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論文題目	Model Simulation and Health Risk Assessment on Traffic Induced Air Pollution in Urban Environment: A Case Study of Kyoto City, Japan (都市環境における交通起源大気汚染のモデルシミュレーションと健康リスク評価：京都市でのケーススタディ)		

（論文内容の要旨）

This research discusses the traffic induced air pollution in Kyoto City, Japan in terms of emission, dispersion, risk-based assessment and management. This research was completed in seven chapters as follows:

Chapter 1 Introduction

Chapter 1 presents the overview of background, problem statements, research objectives and scopes, and outline of the dissertation.

Chapter 2 Literature review

Chapter 2 reviews the previous studies on traffic characteristics, vehicle emission model (Computer Program to Calculate Emissions from Road Transport; COPERT model), air dispersion model (Operational Street Pollution Model; OSPM model), health risk assessment and framework of risk assessment and management.

Chapter 3 Traffic characteristics and pollutant emission from urban road transport

Chapter 3 presents the prediction of traffic characteristics and emissions of air pollutants for two vehicle classifications (passenger cars and trucks) at the roadways in Kyoto City, Japan. The roadways are categorised into five functional classes such as highway under jurisdiction of Ministry of Land, Infrastructure, Transport and Tourism (H-MLIT), highway administered by prefectural authority (H-P), main municipal road (MM), prefectural road (P) and general municipal road (GM). A vehicle emission model, known as the Computer Program to Calculate Emissions from Road Transport (COPERT), was utilised to compute the emission factors (EFs) and total emissions of air pollutants (exhaust particulate matter (PM_{Exh}), benzene, carbon monoxide (CO) and nitrogen oxide (NO_x)) and fuel consumption. H-MLIT with the most congested road segment (degree of congestion; min: 0.28, max: 2.52, mean: 1.38) has intensified vehicle numbers (min: 6,415 units/day, max: 58,810 units/day and mean: 38,651 units/day) and the slower traffic flow movement (min: 7.2kmph, max: 55.0kmph and mean: 22.0kmph). Benzene (passenger cars: 0.007g/km, trucks: 0.007g/km) and CO (passenger cars: 1.079g/km, trucks: 0.671g/km) emissions are more emitted from the passenger cars whereas the trucks are responsible for the greater emission of NO_x (passenger cars: 68.882g/km, trucks: 310.048g/km), PM_{Exh} (passenger cars: 0.006g/km, trucks: 0.041g/km) and fuel consumption (passenger cars: 0.007g/km, trucks: 0.007g/km). The EFs of pollutants were compared with the Japanese Emission Standards through JE05 and JC08 chassis dynamometer test cycles. The estimated EFs of NO_x for both vehicle classification showed inconsistency with the EFs derived from the test cycles. These results are supposed to be deployed as the input in air quality dispersion modelling in urban areas for designing the air pollution abatement strategy.

Chapter 4 Dispersion of pollutants in street canyon of urban environment

Chapter 4 discusses the use of Operational Street Pollution Model (OSPM) to predict the pollutant concentration (NO_2, CO, ozone, benzene, PM2.5, PM10 and suspended particulate matter (SPM)) in the urban street canyon of Kyoto City, Japan. The input such as meteorological condition, urban configuration, traffic characteristics, urban background concentration and emission factor of pollutants. The findings reveal that all modelled concentration of pollutants is permitted to the environmental quality standard. The road no. 9 under category of highway administrated by Ministry of Land, Infrastructure and Transport (MLIT) can be classified as the most polluted road. The correlation analysis exhibits that the pollutant concentrations are positively strong correlated to the traffic volume, wind speed, wind direction and aspect ratio (height/width) of urban street canyon. Otherwise, travel speed indicates the negative correlation to the pollutant concentration. The OSPM performance was tested by the statistical indicators in terms of root mean square error (RMSE), mean absolute error (MAE), bias, index of agreement (IA) and coefficient correlation (R^2). Most of pollutants such as NO_2, CO, ozone, benzene, PM2.5 and SPM reveal good agreements to the model due to higher R^2 (0.77-0.91) and IA (0.86-0.91), lower RMSE (0.01-3.77), MAE (0.04-3.28) and bias (3.4%-19.2%). However, model performance indicator for predicting PM2.5 indicates moderate coefficient correlation (0.47) and IA (0.60), lower RMSE (5.28), MAE (4.57) and bias (18.59%). The OSPM model was overestimated the modelled concentration due to positive value of bias. Overall, the OSPM model had proven to be an applicable model for predicting the pollutant concentration in urban environment of Kyoto, Japan.

Chapter 5 Health risk assessment of traffic induced air pollution in Kyoto City, Japan

Chapter 5 assesses the health risks associated with exposure to traffic induced air pollutants (nitrogen dioxide (NO2), carbon monoxide (CO), ozone (O_3), benzene, suspended particulate matter, PM10 and PM2.5) via inhalation to infants, children and adults. Assessment of inhalation risk is based on the method proposed by US Environmental Protection Agency (US EPA) by means of hazard quotient (HQ) for non-carcinogenic effect and cancer risk (CR) for carcinogenic effect. HQ value for acute, intermediate (normal and worst-case) and chronic intermediate (normal and worst-case) exposure was determined for each pollutant, while cancer risk was calculated for chronic exposure of PM2.5 and benzene. Results reveal that the HQ value for all pollutants for acute and intermediate normal exposure were lower than 1.0 and CRs for PM2.5 and benzene were lesser than 10^{-7}. Infants and children have higher tendency to be affected compared to adults against pollutants exposure, excluding the chronic worst-case condition. Nevertheless, the potential health risks with different severity may be posed by the exposed groups when they inhale the pollutants for long-term exposure. The study population have a negligible risk for short term-exposure and vice-versa for the long-term chronic exposure.

Chapter 6 Development of a holistic framework of risk-based assessment and management for traffic induced air pollution in urban area

Chapter 6 develops a holistic risk management approach for traffic induced air pollution in urban environment. This approach incorporates the concept of urban sustainability and risk management proposed by United Nation Department of Economic and Social Affairs (2013) and the 2018 International Standard Organization (ISO) risk management 31000, respectively. The risk management approach integrates the principles, framework and process as one component and is solely synchronized with the findings of this research. It is intended to be a reference document to help policy makers, urban development departments and environmental practitioners to prepare, implement, and review the issue of transport and air pollution in the urban area.

Chapter 7 Conclusion and Future Recommendation

Chapter 7 brings together the conclusion from each the preceding chapter and suggestion of promising area for future research.

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（論文審査の結果の要旨）

本論文は、京都市の道路環境を対象として、数値シミュレーションモデルによる大気汚染予測の有効性と、大気汚染リスク対策の必要性について検討した成果をまとめたものであり、得られた主な成果は以下のとおりである。

1. 道路交通からの排気ガス計算プログラム(COPERT)と、国土交通省の全国道路・街路交通情勢調査データや京都市の気象データなどを用いて、自動車走行による大気汚染物質の各道路タイプでの排出量を計算した。京都市内の国道は最も混雑した道路であり（平均混雑度:1.38)、非常に多くの自動車が走行し（平均 38,651 台/日)、平均走行速度は小さかった（平均 22.0km/h)。京都市内国道での走行データ等を考慮した排出量は、ベンゼン（乗用車：0.007g/km,　トラック：0.007g/km）と CO（乗用車：1.079g/km, トラック：0.671g/km）は明らかに乗用車からの方が多いが、NO_x（乗用車：0.0722g/km, トラック：0.674g/km）と排出 PM（乗用車：0.006g/km, トラック：0.041g/km）と燃料消費量（乗用車：68.9g/km, トラック：310.0g/km）はトラックの方が大きかった。

2. 操作型街路汚染モデル（OSPM）による解析の結果、汚染物質濃度は交通量（相関係数(r)=0.302～0.834)、風速（r=0.418～0.641)、風向（r=0.449～0.623)、都市街路谷のアスペクト比（高さ/幅）(r=0.325～0.875）と明瞭な正の相関を持ち、走行速度（r = -0.283～-0.735）との相関は少し低かった。OSPM による予測結果は実測データと良い一致を示し（R^2=0.77～0.94)、二乗平均平方根誤差 RMSE も小さく（NO_2[0.006ppm], CO[0.079ppm], オゾン[0.007ppm], ベンゼン[0.074μg/m^3], PM2.5[3.767μg/m^3], SPM[0.006μg/m^3])、偏差も小さかった (4%～18%)。しかし PM10 は R^2=0.47、RMSE=5.275μg/m^3, 偏り=20%と、あまり良くなかった。偏りが正であることから OSPM モデルでは評価対象物質濃度を過大評価する傾向があった。

3. 吸入曝露のリスク評価によると、全ての項目で 1 時間曝露でも通常状態の 24 時間（オゾンは 8 時間）曝露でもハザード比は 1 以下であり、PM2.5 とベンゼンによる発癌リスクも 10^{-7} 以下の小さな値であった。しかし、SPM や PM10 の子供に対する通常状態の 24 時間曝露のハザード比は 1 に近い値であることから、子供に対する潜在的健康リスクが存在するかもしれないとして、大気汚染の総合的リスク管理体制を将来に向けて構築していくことを提案した。

以上の結果は、京都市の道路交通による大気汚染への各種自動車による寄与と、その関係因子についての貴重なデータを提供するものであり、また、今後の大気汚染リスク管理政策構築にも大きく貢献するものであって、学術上、実際上寄与するところが少なくない。よって、本論文は博士（工学）の学位論文として価値あるものと認める。また、令和２年８月７日、論文内容とそれに関連した事項について試問を行って、申請者が博士後期課程学位取得基準を満たしていることを確認し、合格と認めた。なお、本論文は、京都大学学位規程第 14 条第 2 項に該当するものと判断し、公表に際しては、令和３年９月３０日までの間、当該論文の全文に代えてその内容を要約したものとすることを認める。

要旨公開可能日：　　　年　　月　　日以降