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Health Impact Analysis of Construction Projects, a Case Study in Hong Kong

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Abstract - Diesel-powered construction equipment emits large amounts of pollutants including $PM_{2.5}$ and NO_2 due to diesel combustion in various construction activities, which pose threats to the human beings on and around the site. Long-term exposure to diesel pollutants can increase the risk of premature mortality and morbidity, especially from respiratory and cardiovascular diseases. A framework is proposed to assess the health and economic impact of diesel emissions of $PM_{2.5}$ and NO_2 from construction equipment on construction workers from a project level, an AERMOD dispersion model is used to simulate the concentrations of contaminants, appropriate corresponding-response function for health impact assessment (HIA) and the value of statistical life (VOSL) for economic impact assessment (EIA). A case study is made on a building project in Hong Kong with 5 pieces of active construction equipment to demonstrate the significance of health damage and the economic impact of construction equipment emissions on workers, which estimates that the yearly economic impact of the two types of emissions from construction equipment reaches HKD 252,694.85.

***Keywords*:** Health impact analysis; Economic impact analysis; Construction equipment; Diesel emissions; Dispersion modelling.

1. Introduction

As an energy-intensive industry, the construction sector has a significant negative impact on the environment and human health due to the discharge of pollutants into the atmosphere during various construction activities. Construction equipment emits a considerable amount of greenhouse gases and air pollutants in metropolitan areas during construction processes such as site preparation, foundation works, road construction [1], etc. Air pollution is one of the most serious environmental threats to health. It was estimated that in 2019, 4.2 million premature deaths were caused by cardiovascular and respiratory disease, and cancers, due to exposure to fine particulate matter [2]. Both short and long-term exposure to harmful pollutants including carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbon (HC), and particulate matter (PM) emitted from heavy construction equipment can lead to increased risks of mortality and morbidity, especially from respiratory and cardiovascular diseases (Wong et al., 2016).

In Hong Kong, regional air pollution mainly comes from power plants, industry and motor vehicles in both Hong Kong and the Pearl River Delta region [4]. The Hong Kong Environmental Protection Department (EPD) operates a system of air quality monitoring stations consisting of 15 general stations and 3 roadside stations to measure the amounts of primary air contaminants [5]. According to the air quality statistical summary, the highest 1-hour average (240 $\mu g/m^3$) and annual average (65 $\mu g/m^3$) of NO_2 were observed in 2022 in Hong Kong, which is the only type of pollutant that exceeded the annual limit value (40 $\mu g/m^3$) set by the government [6]. The highest monitored annual average concentration of $PM_{2.5}$ reached 21 $\mu g/m^3$ in 2022, which significantly exceeded the limit value of 10 $\mu g/m^3$ recommended by the World Health Organization (WHO).

Air pollution can cause both mild physiological changes in the body and more severe symptoms including coughing, tightness in the chest, nose and throat discomfort, and shortness of breath [4]. Frequent exposure to diesel exhausts over the years can raise the risk of lung cancer. According to HKIE (2016), Hong Kong's annual diesel consumption is about 1,440, 000 tonnes, with the construction sector accounting for around 12.3% of the total. There is now accumulating evidence that long-term exposure to particulates may be connected with neurodevelopment in children, cognitive function, and other chronic disorders such as diabetes [8]. Long-term exposure to NOx can reduce human resistance to respiratory infections and worsen chronic respiratory disorders [9]. To control occupational health issues, government agencies in many nations and regions have launched guidelines and reports especially for high-risk industries like the mining industry, construction industry, chemical industry [10], [11], [12], etc. Occupational exposure limits (OELs) for various chemical substances including NO_2 and $PM_{2.5}$ have been issued to prevent employees from inhaling excessive amounts of contaminants that could be harmful to their health [13], [14], [15], [16], [17]. The time-weighted average concentration (TWA) of a substance over an 8-hour working day for a five-day workweek is generally used to indicate the exposure limit value. For example, the OEL-TWA of NO_2 and inhalable particulate matter are set at 5.6 and 3 $\mu g/m^3$ in Hong Kong. To directly and effectively mitigate occupational health issues raised by air pollutants in the construction industry, it is significant for the government to assess the health impact of construction equipment emissions and set regulatory control measures for emission reduction.

This paper aims to assess the health and economic impact of diesel emissions of $PM_{2.5}$ and NO_2 from construction equipment on-site workers in the foundation works of a building project, using the AERMOD dispersion model to simulate the concentrations of contaminants, and conducting health impact assessment using appropriate corresponding-response function and the economic impact assessment using the metrics of the value of statistical life (VOSL).

2. Health impact analysis and economic impact analysis

The association between emission pollutants from diesel combustion and health has been well established. The World Health Organisation proposed the Environmental Burden of Disease (EBD) as an index for objectively assessing the impact of environmental risk factors on human health at the population level [18]. Among the procedures of HIA, there are two major steps: 1) estimate the exposure of the research group to pollutants, and 2) assess the impact of pollutants on human health using appropriate concentration-response models. Methods for estimating exposure of receptors to pollutants mainly include measuring the concentration using monitor devices, simulation of emission dispersion, and empirical studies for regional research. The commonly used methods for assessing health impact by concentration-response models include the Disability-adjusted life years (DALYs) method reported by World Health Organization [18], Integrated Risk Information System (IRIS) to evaluate the health risks of carcinogens and non-carcinogens to human health [19], and quantifying health damage using relative risks (RRs) and log-linearity or non-linearity concentration-response functions [20], which is adopted in this research and is widely acknowledged and used in HIA research and projects [3], [21], [22].

For construction workers, the exposure to diesel emission pollutants is defined as sub-chronic, which can be categorized as long-term exposure [19]. The health outcomes selected in this research include premature mortality and hospital admissions for cardiovascular and respiratory diseases due to long-term exposure to diesel emissions of $PM_{2.5}$ and NO_2. The attributable health outcome caused by exposure to pollutants can be calculated using Equation (1) and (2).

$$AH_{d,p} = BH_d \times AF_{d,P} \tag{1}$$

$$AF_{d,p} = (RR_{c,p})/RR_{c,p} \tag{2}$$

Where $AH_{d,p}$ is the attributable health outcome d caused by exposure to pollutant p; BH_d is the baseline health outcome data, which is the annual number of health outcome d in Hong Kong, and d refers to non-accidental deaths and hospital admissions for cardiovascular and respiratory diseases in Hong Kong; AF_d is the attributable fraction for health outcome d, which refers to the fraction of the given d resulting from a specific variation in the concentration of air pollutant in epidemiology; $RR_{c,p}$ is the corresponding RR, which refers to the relative risk of the pollutant p for the specific concentration change C.

The corresponding RRs for $PM_{2.5}$, NO2 and CO are calculated by Equations (3) and (4).

$$RR_{d,p,10} = e^{\beta_{d,p}/10 * (\Delta C_{p,A})} \tag{3}$$

$$\beta_{d,p} = lnRR_{(d,p,10)} \tag{4}$$

where $RR_{d,p,10}$ is the RR per 10 μg/m^3 change in the concentrations of the air pollutant p for health outcome i, which can be obtained from cohort epidemiology studies; $\beta_{d,p}$ is the exposure-response coefficient of health outcome d for pollutant p; $\Delta C_{p,A}$ is the corresponding exposure concentration change of pollutant p, which is the adjusted concentration defined by [19] as a sub-chronic exposure, calculated by Equation (5).

$$\Delta C_{p,A} = (\Delta C_p \times ET \times EFr \times ED)/AT \tag{5}$$

where ΔC_p is the simulated concentrations of construction equipment emissions; ET is the exposure time (hrs./day); EFr is the exposure frequency (days/week); ED is the exposure duration (weeks/exposure period); and AT is the averaging time of exposure (hrs./exposure period).

Economic impact assessment (EIA) is the process of evaluating the health effects of air pollution. EIA is significant in the decision-making process of air pollution control because it creates 'external costs' that are borne by individuals whose health is influenced, rather than the polluter. These costs are incurred as a result of increased demand for medical care, the loss of economic productivity due to chronic illness, the need for communities to bear the social costs of informal care for people with disabilities and long-term health issues [23], etc. This research adopts the willingness to pay (WTP) approach to assess the economic impact of diesel pollutants on construction workers' health, which is a widely accepted approach for EIA that uses people's willingness to pay to avoid a premature death in a community-- Value of a statistical life (VOSL) -- to measure the economic costs of premature deaths, as it is the single most important item in the cost estimate (>90%) [3]. The economic impact value due to the change in workers' exposure to diesel emission pollutants on construction sites is calculated using Equation (6).

$$EI_{d,p} = AH_{d,p} \times UC_d \tag{6}$$

where $EI_{d,p}$ is the economic impact of disease d caused by the change of exposure to pollutant p; UC_d is the unit cost of disease d.

3. Diesel pollutant dispersion modelling

Dispersion simulation models for estimating exposure to pollutants mainly include the American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD), Community Multiscale Air Quality (CMAQ), Computational Fluid Dynamic (CFD), Monte-Carlo simulation [24], [25], [26], etc. The AERMOD View dispersion model is used to estimate the pollutant concentration in the construction site area in this research [27]. AERMOD model is a steady-state plume model based on theories of scaling and planetary boundary layer turbulence structure and can be applied to simulate large-scale air dispersion [28]. It is the regulatory air dispersion model for environmental impact assessments in various projects globally [28], [29], [30].

AERMOD has two built-in input data processors: AERMET, the meteorological data preprocessor; and AERMAP, the terrain data preprocessor. The ground meteorological data is acquired online, and the upper-air meteorological data and the terrain data in the form of a DEM file with a 90m resolution is generated and achieved automatically by the built-in preprocessor. The information data of emission points, i.e. the construction equipment, is acquired from the contractor and by site visits. The outputs of the AERMOD model include the text and graphical results of the top few values of pollutant concentrations at various receptor locations, as well as concurrent concentration values in the text format at the pre-set time intervals.

4. Case study

The aim of the case study is to assess the health and economic impact of construction equipment on the site workers. The data and information of the case project are collected from an ongoing student hostel project in Hong Kong by contacting the contractor and site visits. The site area of the project is about 12,620 m^2, with a domestic floor area of 2,500 m^2 and a non-domestic floor area of 970 m^2. The simulation for the dispersion of diesel emission pollutants on the construction site is performed by AERMOD View software. Five pieces of equipment for pile foundation works are located on the site as point sources, with the equipment and emission information presented in Table 1. The meteorological data of July 2023 is used for simulation, and the working hour is set as 8 hours per day, 6 days per week. As NO_2 is unstable and easily reacts with oxygen molecules in the air to form various types of nitrogen oxides, the emission rates are deducted by 30% to achieve approximation values. The example of source input parameters for equipment is shown in Figure 1.

Table 1. Equipment and emission information for the case project

	Model	Power (kW)	Emission standard	Emission rate for $PM_{2.5}$ (g/s)	Emission rate for NO_2 (g/s)
1	ZX520LCH-5B	270	GB 3 (Tier 3)	0.015	0.210
2	DX340LC	191	EU 3A (Tier 3)	0.0106	0.149
3	SK210-YIVI2	118	MoE2 (Tier 2)	0.0098	0.151
4	DX340LC	191	EU 3A (Tier 3)	0.0106	0.149
5	SK350LC-10	209	MoE Stage 2 (Tier 2)	0.0106	0.383

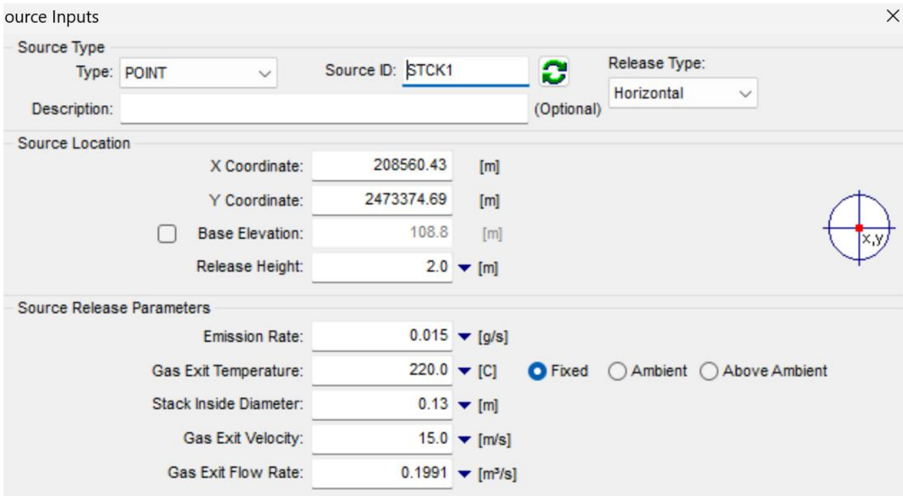

Figure 1. Source inputs for equipment 1

The examples of the dispersion pattern of $PM_{2.5}$ and NO_2 are shown in Figures 2 and 3. It can be observed that the 8-hour averaged concentrations follow the Gaussian distribution, with the highest concentrated within the construction site while the impact on the neighbourhood is relatively small, especially for the dispersion of $PM_{2.5}$.

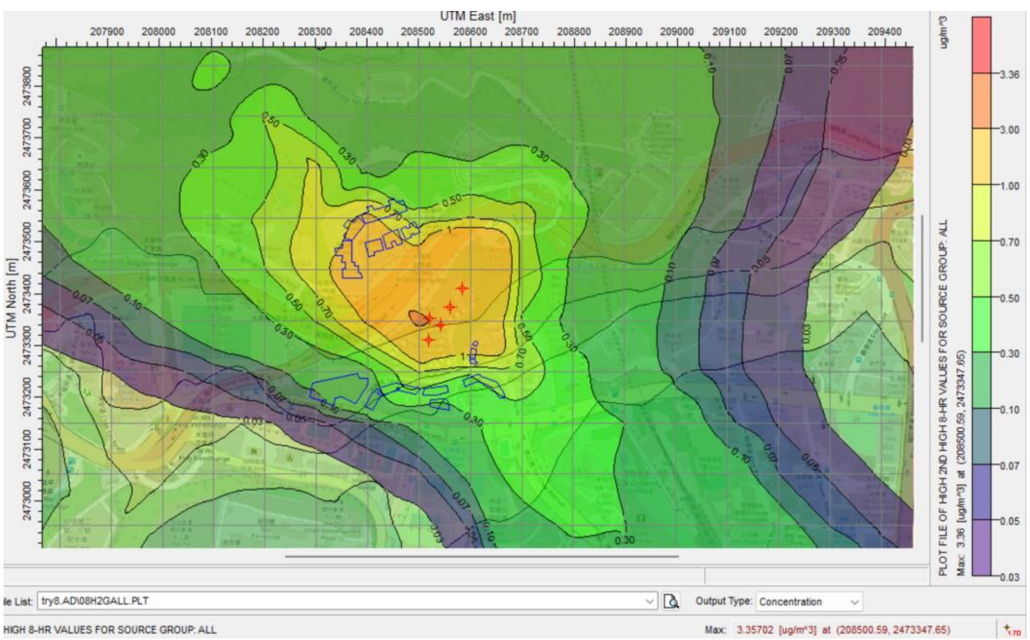

Figure 2. Example of the dispersion pattern of $PM_{2.5}$

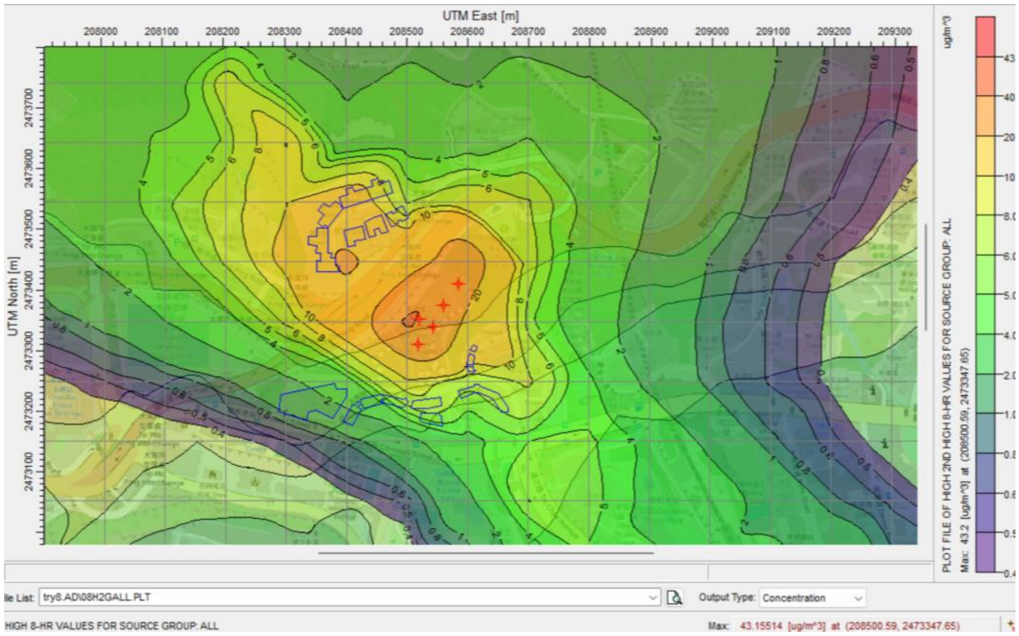

Figure 3. Example of the dispersion pattern of NO_2

The statistics of mortality for the age group 15-64 in 2022 are acquired from the Hong Kong Department of Health [31] as the health outcome baseline data, and the RRs of $PM_{2.5}$ and NO_2 used follow the study of Wong [3], where an overlap of 30% for the impact of two pollutants is considered. Based on Equations (1) to (5), the HIA results for the construction equipment emissions of $PM_{2.5}$ and NO_2 in the case project are calculated. The counted number of workers on site in this preliminary calculation is 20. The health outcome baseline data collected and the adjusted exposure concentration of workers are presented in Tables 2 and 3.

Table 2. Number of mortalities by leading causes by sex and age in 2022

	Population 15-44 (thousand)	All-cause Mortality	Population 45-64 (thousand）	All-cause Mortality
Male	1205.3	795	1056.7	5163
Female	1502	491	1341.3	3083
Total	**2707.3**	**1286**	**2398**	**8246**

Table 3. Results of concentration simulation, μg/m^3

	$PM_{2.5}$	NO_2
8-hour Concentration (Include 5 equipment on site)	3.357-2.093	43.155-27.560
Average concentration	2.725	35.358
Adjusted exposure concentration	0.791	10.265

The VOSL, which is the single most important item in the cost estimate (>90%), is used to illustrate the economic impact of pollutant emissions for on-site workers of the case project. The unit value of the VOSL adopted in the calculation is HKD 15.7 million, following the previous local study (Wong et al., 2016). The calculation of VOSL follows Equation (6), and the results are presented together with the HIA results in Table 4. The VOSL estimated for construction equipment on site for the $PM_{2.5}$ and NO_2 reach HKD 26,962.56 and 225,768.29respectively, with a total value of HKD 252,694.85, illustrating that the health and economic impact of diesel emissions of construction equipment for workers on site is significant.

Table 4. HIA and EIA results of the case project for construction equipment

	$PM_{2.5}$	NO_2
Relative risk (10μg/m^3), All-cause mortality	1.06 (1.02-1.11)	1.039(1.022-1.056)
Relative risk (1μg/m^3), central	1.005844	1.003833
Corresponding RR, central value, average for single equipment	1.000922358	1.007885093
Attributable factor (AF)	0.004599056	0.038509736
Attributable death	0.000171736	0.001438015
VOSL (HKD)	**26962.56**	**225768.29**

5. Conclusions

Long-term exposure to diesel pollutants including carbon NO_2 and $PM_{2.5}$ emitted from heavy construction equipment can increase the risk of premature mortality and morbidity, especially from respiratory and cardiovascular diseases. It is urgent for the government to assess the health impact of construction equipment emissions and set regulatory control measures for emission reduction. This paper proposes a framework to assess the health and economic impact of construction equipment on workers on the project level, which integrates the AERMOD dispersion model, health impact analysis and VOSL method. A case study is used to demonstrate the significance of health damage and economic impact of construction equipment emissions on workers, in which the yearly economic impact of emissions from equipment reaches HKD 26,962.56 and 225,768.29 respectively, with a total value of HKD 252,694.85. The health and economic impact analysis directly illustrates the necessity of emission reduction of construction equipment and provides references for developing feasible strategies and policies. Based on the assessment framework and results, emission reduction measures including replacement and installing retrofitting technologies for construction equipment can be made accordingly to mitigate the health impact considering the cost-effectiveness.

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