

DEVELOPMENT OF HAZARD PREDICTION SYSTEM FOR INTENTIONAL ATTACKS IN URBAN AREAS

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ABSTRACT

A hazard prediction system has been developed for chemical, biological and radiological (CBR) attacks in urban areas with the use of the mesoscale meteorological model, RAMS and its dispersion model HYPACT. The developed simulation system can predict 1) concentration of hazardous gases and 2) the number of casualties based on the population database of Japan.

RAMS is equipped with an optional scheme to simulate airflow around buildings based on the volume fraction of the buildings within each grid cell. However, this scheme requires significant computational time if applied for fine meshes. Accordingly, we have developed a new computational scheme using the RAMS code with a mesh size of a few meters to simulate the effect of a building complex on the dispersion. This scheme requires computational time of as little as a few minutes on a conventional personal computer. The computational scheme first extracts the shapes of the buildings from a digital map database. Then, a set of steady flows is calculated for 16 wind directions using a fine mesh, and the results are saved as a database. Next, the scheme calculates an unsteady flow on a coarse mesh, which is nudged by a linear combination of the relevant data from the 16-wind direction steady airflow database. The nudging is performed at the boundaries of the fine mesh domain using the Least Mean Square Method (LMSM). The dispersion prediction scheme is currently being validated with the use of field and wind tunnel data.

1. INTRODUCTION

In recent years, the likelihood of attacks by chemical, biological and radiological (CBR) agents in mega-cities may be increasing. In Japan, the Japanese cult Aum Shinrikyo carried out Sarin gas attacks in Nagano and Tokyo. The attack in the residential area of Matsumoto City, Nagano resulted in 7 deaths and 586 injuries. The attack on five subway lines in the Tokyo metropolitan area led to 12 deaths and over 5500 injuries.

The Ministry of Education, Culture, Sports, Science and Technology of Japan (MEXT) commenced a national project for urban safety in 2007. As a part of this project, MEXT assigned a research consortium consisting of the University of Tokyo, the National Institute for Advanced Industrial Science and Technology (AIST), Mitsubishi Heavy Industries (MHI) and AdvanceSoft, Corp. to develop a new hazard prediction and mitigation simulation system for CBR attacks. This simulation system is intended for use by first respondents to attacks such as municipal fire protection and police agencies. Therefore, the system needs to be able to simulate gas diffusion with minimal computational time on a conventional personal computer (PC).

2. SIMULATION SYSTEM

2.1 System description

The developed simulation system, called MEASURES, consists of an airflow database, a dispersion model, and a damage prediction model (Fig. 2.1-1). Meteorological data can be loaded onto the system by the user directly or through the Internet. The databases of the airflow, topography, and population are pre-installed on the system. Less than 15 minutes of computational time are required for 12 hours of simulation. The output of simulations such as wind vectors, gas concentration, and casualty counts for every 10 minutes of simulated time are displayed on the screen, and are thus available to the users during and after the simulation.

2.2 Meteorological model

Most meteorological models are available in the public domain as open source codes. Examples of such models are RAMS, WRF, and MM5. To simulate airflow around building complexes with a mesh size of a few meters, the RAMS (Regional Atmospheric Modeling System) code developed by Pielke et al. of Colorado State University (<http://www.atmet.com/>) was modified. First, the two-dimensional turbulence model by Mellor and Yamada (1982) was replaced by a three-dimensional turbulence model as in Trini Castelli (2006) to simulate complex airflow around buildings and terrain. The simulated vertical profiles of wind velocity around a building were compared and verified with the wind tunnel database from Hamburg University (<http://www.mi.uni-hamburg.de/Data-Sets.432.0.html>) (Fig. 2.2-1).

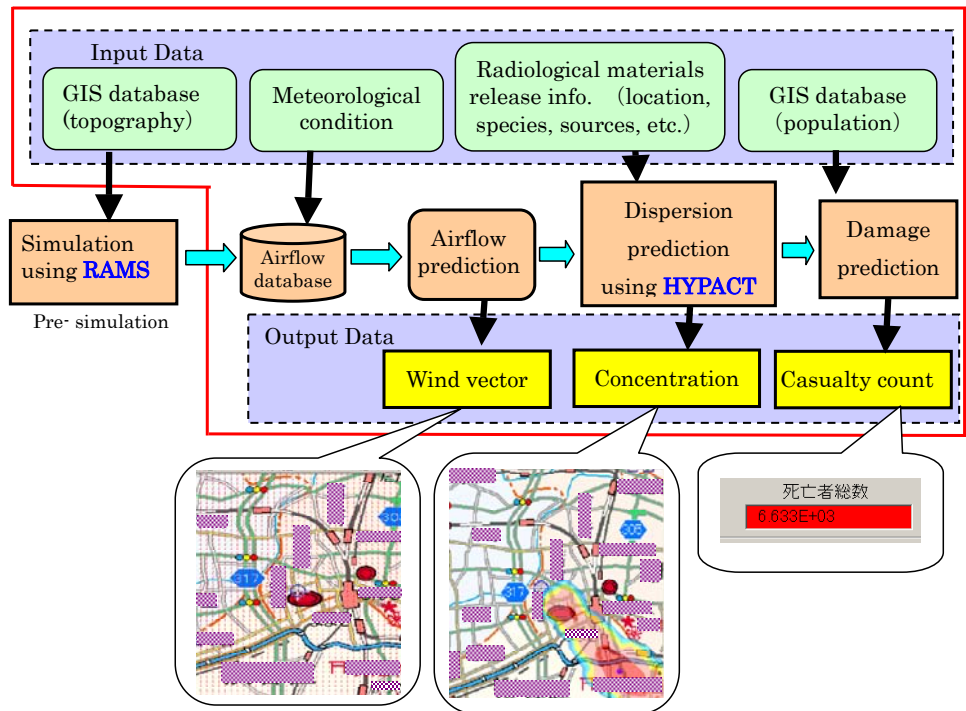


Figure 2.1-1: Structure of the advanced edition of MEASURES

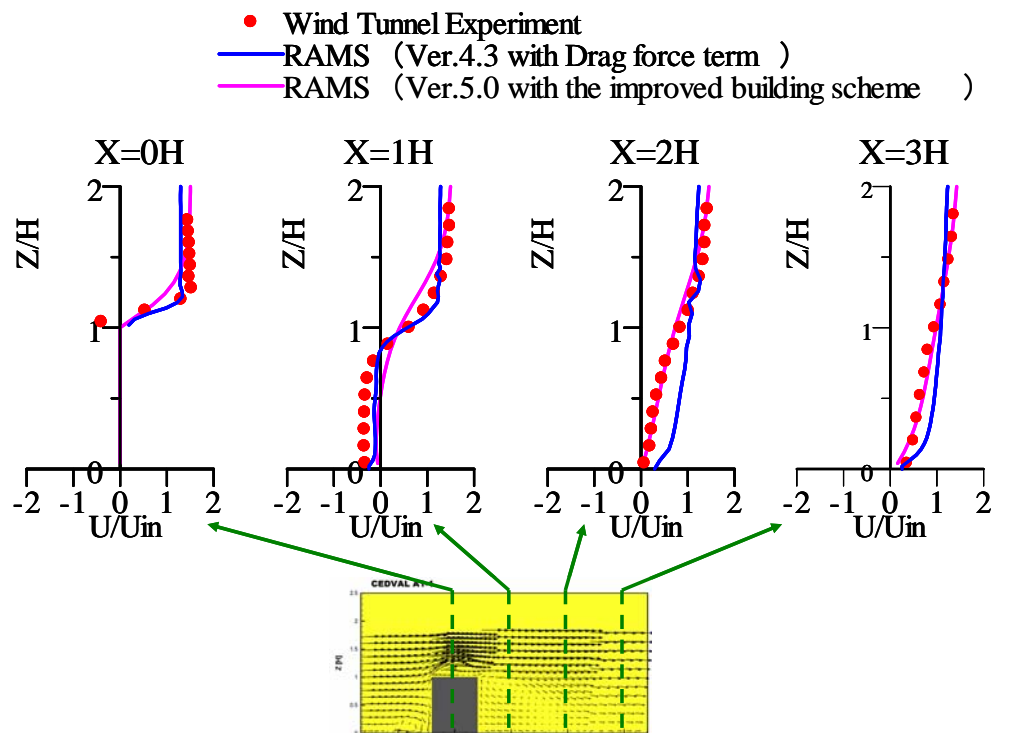


Figure 2.2-1: Comparisons of vertical wind profiles between RAMS simulation and wind tunnel data

Subsequently, the high speed computing scheme, Database Computing System of Air Flow (DCSAF) was developed by MHI (Ohba, 2007). The computing system of DCSAF can be summarized as follows:

1) Steady-state airflow is calculated for a location of interest under various atmospheric conditions: a total of 48 conditions were generated by combining 16 wind directions and 3 atmospheric stabilities.

2) A time series of airflow is generated for the location of interest. In this procedure, the 3-dimensional wind data from the database of 48 atmospheric conditions are interpolated at each time step for the wind direction and the atmospheric stability observed at the location at that time step (Fig. 2.2-2).

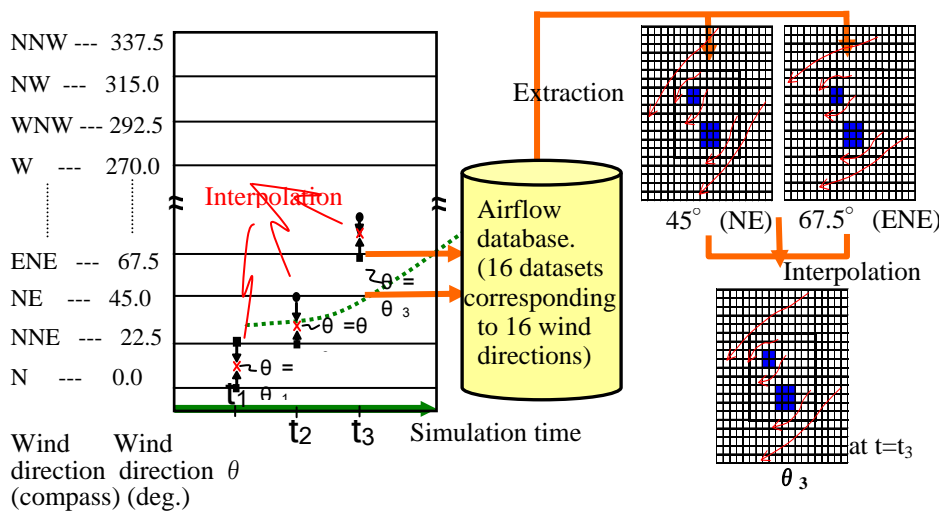


Figure 2.2-2: Simulation of a time-series of unsteady airflow with the interpolation of an airflow database

Because computational time is inversely proportional to the mesh size, simulation with a small mesh size requires significant computational time. However, with the use of DCSAF, the computational time is reduced by a factor of approximately 100 compared to that by a conventional model (Table 2.2-1).

Table 2.2-1: Time required to compute one simulated hour using a PC. Times given are those required to calculate the large-scale grids, the small-scale grids, and the large- and small-scale grids combined, respectively.

Model	100 m <	100 m >	Total
Present model	Few min.	Few sec	Few min.
Conventional	10 min.	200 min.	Few hrs

2.3 Atmospheric diffusion model

The HYPACT (HYbrid PArticle and Concentration Transport) code is an atmospheric diffusion code that can be coupled to RAMS. This code is

based on a Lagrangian particle model that satisfies mass conservation in complex airflow and can adopt the finite difference method at large distances downwind to reduce computational time.

The simulated results of gas concentration were compared and verified with the observational data from Tokai that were collected by the Japan Atomic Energy Research Institute (JAERI) in 1991 and 1992 as shown in Fig. 2.3-1(Hayashi,1998). The effect of building complexes on airflow is well simulated by RAMS and HYPACT for wind velocity and turbulence intensity (Fig. 2.3-2).

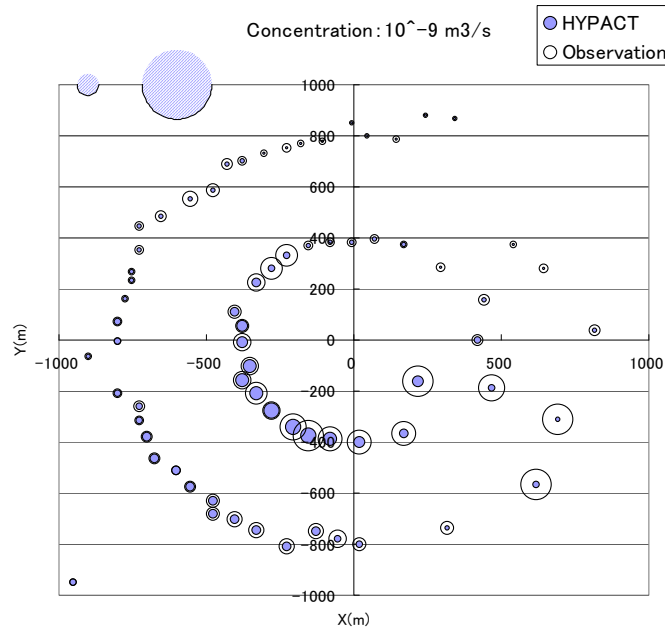


Figure 2.3-1: Comparisons of ground-level concentration at measurement points. The size of the circular symbols indicates the concentration

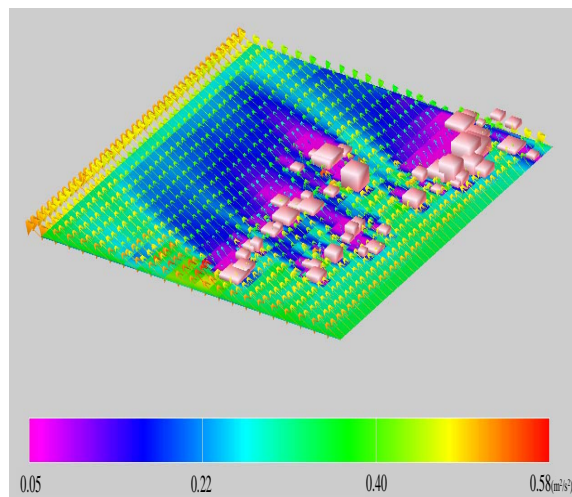


Figure 2.3-2: Simulated wind vectors (arrows) and turbulence intensity (contours) around buildings (white blocks)

3. APPLICATIONS FOR EMERGENCY RESPONSE PLAN

3.1 Overview

The research consortium consisting of the University of Tokyo, the National Institute for Advanced Industrial Science and Technology (AIST), Mitsubishi Heavy Industries (MHI) and AdvanceSoft Corp. is currently in the process of developing a hazard prediction and mitigation simulation system for CBR attacks as assigned by MEXT in 2007. The year-by-year schedule of each sub-theme is shown in Table 3.1-1. A schematic overview of the envisioned completed project is shown in Fig. 3.1-1.

Table 3.1-1: Year-by-year schedule of each sub-theme

Sub theme	2007	2008	2009
1) Prediction system for atmospheric diffusion (MHI)	High-speed computing system	Validation of the system with field experimental data	Evaluation of total system with emergency response drill by Tokyo metropolis
2) Prediction system for diffusion in enclosed space (Advance-Soft)	Base system, Add sub-models	Make-up and Validation of the system	
3) Verification Test (Tokyo University)	Wind Tunnel Experiment	Full-Scale Experiment	
4) Development of evacuation assist system (AIST)	Development of integrated system	Validation of evacuation assist system	
Annual target	Development of fundamental technology	Validation of each technology	Evaluation of total system

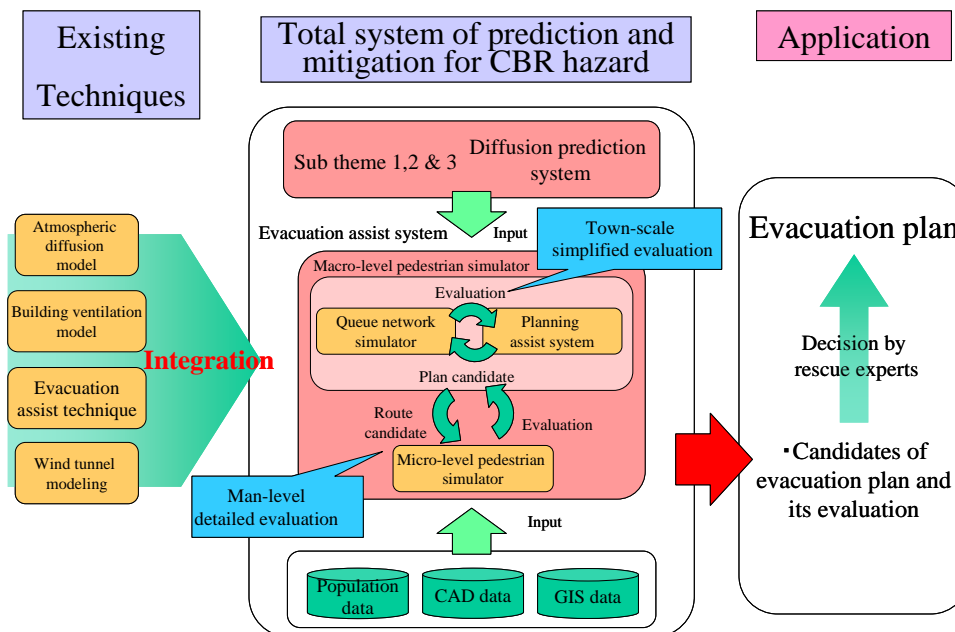


Figure 3.1-1: Schematic overview of the envisioned completed MEXT project for hazard prediction

3.2 Prediction of outdoor gas diffusion

The developed hazard prediction system can display gas concentration and casualties as contour maps.

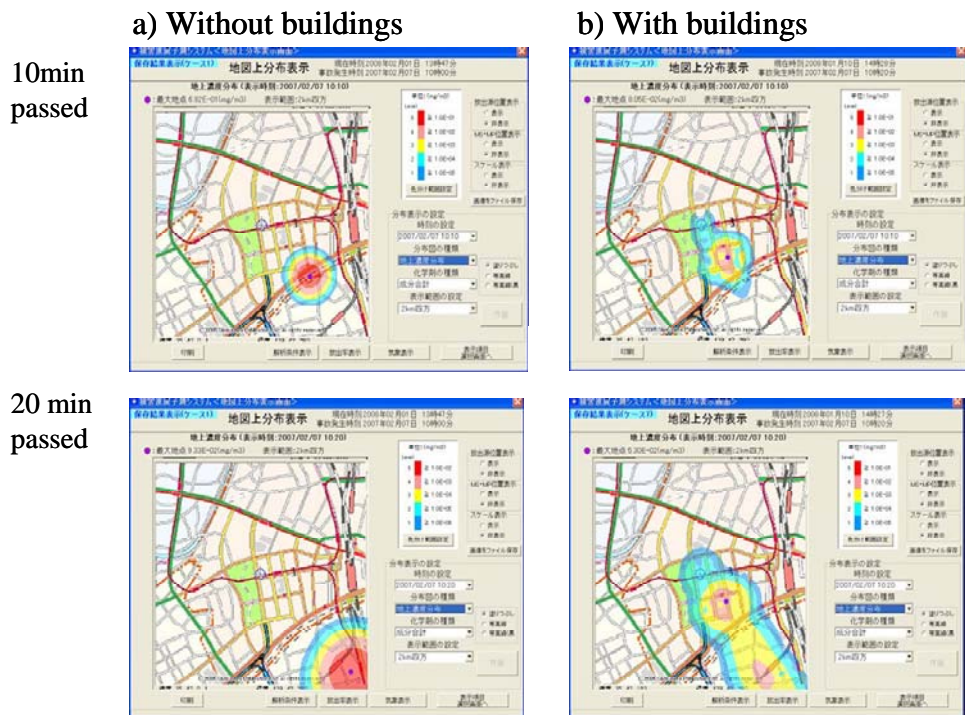


Figure 3.2-2: Comparison of the gas concentration distribution with and without buildings after an instantaneous gas release. Red and blue on the color bars indicate high and low concentrations, respectively.

Fig. 3.2-2 indicates the effects of stagnation by building complexes on gas diffusion in an urban area. Based on a Geographical Information System (GIS) database of building shapes, all the buildings are simplified for the numerical simulation as in Fig. 3.2-3.

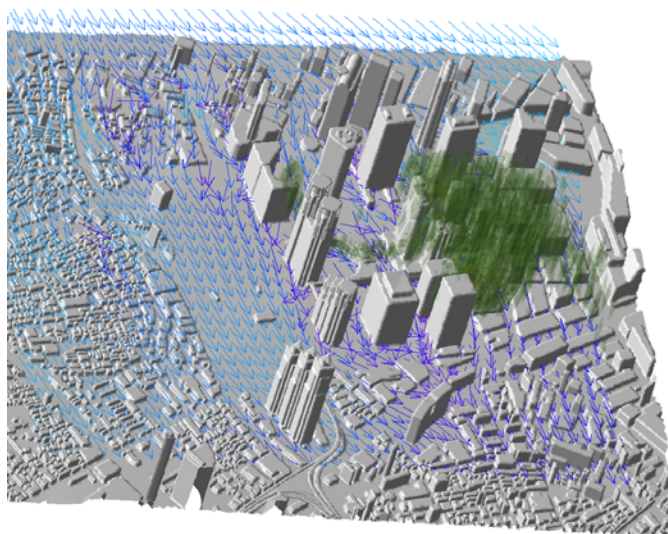


Figure 3.2-3: 3-D view of buildings, extent of diffused gas (green) and wind vectors (blue)

3.3 Prediction system of indoor gas diffusion

AdvanceSoft is developing a practical prediction system for diffusion in enclosed space in the event of a CBR terrorism. This system is based on EVE SAYFA (Enhanced Virtual Environment Simulator for Aimed and Yielded Fatal Accident), which is outcome of the project of “Revolutionary Simulation Software” (RSS) (2005-2008).

The system can be related to airflow control in a space involving complex airflow paths including human activity areas. The structure of EVE SAYFA is shown in Fig.3.3-1.

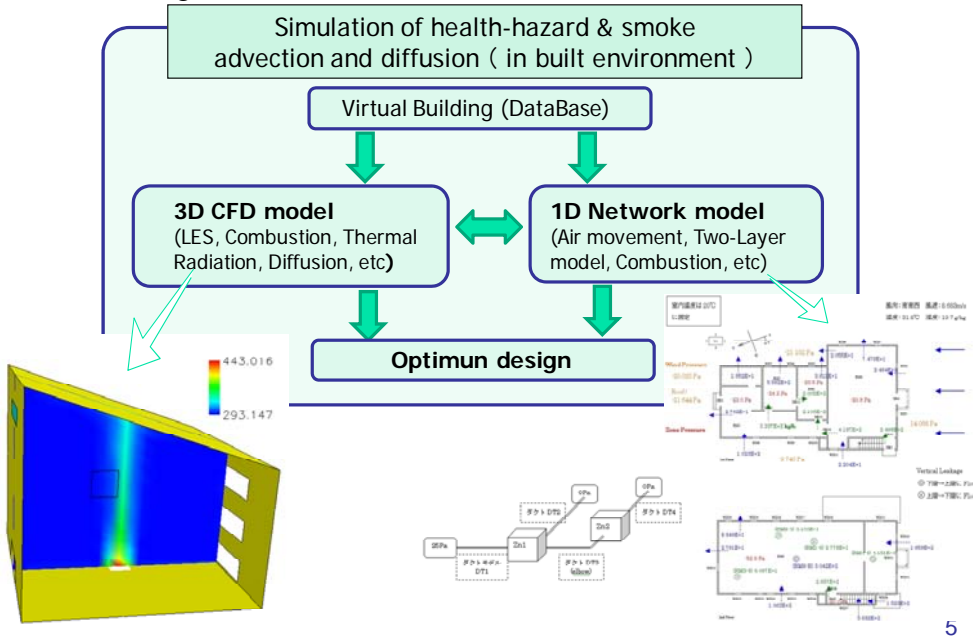


Fig. 3.3-1 Structure of EVE SAYFA

We can reduce the total computing time, saving the result of air movement simulation in Database and reusing for diffusion simulation. This procedure is shown in Fig.3.3-2(right).

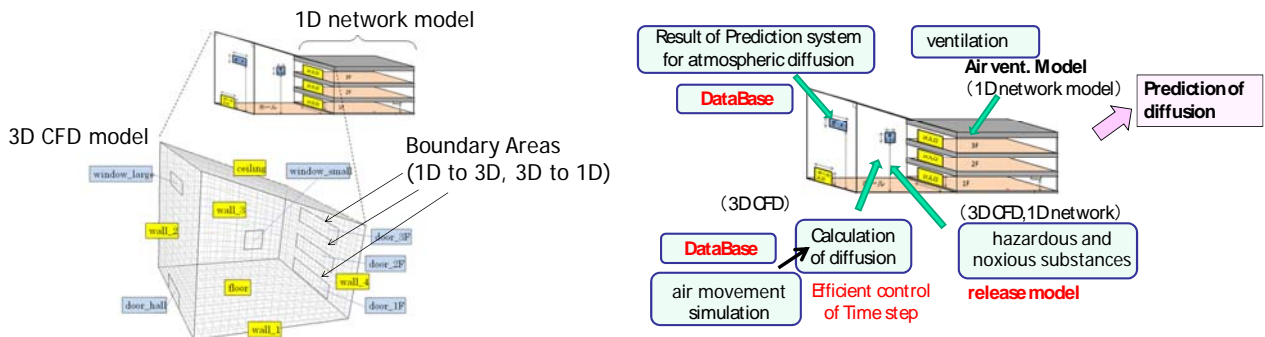


Fig. 3.3-2 Combining models(left) and improvement models(right) of EVE SAYFA

3.4 Assistance system of evacuation planning

National Institute of Advanced Industrial Science and Technology (AIST) proposes an assistance system of evacuation planning, for estimation of evacuation from disasters caused by CBR terrorism. These disasters, which are likely to be caused in urban areas, have many characteristics different from natural disasters. These disasters are caused intentionally, which means we must prepare for the worst; there are still few case that CBR terrorism were actually conducted, which means we still know little about what damage will be caused by such terrorism; unlike natural disasters, these disasters are not always harmful to some of the urban infrastructure, which means that they could be utilized for more efficient evacuation.

We have built a network-based pedestrian simulator, shown in Fig. 3.4-1, to be used to estimate the damage done by CBR terrorism. Compared to previous grid based and continuous space based simulators which took hours to conduct simulations with less than thousands of evacuees, our network-based simulator are designed to conduct simulations much faster, taking less than few minutes for simulation with ten thousands of evacuees.

Our pedestrian simulator is designed to be used with hazard prediction systems of outdoor and indoor gas diffusion, which calculates how harmful gases spread. Using data provided from hazard prediction systems, our assistance system of evacuation planning can be used to estimate how much damage will be done, for various evacuation scenarios. These results could be used to make and evaluate evacuation plans against CBR terrorism.

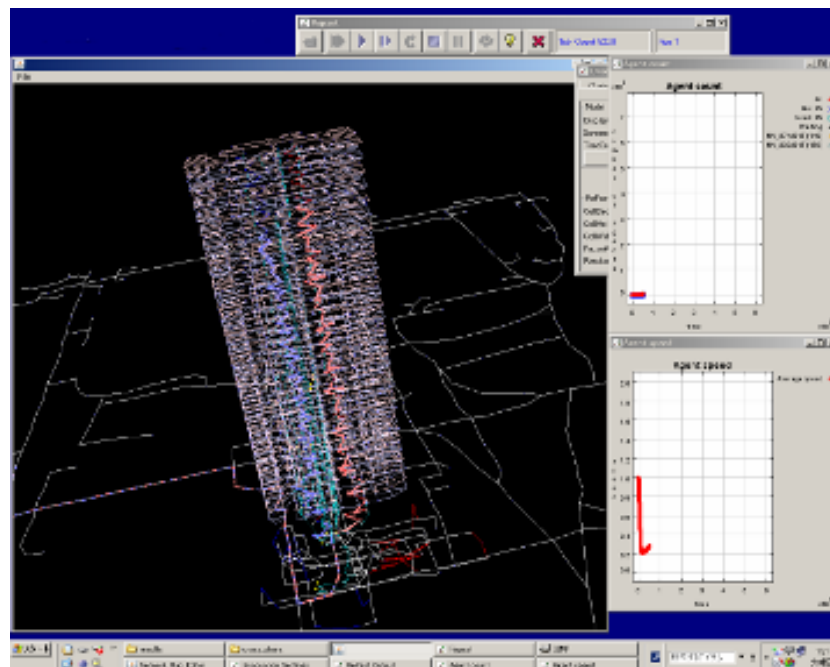


Fig. 3.4-1 3D view of our network-based pedestrian simulator

3.5 Application of prediction system

To validate the applicability of the developed hazard prediction system, the system was run for the CBR attack drills that were conducted in Tokyo and Kitakyushu. The main purpose of this system is to assist municipal fire protection and police agencies at the pre-test stage of routinely conducted drills (Table 3.5-1).

Table 3.5-1: Emergency response items
(Reference: U.S. National Research Council report)

Response items		Time	Action plan
Pre-test	Drill	Routine	Imaginary scenario →round table drill→working drill
Actual accident	Emergency response	0 – 2 hours	Prediction of source terms
	Initial stage	2 – 12 hours	Making a evacuation plan based on real time simulation
	Second stage	12 – 24 hours	Decision making of recovery timing
	Recovery action	1 – few days	Detail reproduction of public hazard

4. SUMMARY

To summarize, the CBR hazard prediction system can:

- 1) simulate the effect of building complexes on airflow and gas diffusion in urban areas.
- 2) compute unsteady airflow and gas diffusion using a mesh size of a few meters on a conventional PC.

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