行政摘要

協定協定協定協定： CE 27/2007 (EP)

升級區域空氣質素模擬系統升級區域空氣質素模擬系統升級區域空氣質素模擬系統升級區域空氣質素模擬系統

香港大氣污染物擴散模型香港大氣污染物擴散模型香港大氣污染物擴散模型香港大氣污染物擴散模型

(PATH)—

可行性研究可行性研究可行性研究可行性研究

 Prepared for:

香港環境保護署

編

纂

英環香港有限公司

報告編號： R1100066

項目編號： HK1100066

二零一一年十一月

日期：

香港

報告要求

有著作權保護的模型(PATH)—可行走研究

開發環境流質體重複模型

編安： CE 27/2007 (EP)

報告要求： CE 27/2007 (EP)
Table of Contents

1. Introduction ................................................................................................................................................ 1

2. Old simulation system and new upgraded simulation system .................................................................. 2

3. Simulation area and grid structure ............................................................................................................. 4

4. Simulation weather events .......................................................................................................................... 7

5. System components ..................................................................................................................................... 8
   5.1 Emission model software ......................................................................................................................... 8
   5.2 Meteorological simulation system ........................................................................................................... 9
   5.3 Chemical transformation model ............................................................................................................... 9
   5.4 Traffic data editing and simulation ......................................................................................................... 10
   5.5 Data analysis and visualization software ............................................................................................... 10

6. System optimization and verification ........................................................................................................... 11

7. Application review ...................................................................................................................................... 11

8. Conclusion ................................................................................................................................................. 11
1. Introduction

To address the complex air quality issues facing Hong Kong, the Environment Protection Department (EPD) of Hong Kong in 2000 (under the contract CE46/95) commissioned the development of a comprehensive computer simulation system known as PATH (Pollutants in the Atmosphere and Their Transport over Hong Kong).

According to EPD's recent research, the current computer simulation system requires upgrading to better understand and solve certain air quality problems in Hong Kong and the Pearl River Delta. The system upgrade includes improvements to the meteorological model, pollution emission model, and pollution dispersion model (PATH).

The objectives of this study include:

• Replacing the existing components of the PATH computer simulation system with the most advanced software available, and enhancing the system's functionality.
• Determining the computer hardware requirements for daily air quality predictions.
• Conducting sensitivity tests of the simulation system to determine the optimal configuration of each sub-system.
• Reviewing the system's performance and providing guidelines for the development of future technologies.

The contract also specified the following tasks:

• Reviewing the latest technology and developments in pollution emission models, meteorological models, and regional air quality models.
• Examining the latest air quality modeling software on the market.
• Reviewing the existing structure and operation of the Hong Kong air pollution dispersion model (PATH).
• Collecting and using Hong Kong and Guangdong traffic data to estimate vehicle pollution emissions.
• Selecting the most advanced software to replace the core components of the existing Hong Kong air pollution dispersion model (PATH).
• Installing the selected software on the existing Hong Kong air pollution dispersion model system.
• Identifying factors that have a clear impact on the simulation results of the upgraded system.
• Evaluating the performance of the upgraded system.
• Training government personnel on the operation and maintenance of the system, and providing recommendations for future development.

In the atmosphere and their transport over Hong Kong, Environmental Protection Department (EPD) of 2000 (under contract CE46/95).
2．舊有的模擬系統與新的升級模擬系統

一套為針對空氣污染問題而建立的數值模型系統，必須能夠處理以下三種大氣中的物理生化過程，分別是氣象運轉、污染物排放模式和化學物轉化。圖一舊有香港大氣污染物擴散模型（PATH）所採用的發展架構簡要圖解。

圖一：舊版PATH系統互動概要

舊有以下列三個不同的模擬組件去計算不同的大氣過程:

- 用於模擬氣象的「中尺度氣象模式第五版本」
- 用於模擬污染源的「污染源模擬系統1995版本」
- 用於模擬污染物擴散和化學轉化的「SARMAP空氣質素模型」

圖二展示了升級後的PATH系統中包含的數個獨立組件的執行流程圖。為了升級舊有的PATH模擬系統，各系統模組的主要組件均選擇應用了技術最新的軟件，包括:

- 

評估和詮釋 (Evaluation and Interpretation)
新版 PATH 組件的互動概要

1. 用於模擬氣象的「中尺度氣象模式第五版本」（Mesoscale Model Version 5, MM5）與「氣候研究預測」（Weather Research Forecast, WRF）系統需要的資料包括:
   a. 日常對高空與地表的觀測，包括風、溫度、相對濕度、海平面氣壓與海平面溫度。
   b. 全球性模型和其他地區性模型的輸出資料。
   c. 地形與土地使用資料。而 SMOKE, CMAQ, and CAMx 模組亦需要 MM5/WRF 軟件輸出的氣象數據作輸入資料。

2. MCIP 是個數據轉換單元，用以把 MM5/WRF 的輸出的數據轉換成能被 CMAQ 使用的型式。

3. Met2CAMx 是個數據轉換單元，把 MM5/WRF 的輸出的數據轉換成能被 CAMx 使用的型式。

4. CMAQ (Community Multiscale Air Quality) 與 CAMx (Comprehensive Air-quality Model with Extensions) 化學傳送模型被選用於模擬污染物擴散和化學轉化。這些模組需要 MM5 或 WRF 模組輸出的數據，亦需要 SMOKE, CONCEPT, MEGAN 和 BEIS 模組預先準備或即時模擬輸出的排放資料。之後 CMAQ 和 CAMx 便可以用作模擬空氣質素數據。
3. 模擬範圍與網格結構

舊有的PATH模擬系統採用了一組分別為40.5, 13.5, 4.5, 1.5和0.5公里的網格結構。而開發於十多年前的模擬範圍更表現了為模擬香港高密度排放跟對電腦運算能力的高需求間的妥協。隨電腦運算能力的提高，系統的網格結構便存在著改良的空間以長期地應付現時空氣質素的問題。籍對現有PATH模擬系統模擬範圍進行研究分析，我們開發了新的網格結構以升級PATH模擬系統。一組包含四個網格區域的模擬範圍會採用於模擬氣象系統，排放模型與化學傳送模型，它們的網格間距分別為27, 9, 3至1公里。下面將詳述這四個網格區域的特徵:

D1 -- 網格一 (27公里):
這最粗糙的外圍網格包括大概整個中國，日本，同時包括台灣，越南，寮國，柬埔寨，泰國等。這遠比舊有PATH模擬系統的外圍網格（只覆蓋華南，台灣與越南北部）要大。

D2 -- 網格二 (9公里):
網格二覆蓋華南（包括廣東省，香港與澳門）。跟舊有PATH模擬系統不同，只覆蓋大半的廣東。

D3 -- 網格三 (3公里):
網格三覆蓋大部份的廣東省，香港與澳門。而舊有的PATH模擬系統則主要覆蓋香港與珠三角地區。

D4 -- 網格四 (1公里):
網格四主要覆蓋珠三角地區，而舊有的PATH模擬系統則只覆蓋香港。

圖三至圖六顯示了四個網格區域的水平模擬範圍。而化學物質傳送模型（CTM）模型的模擬範圍相較於模擬氣象模型的模擬範圍稍細，從而使化學物質轉化模型能套入模擬氣象模型。
協定協定協定協定： CE 27/2007 (EP)

升級區域空氣質素模擬系統

香港大氣污染物擴散模型

可行性研究

HK1100066
協定協定協定協定: CE 27/2007 (EP)

升級區域空氣質素模型

香港大氣污染物擴散模型

(PATH)—可行性研究

HK1100066

圖六

圖六

化學物轉化模型的垂直結構跟隨 MM5/WRF 模型的垂直分層作界定。而 MM5/WRF 模型使用了一個以大氣壓力界定，跟隨地勢的坐標系統，包括了 38 層從地面伸延至 50 mb 氣壓高度（約 20 公里 AGL）的垂直分層。一種平均分層体制被使用作把 CTM 的 38 層分層壓縮至氣象模型的 26 層分層，用以減少化學物轉化模型（CTM）的計算時間。於大部分大氣程序發生的行星邊界層 (PBL) 內的大氣層底部，化學傳送模型 (CTM) 的垂直分層結構與氣象模型的分層結構完全配合。因此，化學物轉化模型 (CTM) 分層結構跟 MM5 垂直分層配合。當處理行星邊界層 (PBL) 外的分層界定時，化學物轉化模型 (CTM) 壓縮了氣象模型的分層，從而得到更高的運算效率。
行政摘要
協定： CE 27/2007 (EP)

升級區域空氣質素模擬系統

香港大氣污染物擴散模型

可行性研究

4. 模擬氣象事件

香港環境保護署（EPD）從過往的時間選擇了四個不同的氣象事件用作測試與論証升級後的香港大氣污染物擴散模型。在27 公里外圍網格測試的每個氣象事件都於首日之前被加上了十天的啟始天數，而較小的網格則在每一個氣象事件的首日之前被加上相對較短的啟始天數。

• 氣象事件一： 2004年9月10日至10月12日；
• 氣象事件二： 2003年11月2日至3日；
• 氣象事件三： 2006年7月24日至25日；
• 氣象事件四： 2006年3月16日至17日。

圖七展示了香港地區用於評估CTM 化學物轉化模型與用於紀錄每個模擬氣象事件的空氣質素監控站位置與識別號。
5. System's Components

5.1 Emission Model Software

SMOKE: SMOKE emission model produces emissions for vehicle, non-road, point, area, and fire emissions as well as biogenic emissions data for the photochemical box model. SMOKE is mainly an emission processing system, not a real emission model system, as emission quantities are simulated based on the "first principle" method. Thus, after eliminating vehicle and natural emission sources, SMOKE emission model is an effective tool to convert the existing emission inventory list into the input format required for the air quality model. SMOKE is also used in all simulation scenarios to prepare point, area, non-road vehicle emissions and non-road non-road non-road vehicle emissions, input data.

CONCEPT: CONCEPT (The Consolidated Community Emissions Processing Tool) emission model utilizes TDM (Traffic Demand Model) Hong Kong data to simulate vehicle emissions for the new emission model system. CONCEPT's road vehicle emission source composition can be represented by road link travel distance (VKT) data, including: speed and vehicle type distribution.

MEGAN: MEGAN (The Model of Emissions of Gases and Aerosols from Nature) simulates natural emissions. MEGAN is the latest natural emission model developed by NCAR (National Center for Atmospheric Research) in the United States, which considers various precursors for ozone and suspended particles. In addition, MEGAN includes the latest version of CAMx secondary organic aerosol module, but other biogenic emission models do not include certain biogenic emission types.

MEGAN is a relatively new biogenic emission model, therefore BEIS (The Biogenic Emission Inventory System) was adopted for simulating biogenic emissions. BEIS3 was adopted for simulating biogenic emissions. BEIS3 was developed in 2001 and is the latest version of the BEIS family. All BEIS3 versions are designed to be compatible with the SMOKE system. The current default version of BEIS is BEIS 3.09. BEIS 3.10 was developed to be compatible with the CMAQ (Community Multiscale Air Quality) model in 2002.

BEIS 3.10 includes a one-kilometer vegetation database used to calculate the crown cover of different tree species; data on emissions coefficients of 34 chemical substances, including 14 monoterpene (monoterpene) and methanol; a calculation method for soil moisture nitrogen content; the relationship between agricultural and non-agricultural land use; and detailed descriptions of CBIV, RADM2, SAPRC99, and related chemical mechanisms. BEIS 3.10 uses a nitrogen content calculation algorithm in soil emissions that was updated in BEIS 3.11, allowing the system to better distinguish agricultural land and non-agricultural land, and limits the changes to temperature, rainfall, fertilizer usage, and the relationship between crop cover and growing season and field area. A leaf cover calculation method was also added to calculate methanol emissions in non-forested areas. BEIS 3.12, published in November 2003, is the latest version. It is an independent component of SMOKE, used to generate emissions with air quality model formats.
CMAQ: CAMx: The Comprehensive Air-quality Model with Extensions (CAMx) is a community model that simulates chemical transformations in the atmosphere. It is used to predict air quality and the impact of various emissions on air quality. CAMx has been upgraded to improve its accuracy and reliability.

CMAQ: CMAQ: Models-3 Community Multiscale Air Quality (CMAQ) is a regional model used to simulate air quality and the impact of various emissions on air quality. It is used to predict air quality and the impact of various emissions on air quality. CMAQ has been upgraded to improve its accuracy and reliability.

CMAQ: CAMx: CAMx: The Comprehensive Air-quality Model with Extensions (CAMx) is a community model that simulates chemical transformations in the atmosphere. It is used to predict air quality and the impact of various emissions on air quality. CAMx has been upgraded to improve its accuracy and reliability.

CMAQ: CMAQ: Models-3 Community Multiscale Air Quality (CMAQ) is a regional model used to simulate air quality and the impact of various emissions on air quality. It is used to predict air quality and the impact of various emissions on air quality. CMAQ has been upgraded to improve its accuracy and reliability.

CMAQ: CAMx: CAMx: The Comprehensive Air-quality Model with Extensions (CAMx) is a community model that simulates chemical transformations in the atmosphere. It is used to predict air quality and the impact of various emissions on air quality. CAMx has been upgraded to improve its accuracy and reliability.

CMAQ: CMAQ: Models-3 Community Multiscale Air Quality (CMAQ) is a regional model used to simulate air quality and the impact of various emissions on air quality. It is used to predict air quality and the impact of various emissions on air quality. CMAQ has been upgraded to improve its accuracy and reliability.

CMAQ: CAMx: CAMx: The Comprehensive Air-quality Model with Extensions (CAMx) is a community model that simulates chemical transformations in the atmosphere. It is used to predict air quality and the impact of various emissions on air quality. CAMx has been upgraded to improve its accuracy and reliability.

CMAQ: CMAQ: Models-3 Community Multiscale Air Quality (CMAQ) is a regional model used to simulate air quality and the impact of various emissions on air quality. It is used to predict air quality and the impact of various emissions on air quality. CMAQ has been upgraded to improve its accuracy and reliability.

CMAQ: CAMx: CAMx: The Comprehensive Air-quality Model with Extensions (CAMx) is a community model that simulates chemical transformations in the atmosphere. It is used to predict air quality and the impact of various emissions on air quality. CAMx has been upgraded to improve its accuracy and reliability.

CMAQ: CMAQ: Models-3 Community Multiscale Air Quality (CMAQ) is a regional model used to simulate air quality and the impact of various emissions on air quality. It is used to predict air quality and the impact of various emissions on air quality. CMAQ has been upgraded to improve its accuracy and reliability.

CMAQ: CAMx: CAMx: The Comprehensive Air-quality Model with Extensions (CAMx) is a community model that simulates chemical transformations in the atmosphere. It is used to predict air quality and the impact of various emissions on air quality. CAMx has been upgraded to improve its accuracy and reliability.

CMAQ: CMAQ: Models-3 Community Multiscale Air Quality (CMAQ) is a regional model used to simulate air quality and the impact of various emissions on air quality. It is used to predict air quality and the impact of various emissions on air quality. CMAQ has been upgraded to improve its accuracy and reliability.

CMAQ: CAMx: CAMx: The Comprehensive Air-quality Model with Extensions (CAMx) is a community model that simulates chemical transformations in the atmosphere. It is used to predict air quality and the impact of various emissions on air quality. CAMx has been upgraded to improve its accuracy and reliability.

CMAQ: CMAQ: Models-3 Community Multiscale Air Quality (CMAQ) is a regional model used to simulate air quality and the impact of various emissions on air quality. It is used to predict air quality and the impact of various emissions on air quality. CMAQ has been upgraded to improve its accuracy and reliability.

CMAQ: CAMx: CAMx: The Comprehensive Air-quality Model with Extensions (CAMx) is a community model that simulates chemical transformations in the atmosphere. It is used to predict air quality and the impact of various emissions on air quality. CAMx has been upgraded to improve its accuracy and reliability.

CMAQ: CMAQ: Models-3 Community Multiscale Air Quality (CMAQ) is a regional model used to simulate air quality and the impact of various emissions on air quality. It is used to predict air quality and the impact of various emissions on air quality. CMAQ has been upgraded to improve its accuracy and reliability.

CMAQ: CAMx: CAMx: The Comprehensive Air-quality Model with Extensions (CAMx) is a community model that simulates chemical transformations in the atmosphere. It is used to predict air quality and the impact of various emissions on air quality. CAMx has been upgraded to improve its accuracy and reliability.

CMAQ: CMAQ: Models-3 Community Multiscale Air Quality (CMAQ) is a regional model used to simulate air quality and the impact of various emissions on air quality. It is used to predict air quality and the impact of various emissions on air quality. CMAQ has been upgraded to improve its accuracy and reliability.

CMAQ: CAMx: CAMx: The Comprehensive Air-quality Model with Extensions (CAMx) is a community model that simulates chemical transformations in the atmosphere. It is used to predict air quality and the impact of various emissions on air quality. CAMx has been upgraded to improve its accuracy and reliability.

CMAQ: CMAQ: Models-3 Community Multiscale Air Quality (CMAQ) is a regional model used to simulate air quality and the impact of various emissions on air quality. It is used to predict air quality and the impact of various emissions on air quality. CMAQ has been upgraded to improve its accuracy and reliability.

CMAQ: CAMx: CAMx: The Comprehensive Air-quality Model with Extensions (CAMx) is a community model that simulates chemical transformations in the atmosphere. It is used to predict air quality and the impact of various emissions on air quality. CAMx has been upgraded to improve its accuracy and reliability.

CMAQ: CMAQ: Models-3 Community Multiscale Air Quality (CMAQ) is a regional model used to simulate air quality and the impact of various emissions on air quality. It is used to predict air quality and the impact of various emissions on air quality. CMAQ has been upgraded to improve its accuracy and reliability.
CAMx 4.51 is used as the atmospheric chemistry model and CAMx is configured to run with a horizontal resolution of 27/9/3/1 km grid. However, CAMx's initial configuration setup uses double-nested grids for the 27/9/3/1 km simulation range, and single-nested grids for the 9/3/1 km and 3/1 km simulation ranges (CMAQ does not support double-nested grids). Since the entire 27/9/3/1 km grid structure is too large, typical computer memory cannot simulate all four sets of simulation ranges using double-nested grids. Most of the sensitivity tests only check the parameters of the 3/1 km and 1 km simulation ranges, therefore single-nested grids are more efficient in computation.

CAMx's basic configuration is set to 26 layers vertically up to 50 mb height (equivalent to ~20 km altitude on the ground), which is the same as CMAQ's basic configuration. PPM advection scheme is used for spatially variable dispersion methods, while CAMx's vertical dispersion simulation uses the K-theory. CAMx's vertical transport of species is the same as CMAQ's MCIP3.3 model's "pass through" option. MET2CAMx processor is responsible for handling medium scale numerical weather models (MM5) and the Weather Research and Forecasting (WRF) model's data. In the initial setup, CAMx is configured to work with CB05 for gas-phase species, RADM for liquid species, and CMU/ISORROPIA for aerosols as the basic configuration. The upgraded SOAP secondary organic aerosol scheme is also used as CAMx's basic configuration. This version includes improvements to the treatment of emissions derived from isoprene and sesquiterpenes. The final optimization and verification simulations use the latest CAMx V5.3 CTM.

Traffic data processing and modeling were conducted by the Environmental Protection Department using the EMFAC-HK vehicle emission model for air quality planning and related work. However, EMFAC-HK is not always suitable for use with ConCEPT for emission modeling, so it is necessary to address this issue during the PATH system upgrade study. EMFAC-HK is adapted from the 2002 EMFAC software used in California. The Mobile6 (MOBILE6) model developed by the US Environmental Protection Agency is widely used in many states except California to manage air quality emissions from road vehicles. According to the requirements of the summary, the Mobile6 model was used to evaluate Hong Kong's vehicle emissions, and the research team also developed a suitable Mobile6 version for Hong Kong.

ConCEPT V5.0 is used for Mobile6-HK vehicle emission data and annual average vehicle distance driven (VKT), with the output being used to estimate Hong Kong's total vehicle emissions. Annual average vehicle distance driven and speed are obtained from TDM, a traffic demand model developed by MVA Hong Kong Limited. The model is based on the year 2005 as the base year. Other study years (2003, 2004, and 2006) were estimated using the traffic statistical data from the Transport Department and predicted/reconstructed coefficients. ConCEPT uses the Mobile6-HK emission model and journey characteristic VKT data to produce high-resolution, temporal, and spatial vehicle emission inventories. The gridized temperature and humidity data from the MM5 and the Weather Research and Forecasting (WRF) weather model are used to adjust the Mobile6-HK emission factors. The data analysis and visualization software used by the research team is designed to display the results of meteorological, emission, and chemical transport models. To handle the results of meteorological, emission, and chemical transport models, we have modified the data analysis tools to display model results in scatter plots, time series graphs, and model performance statistics and spatial maps. In addition, these tools have been modified to display the input and output data of meteorological, emission, and chemical transport models, and provide two- and three-dimensional interactive visualization features.
6. 最新版本的CMAQ与CAMx化学物转化模型成功地应用于三个过往的气象事件以估计香港与珠江三角洲地区的空气质素。同时，两个化学物转化模型的使用与使用了中尺度数值天气模式（MM5）与天气研究与预报模式（WRF）气象模型的模拟结果作为输入数据的论证模拟都未遇到问题。最后的模拟验证了两个化学物转化模型是可操作的，并准备好协助香港环境保护署处理空气质素的问题。

7. 应用检讨

当升级了的香港大气污染物扩散模型（PATH）被提交给环境保护署并在环保署的电脑上安装后，对环保署的员工进行了培训使用系统。环保署已使用本模拟系统对香港与珠三角区域进行了2010整年的气象与空气质素预测。在开发新的空气质素模型系统的过程中，研究团队一直致力于更新模型系统，使模型系统应用了最新的模型组件。而在最后的优化与论证模拟中，使用了最新版本的CMAQ（4.7.1版本，于2010年7月发行）和CAMx化学传送模型（5.3版本，于2010年12月发行）。

当化学物转化模型应用于模拟2003年至2006年的气象事件和预测2010年整年的气象与空气质素预测时，新空气质素模型系统验证了于香港与珠三角地区制定空气质素管理计划的功效。模型系统现已全面运行并准备好进行日常的应用。