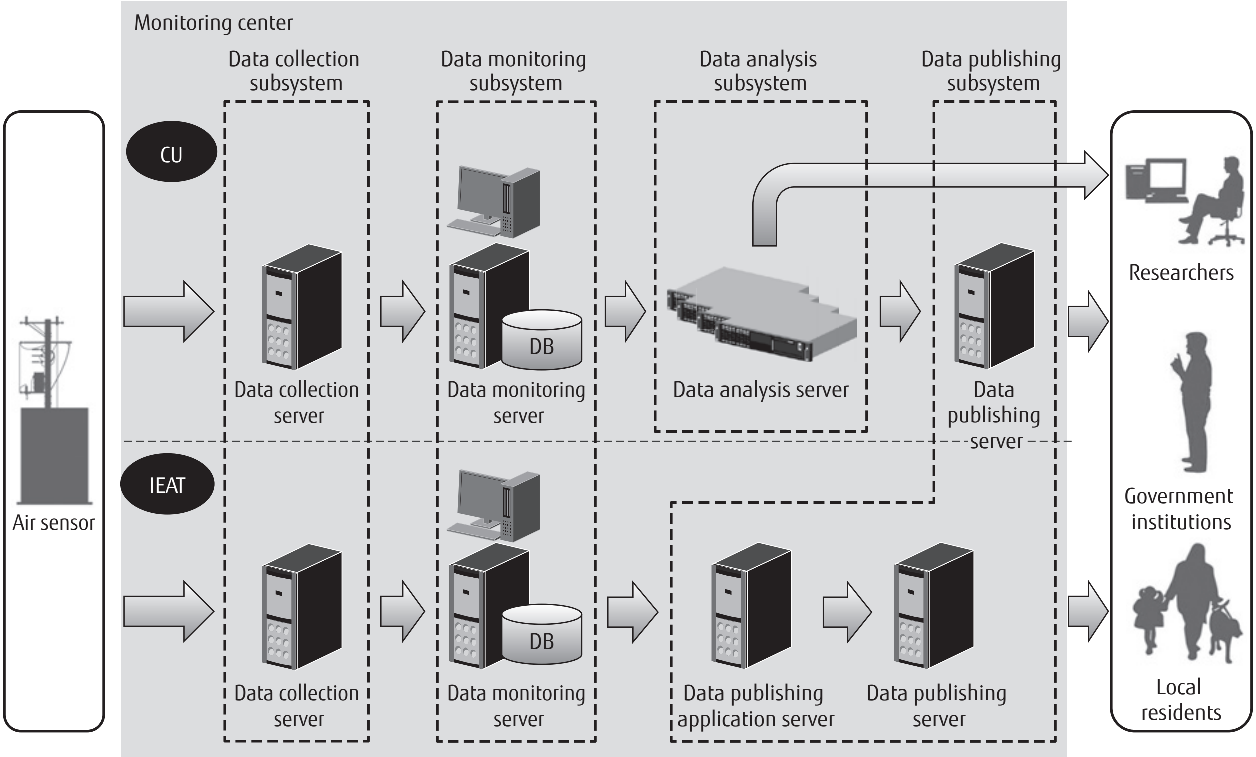

Figure 1
VM-EIMS overview.

Table 1
Air sensors and monitored substances.

	VOC	Malodorous substances (individual concentration)	Malodorous substances (index)	Ozone
Targets of monitoring	19 types (see below)	10 types (see below)	Total odor index	Ozone (O_3)
Monitored areas	Vicinity of emission source		Residential area	
Measurement stations	5 new stations		3 existing stations	
Air sensors	PTR-MS (Proton-transfer-reaction mass spectrometry)		Odor index sensor	Ozone sensor

No.	VOC: 19 types	No.	VOC	No.	Malodorous substances: 10 types
1	Benzene	11	Acrolein	1	Ammonia
2	Vinyl chloride	12	Acrylonitrile	2	Methyl mercaptan
3	1,2-dichloroethane	13	Benzyl chloride	3	Hydrogen sulfide
4	Trichloroethylene	14	Bromomethane	4	Dimethyl sulfide
5	Dichloromethane	15	Carbon tetrachloride	5	Dimethyl disulfide
6	1,2-dichloropropane	16	1,2-dibromoethane	6	Trimethylamine
7	Tetrachloroethylene	17	1,4-dichlorobenzene	7	Methyl isobutyl ketone
8	Chloroform	18	1,4-dioxane	8	Toluene
9	1,3-butadiene	19	1,1,2,2-tetrachloroethane	9	Styrene
10	Acetaldehyde			10	Xylene

format. It overlays these forecast data on geographical data for the targeted area to create an image file that can be passed to the data publishing subsystem for posting on the Internet.

5) Data publishing subsystem

This subsystem receives hourly measurements of the VOC concentrations from the data monitoring subsystem and publishes them on the Internet via a variety of services. These include the superposition of that data on maps (map mode) and a time-series presentation of that data linked with Google Maps (graph mode), as shown in **Figure 2**. Image files received from the data analysis subsystem showing the results of atmospheric diffusion forecasts are also published.

3. Environmental risk

The concept of "environmental risk" is essential to acquiring an accurate understanding of the damage caused by environmental pollution and to taking appropriate measures. Environmental risk can be expressed in two ways: by the hazard represented by a pollutant (to what extent is that pollutant harmful) and the amount of exposure to that pollutant (to what extent are people exposed to that pollutant).[2] Environmental risk cannot be reduced to zero as long as human beings are involved in economic activities. Therefore, the members of a community must share the environmental risk and aim for coexistence while reducing that risk to within an allowable range.

Environmental risk can be dealt with by following a three-step procedure consisting of risk evaluation, risk management, and risk communication. Risk evaluation means using scientific techniques to obtain an objective and quantitative understanding of risk exposure and the harm associated with that risk. Risk management means investigating and implementing measures to reduce the environmental risk, and risk communication means sharing information about that risk among all concerned persons so that they can exchange opinions and comments about it.

The data-analysis and data-publishing components of VM-EIMS incorporate the ideas of risk evaluation (especially with regard to exposure) and risk communication, respectively. These components are based on advanced technologies developed using the knowledge of experts in air quality and Web design who participated as project members. The following section introduces the core technologies that we incorporated in VM-EIMS in collaboration with these experts.

4. VM-EIMS advanced technologies

Following consultations with experts and CU researchers in the field of air quality, we selected the WRF and CMAQ models for use in evaluating exposure on the basis of atmospheric diffusion forecasts and data analysis. These methods are the most advanced and accurate in the field.

Next, to decide on a method for data publishing,

Figure 2
Screenshots of data publishing subsystem.

we consulted with experts in air quality research on data publishing policies and sought the advice of Web designers in designing screens for presenting data on the Web. We also incorporated a function for accepting information on pollutants from general users. The result was an ideal risk communication tool that facilitates bidirectional communication between the side that publishes the data and the side that receives it.

4.1 Risk evaluation

As shown by the entries for "data analysis server" in **Table 2**, we deployed a PC cluster system having a top level of computing performance in Thailand and set up an execution environment for the WRF/CMAQ atmospheric diffusion forecast models.

This PC cluster system is equipped with Platform Cluster Manager (PCM), Fujitsu Edition, incorporating Fujitsu's technology related to technical computing. The CPU occupation time for conducting a simulation usually depends on the model parameters used by the researcher (computational grid fineness, target calculation time, etc.). Consequently, with the aim of enabling computations that are not affected by the researcher carrying them out, we adopted a scheme that prepares a model execution environment for each user and optimizes the use of ten PCM compute nodes for that user.

The physical phenomena reproduced and analyzed in an atmospheric diffusion forecast model can be summarized as follows.[3)]

1) Discharge of air pollutants into the atmosphere (emission)
2) Flow of air pollutants in wind and their movement in the atmosphere (advection)
3) Autonomous scattering of air-pollutant particles over a wide range (diffusion)
4) Chemical behavior of air pollutants (chemical reactions)
5) Adhering of air pollutants to the ground and buildings (deposition)
6) Final concentrations of air pollutants in the computational domain

In the calculations for these phenomena, "wind" is treated as a meteorological field in the computational domain. It is calculated for each time step in the WRF model using measured wind direction, wind speed, temperature, humidity, and solar radiation as initial values. Then, after this field is calculated in the computational domain, measured concentrations of air pollutants referred to as the "emission inventory" are given as initial conditions and boundary conditions so that various physical equations can be solved in the

Table 2
VM-EIMS computer specifications.

	Name	Quantity	OS	CPU	No. of cores	Memory (GB)	Disk capacity	Installation site
Data collection server	PRIMERGY TX200 S6	2	Windows Server 2008 R2 Standard	Intel Xeon Processor E5620 (2.40 GHz)	4	8	300 GB	IEAT, CU
Data monitoring server	PRIMERGY RX300 S6	2	Windows Server 2008 R2 Standard	Intel Xeon Processor E5603 (1.60 GHz)	4	8	600 GB	IEAT, CU
Data publishing server	PRIMERGY RX300 S6	1	Red Hat Enterprise Linux 5.5	Intel Xeon Processor E5603 (1.60 GHz)	4	8	300 GB	IEAT, CU
Data publishing application server	PRIMERGY RX300 S7	1	Windows Server 2008 R2 Standard	Intel Xeon Processor E5-2603 (1.80 GHz)	4	8	300 GB	IEAT
Data monitoring storage	ETERNUS DX80 S2	2	–	–	–	–	600 GB	IEAT, CU
Data analysis server	PRIMERGY BX922 S2	10	Red Hat Enterprise Linux 5.5	Intel Xeon Processor X5647 (2.93 GHz)	8	24	160 GB × 2	CU
File server	PRIMERGY RX300 S6	1	Red Hat Enterprise Linux 5.5	Intel Xeon Processor E5645 (2.40 GHz)	12	24	300 GB × 5	CU
Backup server	PRIMERGY RX200 S6	1	Windows Server 2008 R2 Standard	Intel Xeon Processor E5606 (2.13 GHz)	8	8	600 GB × 3	CU
Data analysis storage	ETERNUS DX80 S2	1	–	–	–	–	600 GB × 6, 1 TB × 6	CU
Tape library	ETERNUS LT20	1	–	–	–	–	–	CU

CMAQ model to determine these phenomena.

The calculation results can differ between simulations depending on the initial and boundary conditions used, so these conditions must be carefully set. It is also necessary to set the computational domain and computational grid in accordance with the scale of the physical phenomena to be reproduced. The physical processes underlying the reproduced phenomena can be examined by comparing the obtained calculation results with the measured values. Advanced skills in the field of air quality are needed to analyze the preconditions established in a simulation and to analyze the calculation results obtained. For this reason, we welcomed experts from the Asia Center for Air Pollution Research (ACAP) in Japan and researchers belonging to JAPAN NUS Co., Ltd. as project members. In addition to setting up an execution environment for atmospheric diffusion forecasting, we also held technical training sessions for Thai researchers that covered model execution and analysis methods. We also promoted technology-transfer activities in the field of air-quality research.

4.2 Risk communication

VM-EIMS enables measurement data to be published using Web-GIS (a geographic information system) and user contributions on pollution conditions to be input using a Web screen. In short, the system provides for communication tools that enable both the data-publishing side and the data-receiving side to share and discuss environmental risk. The following measures have been taken to make these tools attractive even to users who neither have an interest in nor knowledge of environmental pollution.

1) A bright, engaging screen design has been adopted to counter the negative images typical of dealing with environmental pollution.
2) The saturation and contrast of all screens have been increased while using blue as a base color to invoke images of a clear sky.
3) Dynamic screen graphics have been achieved by frequent use of animation and screen switching in accordance with user operations.

These screen-design measures, taking into account the user experience, aim to encourage users to interact with the Web site and to remain on that site for a longer time. The artistic elements reflect the general preference in Thailand for flashy screen designs. The resulting screen designs have been highly evaluated on the Thai side. Furthermore, by creating prototypes from the early stages of development, we were able to eliminate the differences in preferences for the graphical user interface (GUI) arising from differences in Japanese and Thai cultures.

To make a contribution on the Web site and have it posted, the user first selects the measurement station, present location, and other parameters and then specifies the severity (very bad, bad, somewhat bad, etc.) of the offensive odor in that area. An offensive odor is a composite byproduct of the malodorous substances listed in Table 1 and constitutes information obtained from the human sense of smell. VM-EIMS therefore enables information derived from human senses to be treated as air quality data.

5. Achievements and future issues

The data analysis subsystem was deployed at CU as a simulation execution environment for environmental research. Since its introduction, both Japanese and Thai researchers have been making calculations for atmospheric diffusion forecasting of VOC, NO_x, and ozone in the Map Ta Phut area. The results of some of these calculations are shown in **Figure 3**.

The data publishing subsystem has been deployed at IEAT as a risk communication tool between IEAT and the Map Ta Phut community. However, the damage caused by extensive flooding throughout Thailand in 2011 delayed installation of air sensors on the Thai side. All concerned look forward to full-scale operation of VM-EIMS once these air sensors are installed. The public release of measurement data and user contributions is not without problems given the nature of that data. A consensus must be built with Thai-side institutions and their governing institutions in determining the extent to which such data should be published for general consumption. The distribution of erroneous information can generate confusion in the community. On the other hand, concealing data above and beyond what is necessary hinders the process of risk communication. It is therefore necessary that policies prescribing the testing of measurement data and the screening of user contributions be established by Thai institutions and that Fujitsu provide support for implementing those policies.

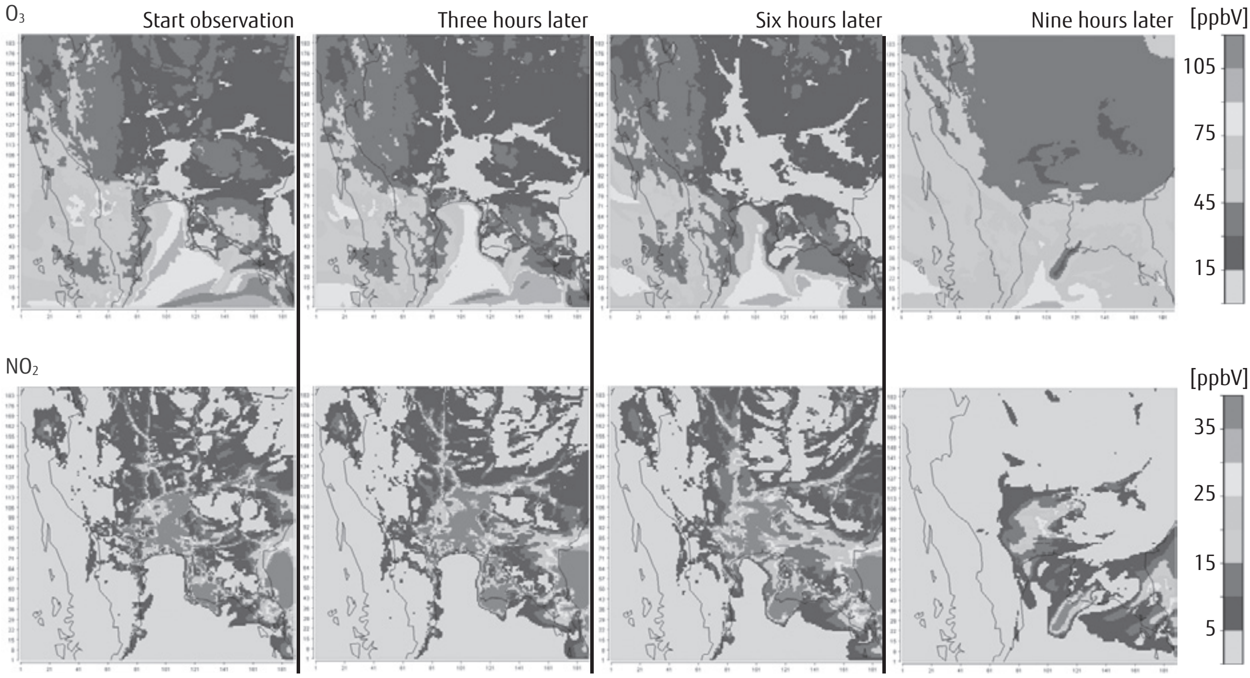

Figure 3
Atmospheric diffusion forecasted in three-hour intervals.

We have successfully implemented a system having a foundation in risk evaluation and risk communication. As Thai institutions come to use this system for risk management, collaborative activities addressing environmental problems will be undertaken while achieving genuine coexistence with the residents and community of Map Ta Phut.

6. Conclusion

This paper presented an overview of Fujitsu's VM-EIMS project, focusing on its risk-evaluation and risk-communication functions. Going forward, Fujitsu will apply the knowledge and experience gained through this project to solving other environmental problems in emerging nations.

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