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Research Article

The study of health effects on the residents caused by highway mobile source in the central air quality district of Taiwan, ROC

Sheng Lung Lin[1,*], Shih Chun Wang[1,2]

ABSTRACT

This study assesses the externalities in health effect caused by carbon monoxide (CO) and nitrogen oxide (NO_X) from highway transport in the central air quality district, Taiwan. The utilization of typical vehicle emissions, dispersion model and monetary valuation had been adapted and integrated from the EU-based IPA. The outputs include the estimated CO quantities were 269 tons and NO_X quantities were 270 tons in 2005. Then, the prediction of the average ambient concentration obtained by combining CALINE-4 and GIS of CO was 5.9ppm and NO_X is 0.22ppm. The results conjectured for high impact area show that the emissions spread to the leeward side of highway. Moreover, the calculation of damage costs based on dose-response functions had been displayed by GIS grid distribution. Particularly, acute mortality caused by nitrogen oxide, dominate in terms of cost. Ultimately, the results have been scaled up nationwide, total environmental externalities due to CO & NO_X were totalized to USD 37.57 million ~ USD 521.21 million standing for 0.07% of the GDP of the study area in 2005.

Key words: CALINE-4, GDP, Environmental external cost, Impact pathway approach, Health impact

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INTRODUCTION

It is known the transport-related air pollution could induce human health problems. The issues related to environmental externalities are almost used to being out of consideration [1]. The main problems causing market failure related to traffic activities and air pollution were concentrated in the central air quality district of Taiwan, ROC. Furthermore, EPA (Environmental Protection Administration of ROC) leak out the air pollutants contributed by those mobile sources had been prioritized, and accounted for 71% of CO, 69% of NO_X. Leaning on the mobile sources have significant contribution on human health effects, the speculated dimension of high traffic flow is needed to be devoted to this issue. With the high density of transport activities, there were 4.3 million automotive trips each month on highway in the central air quality of Taiwan, 57% contributed by no.1 and 43% by no.3 (Figure 1). And this paper is a retrospective study based on the traffic changes one year after the no.3 was opened to traffic. This research method will employ IPA [1].

The quantification of human health effects associated with air quality is highly related to transport activities. Although there are a lots of GDP growth that could be calculated from the production and consumption of the economic behaviors, the decision-maker is curious about measuring invisible effects in monetary terms [1]. Eventually, the internalization of damage costs has been sensibly linked with the fair tax policy [2]. The Extern-E project had provided an integrated methodology for quantification of externalities [3], and the methodology had been expanded to transport-related sources [4].

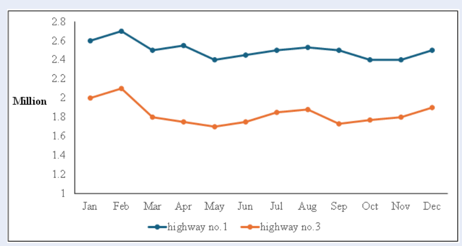

Figure 1: Monthly traffic flow distribution in the central air quality district (2005)

The goal of this paper is to quantify the human health effects produced by mobile sources from the highway transport activities in the central air quality district of Taiwan, and the air pollutant of conspicuous contribution discussed in this area were CO and NO_X. Uncertainties of these consequences would be presented with a range of the estimated externalities and emphasized in this paper.

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METHODOLOGY

Adapted IPA

The framework of impact pathway approach (IPA)[5] has been developed to evaluate externalities. It is a bottom-up method and had been modified to present in Figure 2.

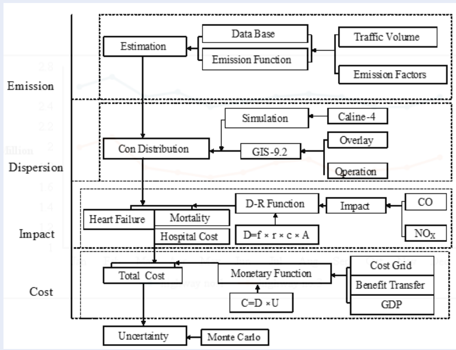

Figure 2: Adapted IPA flow

In practice, it needs a large amount of data to input into the model, and first of all, the traffic volume in the studied area was following records collected from the toll stations on the highway[6].Then the emissions of the whole vehicle line were calculated with the emission function, and the formula could be shown as Equation (1)[7]:

$$E = V \times C \tag{1}$$

Where E is the emission of pollutant (ton), V is the traffic volume, with data sourced from the ministry of transportation's toll station passage data (2005), and C is the pollutant emission coefficient (ton/vol), with data sourced from the EPA's emissions inventory TEDS 6.1 (2005). Lastly the estimated quantities would be marshaled to create databases.

Dispersion model and GIS grid distribution

The dispersion model used in this work was Caline-4 which was used to be applied to predict the ambient concentration near the roadway. Caline-4 was developed using the Gaussian diffusion model. This diffusion model is an improved program developed by the California State Department of Transportation. And to utilize the spatial information of predicted concentration by Caline-4 was able to integrate in the GIS[8]. The GIS used in this research was the Arc-View package and grid-based distribution display. The basic data on the highway and study area was digitized, including the entire district and the segment of highway no.1 and no.3. After simulating the concentrations, the damage costs were displayed using a grid-based method.

Monetary valuation and Externalities

Firstly, in order to define the health effect, this paper presents an assessment procedure of the environmental externalities of traffic activities for study area. The main external costs were related to health lesions and environmental quality. According to the recommendation of the European Commission, Lin[1] figured out the modified dose-response functions based on EU-data could be shown as Equation (2):

$$D = f \times \rho \times c \times A \tag{2}$$

According to the study of Spadaro[8], here D is the human health impacts for mortality and hospital cost which was due to increased exposure to high exposure of NO_X. Otherwise, too much CO would bring about the human health effect for heart failure (65+). And f is the slope (pers–year–μg/m^3) by the epidemiological studies. The term of c is ambient concentration (μg/m^3). The item of ρ represents the average density of population in the entire district (pers/m^2), and A is the studied area of district (m^2). Secondly, this paper treated the monetary multipliers[9], U_M, by utilizing the related EU-data and the adaptation of U_M was calculated as Equation (3):

$$U_M = U_N \times (Y_M / Y_N) \tag{3}$$

In which, U_M and U_N present unit monetary multipliers of Taiwan and comparative country respectively; Y_M and Y_N are social factors and the gross national income per capital of Taiwan and reference country individually; and ε is the income elasticity and is estimated as 0.41 for environmental goods in this paper[10].

The final step, the estimation of the externalities caused by CO and NO_X emissions could be calculated in Equation (4), and the cost is

$$C = \sum D \times U \tag{4}$$

Where, U was the unit monetary multipliers of NO_X for mortality and hospital cost, with CO for heart failure (65+) respectively.

RESULTS AND DISCUSSION

The estimation of transport emissions

The emissions inventory of studied district was based on the emission function methodology and provided the data included in Table 1.

The LDV transport on highway produced the main part of CO emissions, and it was responsible of a significant share of total emissions for CO (81%). Another transport, HDV, dominated in terms of NO_X emissions and contributed over 54%. Table 2 shows the contribution related to each mode of transport emissions.

Table 1: Air pollutant emissions in the central air quality district (2005)

	CO	NO_X
	t	t
light duty vehicle(LDV)	217	42
heavy duty vehicle(HDV)	34	147
heavy duty truck(HDT)	18	81
Total all sectors	269	270

Table 2: Percentile transport emissions in the central air quality district (2005)

	CO	NO_X
% highway transport		
LDV	81	16
HDV	12	54
HDT	7	30

The ambient concentration of air pollution

As the predicted concentration by Caline-4, the consequences proved the crisis possibilities for human induced by CO and NO_X. The following data could demonstrate this viewpoint. Table 3 contains the number of times that standard thresholds had been exceeded in studied region, depending on the declaration of EPA of Taiwan. The simulated effects clearly exhibited that there was potential harm for health in the district.

Total pollution costs by transport mode

The human health effects caused by CO and NO_X were quantified on heart failure (65+), mortality and hospital cost respectively. The results of effects obtained from increased exposure to CO and NO_X could be translated into costs using the monetary valuation approach modified by Extern-E methodology (Equation (4)). The spatial distribution of total damages cost is displayed in Figure 3 by 1km × 1km grids and the hourly significant value amount to USD 0.63 per km^2 in (Figure 3a) and USD 113.03

Table 3: The numbers of simulated exposure alerts caused by highway mobile source (2005)

Standard threshold	CO (ppm)		NO_X (ppm)	
	Restrict	Times	Restrict	Times
Hourly restrict value	35	0	0.25	29
Upper alert	8	12	0.1	2846
Lower alert	6	3285	0.05	422

per km^2 in (Figure 3b). As anticipated, the main damage areas were riveted on the downwind side of highways where the high exposure grid of air pollution related to transported activities. The differences between (Figure 3a) and (Figure 3b) are possible to the variable increment of traffic volume that is conduced to the disparities of travel time.

Human health effects related to transport modes were shown in Table 4. It gives the 5th and 95th percentiles, as well as the center estimated for mortality, hospital costs and heart failure (65+) of studied district. In the case of transport modes on human health costs, the HDV contributed with USD 26.39 million on mortality, and that were more essential than hospital costs – USD 0.97 million and heart failure (65+) – USD 0.03 million, respectively. These results could be used to establish tax policies system for different transport sectors.

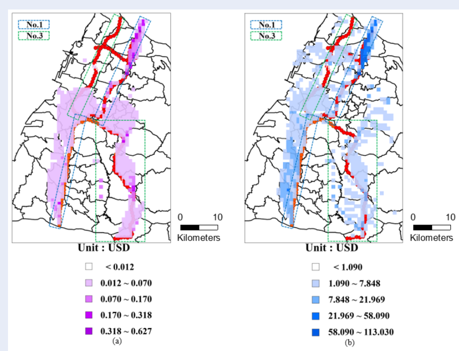

Figure 3: Spatial distribution of damage costs due to (a) CO and (b) NO_X expressed by 1km×1km grid

This section represents a comparison of costs for highway no.1 and highway no.3. In order to achieve this target, costs due to LDV, HDV and HDT were considered. The costs were related to the support of each type of vehicle to promote contrast between two highways. The following Figure 4 refers to marginal costs,

Table 4: The estimation of health effect costs caused by all transport mode (2005)

	Mortality(MUSD)			Hospital costs(MUSD)			65+ heart failure(MUSD)		
Modes	5th percentile	Center estimated	95th percentile	5th percentile	Center estimated	95th percentile	5th percentile	Center estimated	95th percentile
LDV	3.059	4.921	5.819	0.197	0.204	0.235	0.211	0.242	0.272
HDV	23.965	26.385	29.470	0.962	0.970	1.183	0.019	0.031	0.044
HDT	8.783	10.944	12.846	0.348	0.439	0.516	0.008	0.014	0.024

and all marginal costs presented refer to specific status, illustrated the costs in different transport modes. It is not prone to be expounded by ordinary conceptions respectively[11]. The Figure 4 shows the measurement of human health impacts linked to air quality is closely connected to transportation activities. And it demonstrates the damage costs due to transport modes on two highways. It is obvious that the costs due to HDV dominate the cost. This is primarily caused by different health effects by various transport modes. Except for the traffic volume and the partial climate change had a momentous influence on the receptor exposure, the monetary valuation of the mortality was the crucial element for all. Light duty vehicles contributed to lower costs per kilometer compared to HDV and HDT, as the pollutants LDV emitted, leading to lower health effects. On a transport kilometer foundation, highway no.1 performed better than no.3 due to its number of memberships.

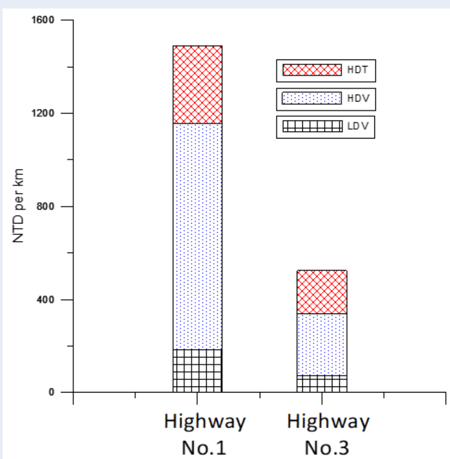

Figure 4: Air pollution costs due to transport modes (2005)

The uncertainty analysis

This paper discussed the uncertainties by using a probabilistic distribution function and transferring monetary values of CO and NO_X externalities from the EU to Taiwan. A lognormal distribution was defined to estimate the damage costs with the range of 5th and 95th percentiles[1]. Damage costs related to health impacts of transport modes are drafted in the box-and-whisker diagram. The low and high limits display estimated values of 5th and 95th percentiles with the middle lines are the median estimations. The uncertainties of damage cost in different transport modes are spread. The range of values between 5th and 95th percentiles shown in Figure 5 considering for the uncertainties involved in the monetary transfer from EU-data and Taiwan. The range for LDV is MUSD 36.36 to 63.64, the range for HDV is MUSD 248.48 to 333.32, and the range for HDT is MUSD 96.97 to 136.36.

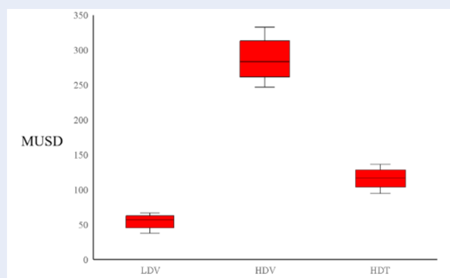

Figure 5: Annual damage costs related to health effect of transport mode (2005)

CONCLUSIONS

This study had valuated the human health effects generated by mobile sources in the central air quality district of Taiwan. The damage costs were estimated based on monetary transfer from EU to Taiwan. Monte Carlo simulation was made use to present the median values with its range between 5th and 95th percentiles. For the entire area, the damage cost was USD 44.24 million with the range from USD 37.58 million to USD 521.21 million. The calculated consequences show that human health effect costs produced approximately 0.07% of the GDP of the region. The primary costs are the damage to the effects on mortality. In addition, the estimated externalities in this paper represented only a part of total external costs. On the strength of this consideration, the more sophisticated inventories toward parameters of the IPA procedure would be defined before the adaptation of these values. The proposed framework was exploratory and could be applied as the foundation for further related studies.

COMPETING INTERESTS

There is no conflict of interest regarding this manuscript.

AUTHORS' CONTRIBUTIONS

Sheng Lung Lin was responsible for research design and methodology.
Shih Chun Wang handled data collection, processing and contributed to writing and revising the manuscript

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Bài nghiên cứu

Nghiên cứu ảnh hưởng của nguồn phát thải giao thông đến sức khỏe cộng đồng tại khu vực trung tâm của Đài Loan

Sheng Lung Lin[1], Shih Chun Wang[2]

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TÓM TẮT

Nghiên cứu này đánh giá các ngoại tác về sức khỏe do khí carbon monoxide (CO) và nitrogen oxide (NO_X) từ giao thông đường bộ (đường cao tốc) tại khu vực trung tâm ở Đài Loan. Việc sử dụng mô hình phát thải giao thông điển hình, mô hình khuếch tán và phương pháp định giá tiền tệ đã được điều chỉnh và tích hợp từ mô hình IPA dựa trên EU. Kết quả đầu ra bao gồm ước tính lượng CO phát thải là 269 tấn và NO_X là 270 tấn vào năm 2005. Sau đó, dự đoán nồng độ môi trường trung bình bằng cách kết hợp công cụ CALINE-4 và GIS cho thấy nồng độ khí CO là 5,9 ppm và NO_X là 0,22 ppm. Kết quả dự đoán cho khu vực có tác động cao cho thấy ô nhiễm lan truyền về phía khu vực dưới gió của đường cao tốc. Hơn nữa, việc tính toán chi phí thiệt hại dựa trên các hàm liều lượng - đáp ứng đã được thể hiện bằng phân bố lưới GIS. Đặc biệt, tỷ lệ tử vong cấp tính do khí nitrogen oxide chiếm ưu thế về mặt chi phí. Cuối cùng, khi mở rộng quy mô nghiên cứu trên toàn quốc, tổng chi phí ngoại tác môi trường do CO và NO_X gây ra được ước tính từ 37,57 triệu USD đến 521,21 triệu USD, chiếm khoảng 0,07% GDP của khu vực nghiên cứu vào năm 2005.

Từ khoá: CALINE-4, GDP, Chi phí ngoại tác môi trường, Phương pháp đánh giá tác động, Ảnh hưởng sức khỏe

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