國立成功大學

交通管理科學研究所

碩士論文

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-以高雄市區為例

Improvement Strategies of Fine Particulate Matter (PM2.5) from Mobile Pollution Source-

Case Study in Urban Area of Kaohsiung

研究生：蔡承庭

指導教授 ： 張有恆 博士

中華民國 108 年 6 月

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摘要

隨著高度工業化與經濟迅速發展，空氣污染日趨嚴重，對健康、環境、醫療成本等方面造成許多負面影響，也讓空氣污染成為國際間關注的議題。在臺灣空氣污染防制法規定的六種空氣污染物中，只有 PM2.5 的濃度是高於法定標準的，醫學研究已證實暴露於高濃度的 PM2.5 中會增加呼吸道疾病及心血管疾病的發生率，甚至與肺腺癌有關。PM2.5 的減量改善策略在臺灣實已為不可忽視的重要議題，其中高雄地區為臺灣六都裡 PM2.5 污染最為嚴重的區域，又考量移動污染源在 PM2.5 中的比例以及其對健康的直接影響，故本研究將以舊高雄市區為例，探討 PM2.5 移動污染源的改善策略。

先前許多研究提出了 PM2.5 的管理政策及減量方法，但多為針對單一策略的研究。但 PM2.5 一旦進入人體即無法排出，政策制定者必須在有限的時間與資金裡，做出最佳的決定來減少 PM2.5 對人類健康的影響。本研究透過文獻回顧並參考世界各國的管理及改善策略，透過模糊德菲爾法(FDM)分析後，歸納出 PM2.5 移動污染源的 18 項改善策略，並將這些策略分成五個構面，分別是：法規管制、政策推廣、社會教育、環境及共享經濟以及科技演變，接著透過模糊層次分析法(FAHP)及可行性分析找出各項改善策略相對重要度及可實現性。

研究結果發現「制定新排放標準」、「淘汰老舊柴油車」、「車輛定期檢驗」、「電動車補貼優惠」、「廣設電動車充電站」以及「開發新型電動車電池」等六項策略具有高重要性和高可行性，可以列為優先發展的策略，本研究之結果能幫助決策者釐清各項政策的優先順序及可行性，在適當的時機、利用有限的資源做出最好的決策。

關鍵字：細懸浮微粒(PM2.5)、空氣污染、模糊德菲爾法(FDM)、模糊層級分析法(FAHP)

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Abstract

In recent years, with the industrialization and rapid development of the economy, the serious air pollution has caused many negative impacts on health and environment. In Taiwan, all air pollutants have already been in control except PM2.5. Exposure to high concentrations of PM 2.5, not only increases the risk of all-cause mortality and the risk of cardiopulmonary diseases, it is also associated with lung adenocarcinoma. From the above, lowering PM2.5 emission in Taiwan is an important topic. Moreover, Kaohsiung is the most serious polluted area among six main municipalities. Considering proportion of PM2.5 and affection to human health, this research will focus on the mobile pollution source and make a case study in Kaohsiung.

Many improvement strategies of PM2.5 have been suggested by former research. But most of them are reduction methods for a single strategy. However, there is no solution to PM 2.5 that has already been inhaled into the body currently. Decision makers have to reduce effects of exposure to PM2.5 with limited time and funds. They must be able to prioritize strategies in order to achieve best results. This research reviews literatures and related policies around the world to formulate strategies of mobile source PM2.5. By implementing FDM with experts' opinions, this research divides 18 improvement strategies into 5 dimensions (Legislative Regulation, Policy Promotion, Social Education, Environment & Sharing Economy and Technology Change) and identify the priority and achievability by FAHP and IAA. This research finds out that 'new emission standard', 'old diesel vehicle elimination', 'examination of vehicles', 'electric vehicles subsidy', 'development of charging stations' and 'novel battery in electric vehicles' are important and highly feasible.

Keywords: PM2.5, Air pollution, FDM, FAHP

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從大學到研究所在成大六年的時光晃眼就過去了，臺南是個充滿人情味的好地方，成大則是滿載回憶的溫暖學校。碩士班畢業其實不像國小國中高中那樣離情依依，更多的是對一個階段自己的告別並代表新生活來臨的信號。但在致謝的的篇章裡，還是想對在成大一路上幫助自己的人道聲感謝。

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Chapter 1 Introduction

1.1 Research Background and Motivation

The aim of this research is to discover the improvement strategies of fine particulate matter (PM2.5) from mobile source pollution, find out the priority of the improvement strategies and develop future policies suggestion to government and decision makers.

Because of rapid industrialization and urbanization, air pollution issues and related environmental problems have become more and more serious. According to The Global Burden of Disease project (GBD), 3.2 million deaths and 3.1% of disability-adjusted life-years are related to outdoor air pollution annually, that is to say, exposure to air pollution is the leading environmental risk factor and also the most critical modifiable risk factors for the global disease burden (Lim et al., 2012).

The World Health Organization (WHO) believes that particulate matter (PM) affect more people worldwide than any other pollutant. In their 2005 report, the organization declared that ‘Approximately all of the population is affected, but severity to the pollution may be different due to age and health’ (WHO Air quality guidelines, 2005). There are 92% of the world’s population is exposed to PM2.5 concentrations above the WHO air quality guidelines (10 $\mu g/m^3$), reduction of PM2.5 concentration become a worldwide controversy. (Brauer et al., 2012; WHO, 2016). Recent studies have proved that short-term exposure to high levels of PM might lead acute respiratory system responses (Janssen et al., 2013; Meister et al., 2012). And long-term exposure may cause health problems such as lung cancer and cardiovascular diseases. (Yitshak-Sade et al., 2015; Brook et al., 2010).

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Environmental Protection Agency (EPA) calculates the Air Quality Index (AQI) for six major air pollutants regulated by the ‘Clean Air Act’: O_3, PM_{10}, $PM_{2.5}$, SO_2, CO, and NO_2 (Glossary of Environmental Terms, 2016). As figure1-1 to figure1-6 showed, the concentrations of these air pollutants meet the standard except PM2.5.

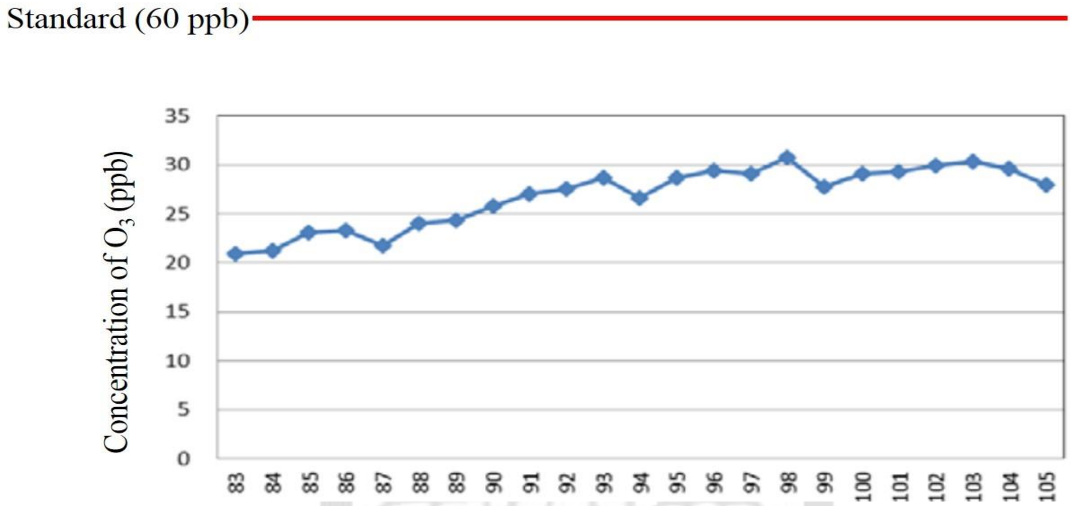

Figure 1-1 Annual average concentration of O_3

Source: Taiwan EPA (2017)

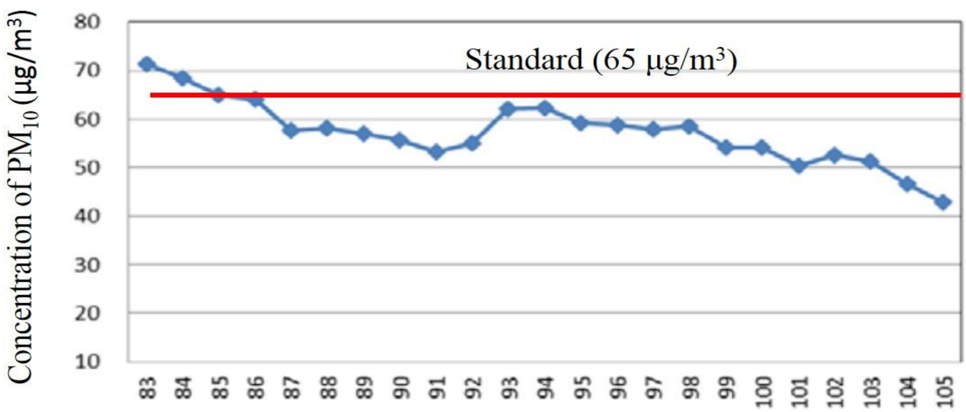

Figure 1-2 Annual average concentration of PM_{10}

Source: Taiwan EPA (2017)

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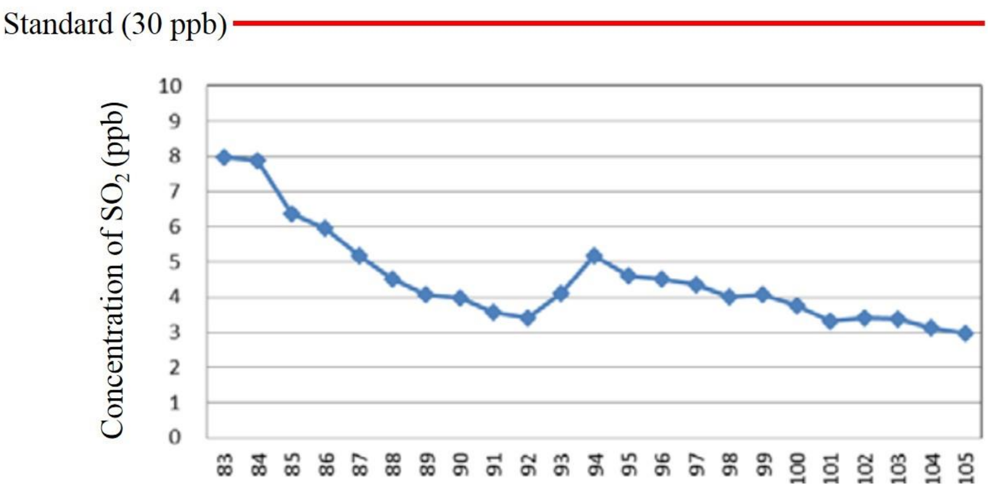

Figure 1-3 Annual average concentration of SO_2

Source: Taiwan EPA (2017)

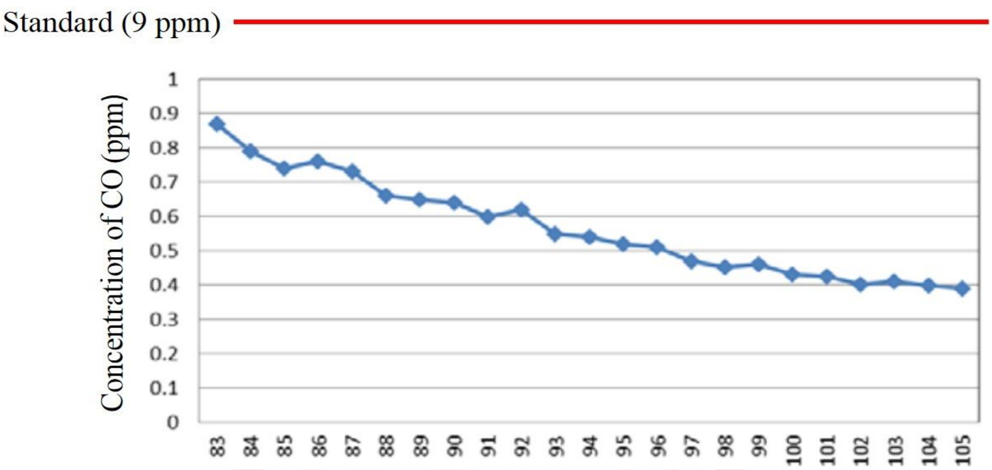

Figure 1-4 Annual average concentration of CO

Source: Taiwan EPA (2017)

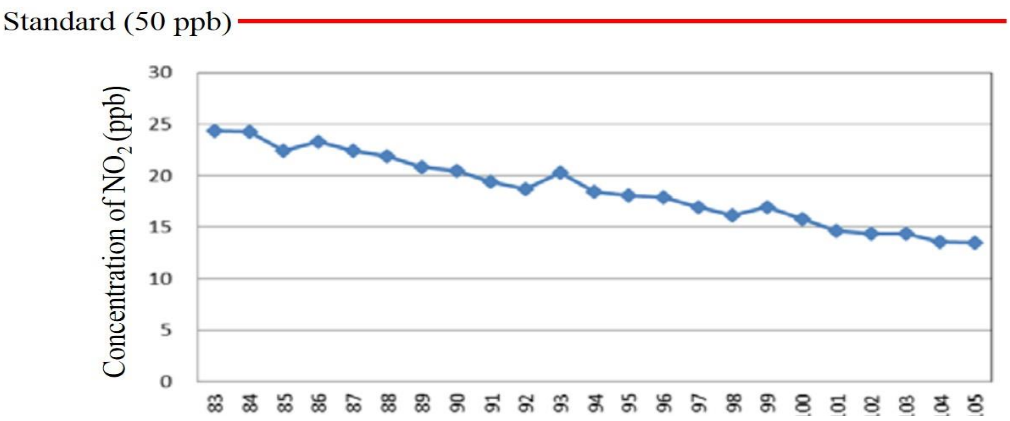

Figure 1-5 Annual average concentration of NO_2

Source: Taiwan EPA (2017)

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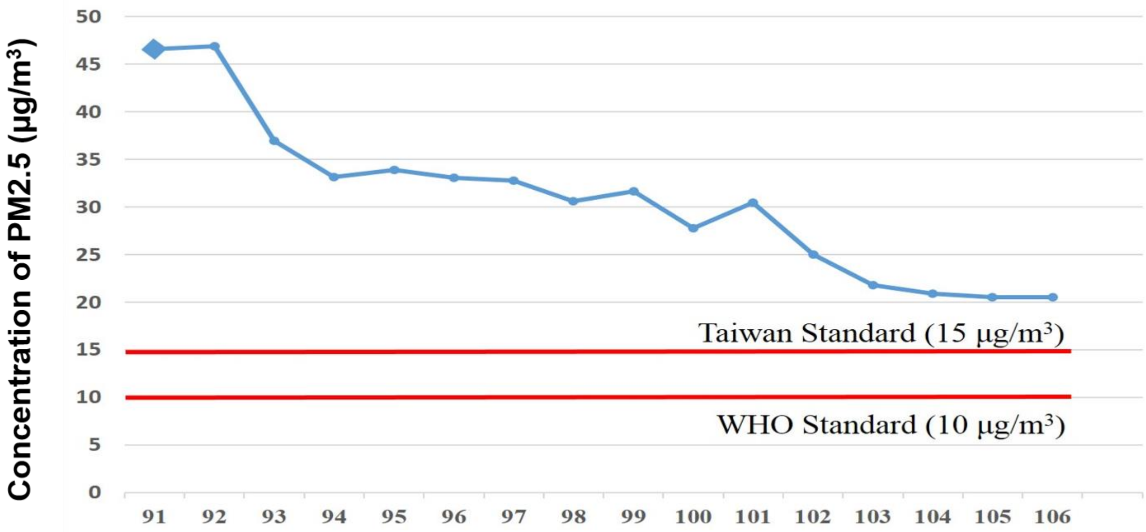

Figure 1-6 Annual average concentration of PM2.5

Source: Taiwan EPA (2017)

As mentioned above, PM2.5 concentration control is undoubtedly an urgent task. In Taiwan, main sources of PM2.5 could divide into three parts, Mobile emission (e.g., vehicle exhaust, motorcycle exhaust, truck exhaust), Industry emission (e.g., power industry, oil refining industry) and Other emission (e.g., road dust, catering operation). Among these three part, Mobile emission not only accounted for a large proportion (30-37%) but also be the most dangerous part. According to Taiwan Megacity Environmental Research, the concentration of PM2.5 actually exposed in the metropolitan area may be much higher than the concentration of the ambient atmosphere due to close contact with mobile pollution sources. In addition, the polycyclic aromatic hydrocarbon (PAHs) generated by the mobile pollution sources will affect the cardiopulmonary function of the human body. It'll increase the mortality of cardiopulmonary related diseases (Lung & Cheng, 2010). Without any doubt, developing improvement strategies of PM2.5 from mobile pollution source might be a practical and effective way to improve people's health level.

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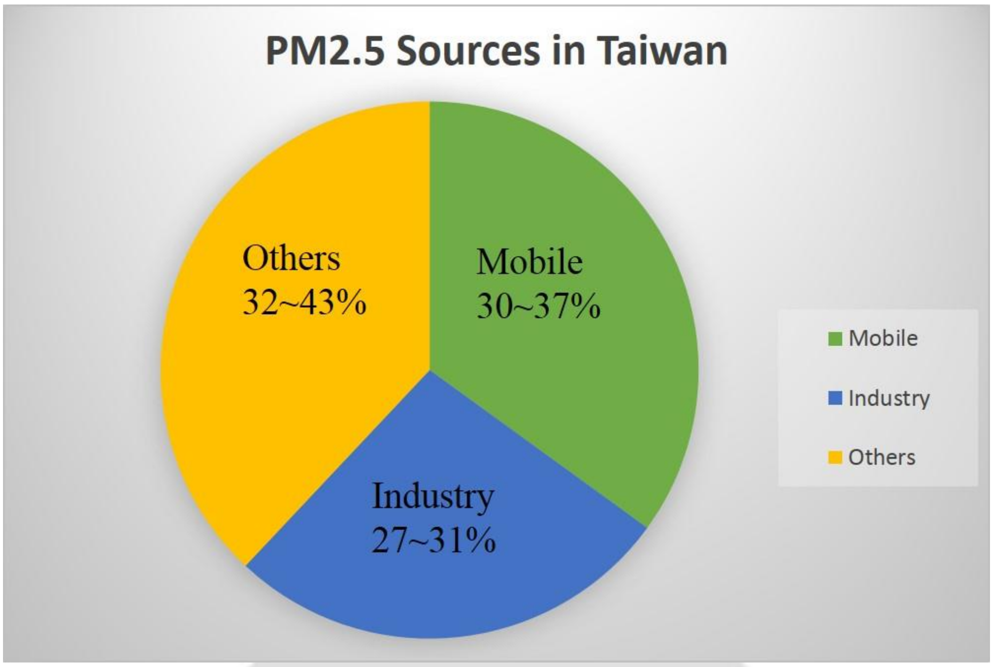

Figure 1-7 PM2.5 Sources inTaiwan
Source: Taiwan EPA (2016)

In order to reduce the PM2.5 concentrations, Taiwan EPA carried out a series of plans. First, they execute ‘Clean Air Plan’ in 2015. And then, based on it, they proposed ‘Air Pollution Control Plan of Action’ in 2017 to set clear goal and update the timetable for the plan, it included 14 strategies such as two-stroke motorcycle elimination, public transport promotion and electric vehicles subsidy (Taiwan EPA, 2017). Taiwan EPA also amended the ‘Air Pollution Control Act’ in 2017. This amendment mainly focused on mobile source air pollution. These revisions would enable local governments to create ‘air quality protection zones’, restricting the access of diesel vehicles over 20 years old as well as two-stroke motorcycle. There are also new provisions for an offset scheme on the fixed pollution limits. Companies will be able to buy emissions credits by paying to take old vehicles off the roads.

The ultimate goal of all these strategies and plans above is to reduce average annual PM2.5 concentration to 18 $\mu g/m^3$ in the end of 2019 (It was 20.7 $\mu g/m^3$ in

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2017). The EPA Minister declared that Taiwan EPA will assess the achievement in 2019 and also launch the next stage reduction plan of PM2.5 concentration to reach the goal of 15μg/m^3.

WHO and the International Agency on Cancer Research (IACR) have identified air pollution and in particular PM2.5 as a class one carcinogen (IACR, 2013). In Taiwan, besides Yilan, Hualien, Taitung, Kenting and Yangming, all the numbers of PM2.5 concentration collected from air quality monitoring stations were above the WHO standard (Taiwan EPA, 2016). Among them, Kaohsiung was the most serious. As Figure 1-8 shown, in Kaohsiung, PM2.5 alert days (concentration over 25 μg/m^3) accounted for 57% days in 2017. Furthermore, Table 1-1 declared that Kaohsiung had worst air quality of Taiwan in 2018, with an average PM2.5 concentration of 23.9 (Taiwan EPA, 2019). In the other hand, Air Clean Taiwan (ACT) also indicated that Zuoying was the worst air quality area in Taiwan (TEIA, 2018).

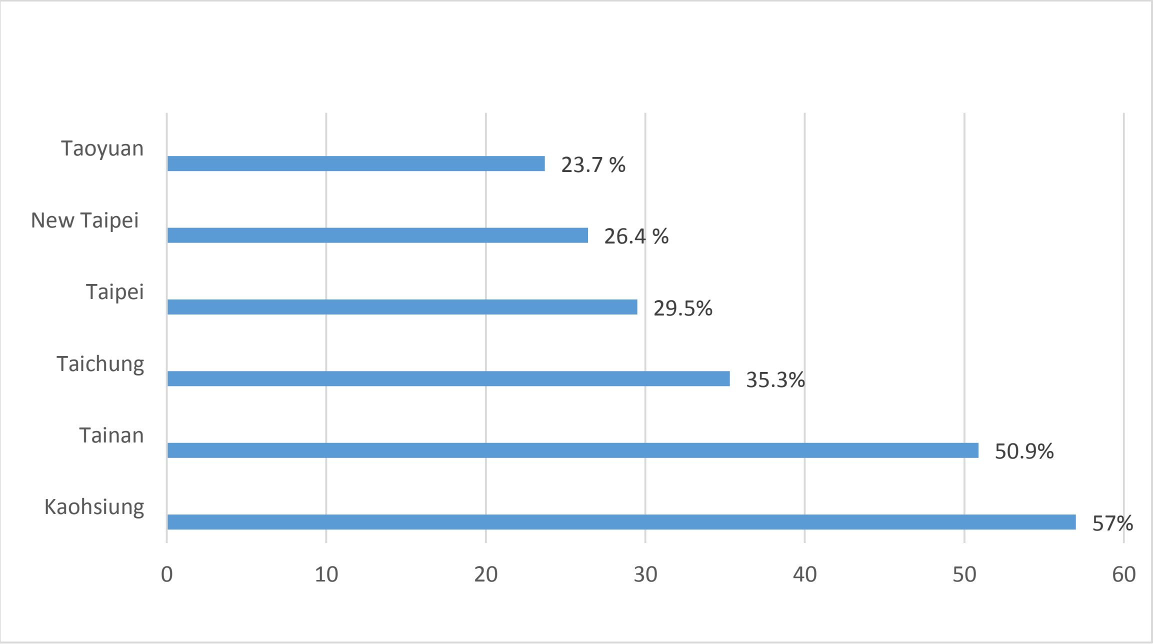

Figure 1-8 Percentage of PM2.5 alert days (concentration > 25 μg/m^3) in 2017

Source: TEIA (2018)

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Table 1-1 Average concentration of PM2.5 in main city (2019)

City	PM2.5 (μg/m3)
Keelung	13.0
Taipei	15.0
New Taipei	15.3
Taoyuan	17.6
Hsinchu city	19.7
Taichung	18.8
Chiayi city	23.7
Tainan	23.8
Kaohsiung	23.9

Source: Taiwan EPA (2019)

Currently, there is no solution to PM2.5 that has already been inhaled into the body. The main preventive measure is to minimize its exposure. Developing more effective PM2.5 improvement strategies is undoubtedly a serious issue in Taiwan. As mentioned in the previous paragraph, the first stage reduction plan of PM2.5 concentration will be expire in the end of 2019. In Yang's simulation, Taiwan EPA probably couldn't reach the goal by that time with conducting 'Clean Air Plan' (Yang, 2015). Formulating better strategies in next stage reduction plan of PM2.5 concentration will be a tough challenge for the government.

Many studies have already discussed relationship between health and PM2.5 and some studies found out prevention strategies, but how could the government take the right strategies with limited time and money? They must be able to prioritize the strategies and conduct the more effective ones to get the best results under limited resources. Thus, finding out priority of improvement strategies of PM2.5 from mobile pollution source will be worth some discussions.

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1.2 Research Objectives

This research looks into improvement strategies of mobile pollution source PM2.5. Decision makers in government should take and prioritize the strategies due to limited time and resources. Furthermore, this study will also examine achievability of every strategy. With these goals, the purpose of this study is as follows:

1. Identify preliminary reduction strategies of mobile source PM2.5 by literature review and related policies around the world.
2. Formulate appropriately improvement strategies regarding to the results of consensus significance value in FDM.
3. Discovery the advantages, disadvantages and insufficiencies of these strategies by relative importance and improvement achievability analysis.

1.3 Research Framework

Figure 1-9 is the flowchart that indicates the process in this research. This research starts with background research, literature review and related policies around world overview. Through these three steps, the preliminary PM2.5 improvement strategies will be found out. These strategies will be examined by examined by environmental experts including government officials and scholars. With the suggestions from these experts, the questionnaire will be formulated. The survey will be conducted for collecting opinions from government officials, scholars and environmental groups in Taiwan. The data collected will be analyzed to develop the relative importance and achievability. Last, using importance-achievability analysis to find out of characteristics about improvement strategies of mobile pollution source PM2.5 and give research conclusions and suggestions (illustrated as Figure 1-9).

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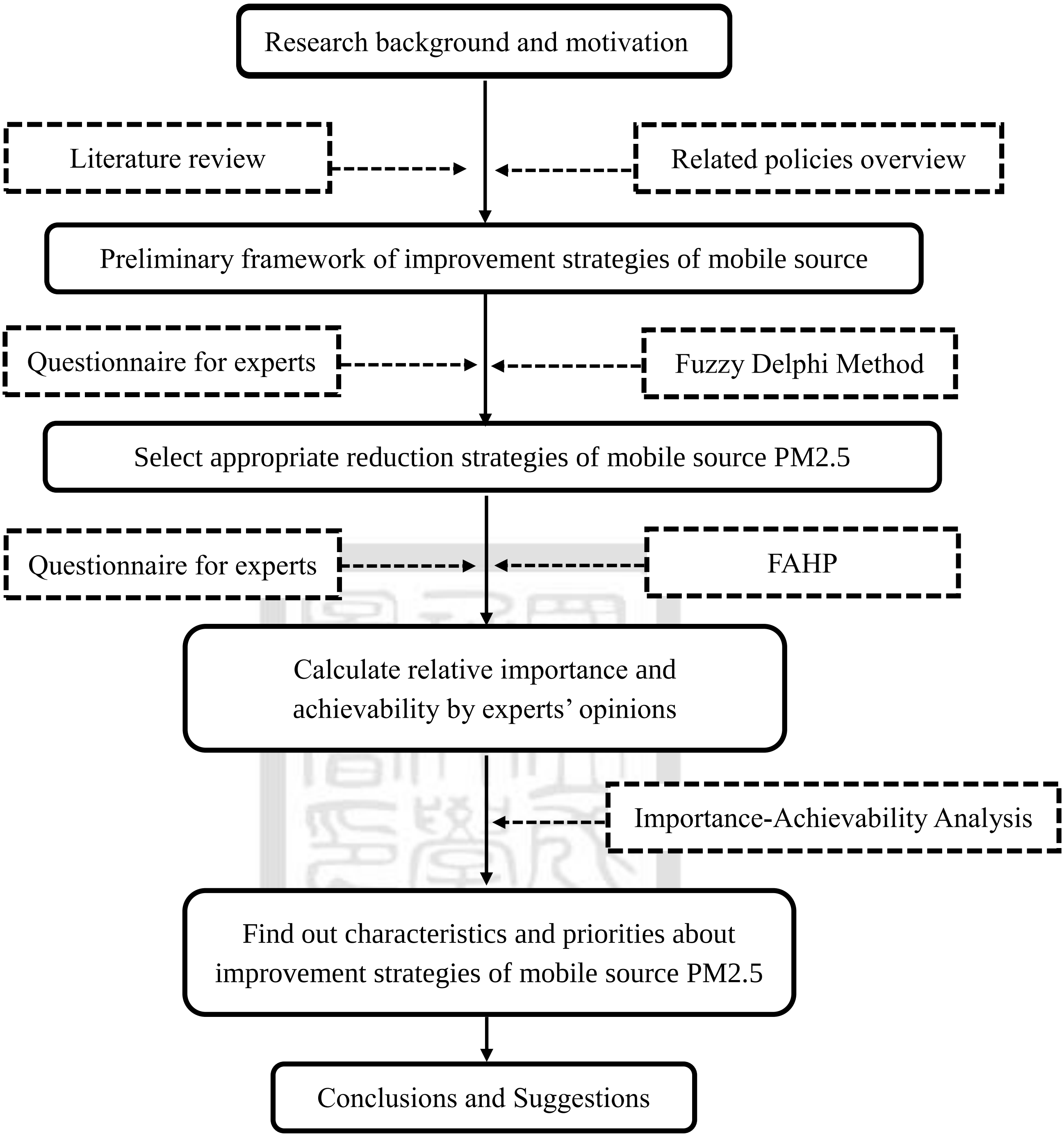

Figure 1-9 Research Flowchart

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1.4 Research Scope

To achieve the objectives mentioned above, this research would construct the framework of PM2.5 improvement strategies by literature review and related policies around the world. Based on the framework, a four-part analysis will begin. The first stage is to use the fuzzy Delphi method (FDM) with opinions from scholars and government officials to choose appropriate strategies. The second stage is based on the use of a fuzzy analytic hierarchy process (FAHP) to find the criteria weight. Third, calculate feasibility through expert questionnaires. In the last stage, use importance-achievability analysis (IAA) to find out the advantages and disadvantages about improvement strategies of mobile source PM2.5.

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Chapter 2 Literature Review

This chapter provides a deep discussion about the effects of PM2.5 and how to prevent it. Not only the definition and basic information of PM2.5 will be provided, but also reviews of both management policies around the world and improvement strategies specific literature will be listed clearly. After reviewing these policies and strategies, there will be a review about methodology of dimension choice. At last, the strategies will be discussed detailed.

2.1 Background - PM2.5

2.1.1 Definition of PM2.5

US EPA defined Particulate Matter (also called particle pollution) as an air-suspended mixture of both solid and liquid particles. Common particle pollution is often separated into two types: PM10 and PM2.5. PM10 also known as Coarse dust particles, with diameters that are generally between 2.5 to 10 micrometers. And PM2.5, also called fine particles, are 2.5 micrometers in diameter or smaller, and can only be seen by an electron microscope. Some PM2.5 is naturally occurring, such as dust and sea salt, and some is manmade, such as particulates formed in combustion processes, motor vehicles, power plants and residential wood burning. PM2.5 is widely acknowledged as being the air pollutant which has the greatest impact on human health. PM2.5 is generally considered more harmful than PM10 because it can pass from our lungs into our blood supply (Cao et al., 2014). PM2.5 can penetrate deeply into the lung, irritate and corrode the alveolar wall, and consequently impair lung function (Xing et al., 2016).

2.1.2 Standard of PM2.5

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According to the scientific literature which indicated that health effects can be expected when annual mean PM2.5 concentrations are in the range of 11-15 μg/m^3, WHO set an annual mean concentration standard of 10 μg/m3 and 25 μg/m3 for 24-hour mean. In addition to standard of WHO every country also set their own standard to regulate PM2.5 concentrationin (Table 2-1). As figuer2-1 shown, almost all areas around the world are above the PM2.5 concentrationin standard of WHO.

Table 2-1 PM2.5 concentration standard around the world

Country/Area	Time Unit	Concentration	Notes
WHO	Annual mean	10 μg/m^3	Set in 2006.
	24-hour mean	25 μg/m^3	
Taiwan	Annual mean	15 μg/m^3	Enacted in 2012.
	24-hour mean	35 μg/m^3	
U.S.A.	Annual mean	12 μg/m^3	Revised in 2013.
	24-hour mean	35 μg/m^3	
E.U.	Annual mean	25μg/m^3	Enacted 2008, second stage target to be achieved by 2020.
	24-hour mean	-	
China	Annual mean	35 μg/m^3	Enacted in 2012, enforcement 2016.
	24-hour mean	75μg/m^3	
Japan	Annual mean	15 μg/m^3	Enacted in 2009.
	24-hour mean	35 μg/m^3	
Korea	Annual mean	25 μg/m^3	Enacted in 2011, enforcement 2015.
	24-hour mean	50 μg/m^3	

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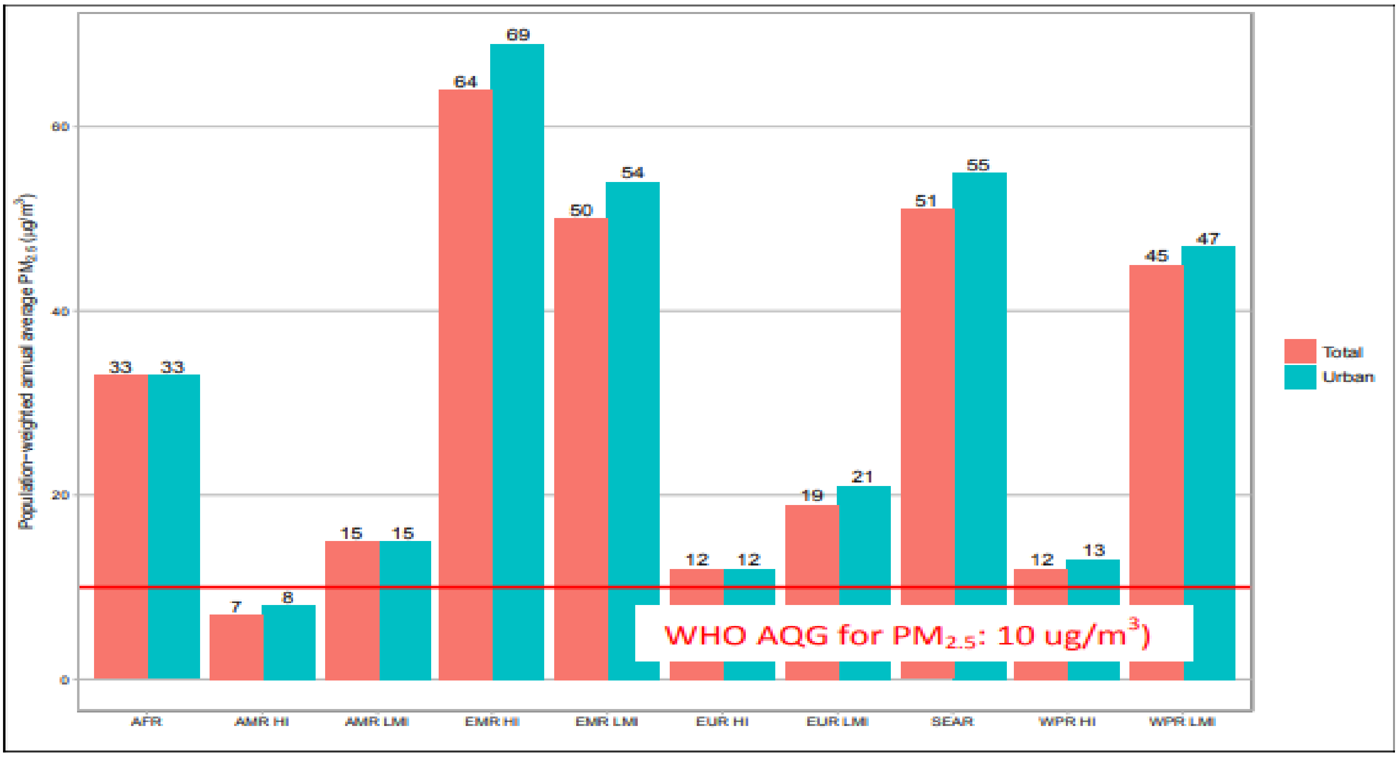

AFR: Africa; AMR: America; EMR: Eastern Mediterranean; EUR: Europe; SEAR: South-East Asia; WPR: Western Pacific; LMCI: Low- and middle-income countries; HIC: High-income countries.

Figure 2-1 Annual average exposure to PM2.5

Source: WHO (2018)

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2.2 Health effects of exposure to PM2.5

Human exposure to high concentrations of PM2.5 not only increase the risk of all-cause mortality, research has also suggested that it is associated with cardiopulmonary diseases, respiratory diseases, and premature birth. Figure 2-2 showed the detailed symptoms of PM2.5.

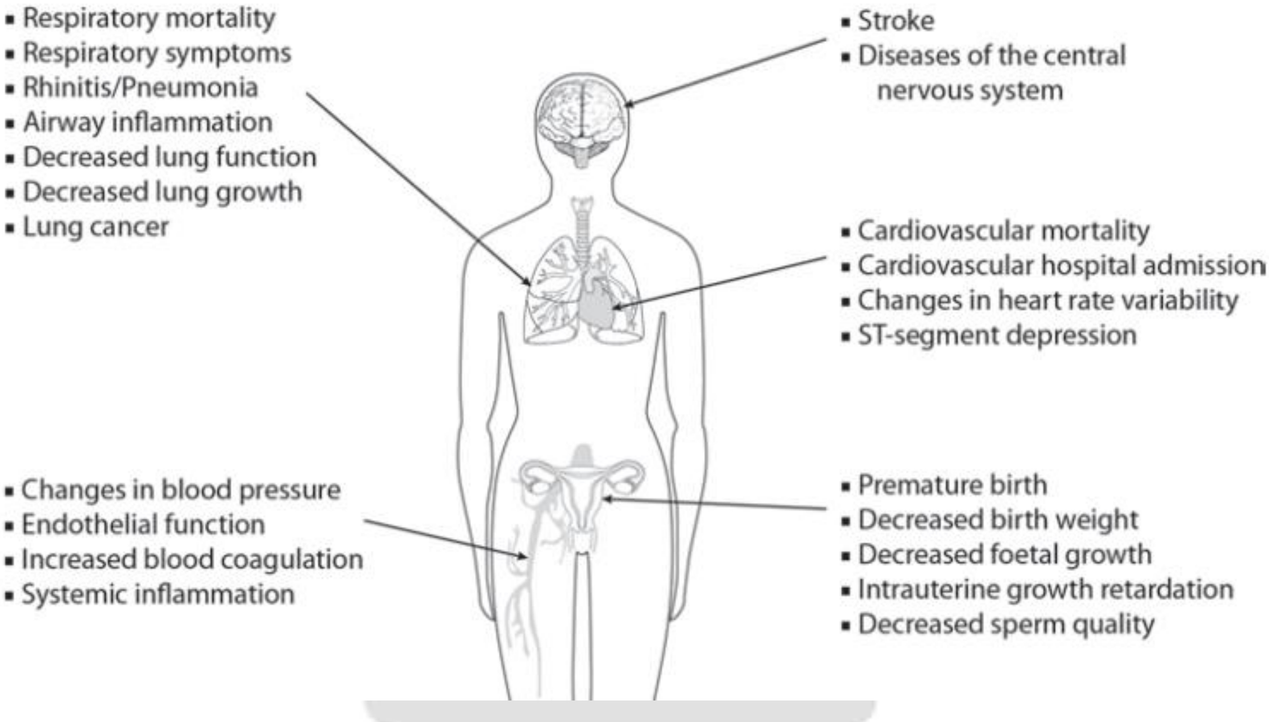

Figure 2-2 Health effects of PM2.5

Source: Rückerl et al. (2011)

2.2.1 Mortality effect

In Pope's study PM2.5 concentration is highly related with mortality. Reductions in particulate matter air pollution are associated with reductions in both cardiopulmonary and overall mortality.

Correia's study (2013) assembled 545 U.S. counties with yearly county-specific average PM2.5, yearly county-specific life expectancy, and several potentially confounding variables during 2000 and 2007. The result of this study indicated that

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a decrease of 10 μg/m^3 in the concentration of PM2.5 was associated with an increase in mean life expectancy of 0.35 years, and this association in more urban and densely populated counties would be stronger.

A similar study was done by Stieb (2015) in Canada, it estimated public health impacts of changes in concentrations of PM2.5 in Canada, from 2000 to 2011. Using standard life table methods to estimate changes in life expectancy, this study found out that a population weighted average decrease in PM2.5 of 2 μg/m^3 would result in 0.10 years' life expectancy increase in national population. This study declared that changes in PM2.5 concentrations were associated with an estimated improvement in national population weighted average life expectancy and a net reduction in mortality and morbidity.

2.2.2 Cardiovascular disease

Cheng et al. (2016) use regression model to estimate short-term and long-term PM exposures on individual. He demonstrated that long-term exposures to PM are associate with increases in diastolic blood pressure. The impact of short-term exposures to PM on cardiovascular system may be primarily through cardiac and vasomotor dysfunction rather than blood pressure fluctuation; while long-term exposures to PM are associated with elevated blood pressure and atherosclerosis. Its result showed that both short-term and long-term exposure would affect individual's cardiovascular metrics.

Epidemic-logical studies also show how PM2.5 exposure is closely related to increased risks of respiratory and cardiopulmonary diseases (Dockery &7 Pope, 2014; Salomon et al., 2013). Van Winkle (2015) even suggested that exposure to PM2.5 is related to platelet activation and inflammation in the lungs, which might cause cardiovascular diseases and lung cancer.

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Huang et al. (2017) conducted a meta-analysis to find out the relationship between exposure to PM2.5 and lung cancer incidence and mortality. They chose 17 studies which met their criteria and provided essential information to estimate the change in lung cancer risk per 10 μg/m3 increase in exposure to PM2.5. They found relative risks of lung cancer incidence and lung cancer mortality following exposure to PM2.5 were 1.08 and 1.11, respectively. Their findings suggest that long-term exposure to PM2.5 is significantly associated both with lung cancer incidence and lung cancer mortality. Furthermore, the association between PM2.5 and lung cancer mortality was stronger than that between PM2.5 and lung cancer incidence.

Yang (2018) also investigate the effects and potential mechanisms of PM2.5 on tumor development in a lung cancer mouse model. They randomized mice into two groups: the PM2.5 or NS exposure group. In the experiment, mice in the PM2.5 exposure group showed an increased number of tumor nodules. These two studies revealed a truth that PM2.5 exposure might increase the lung cancer rate.

2.2.3 Premature birth

According to Jae-Yeon Jang et al. (2014), pregnant women exposed to PM2.5 are 6.8 percent more likely to have a premature birth.

Hackmann and Sjöberg (2016) have done a study in the United States. Their analyses were based on approximately 3 million births in Canada between 1999 and 2008. They examined the association between PM2.5 and preterm birth by regression model that incorporated observations from fixed-site monitoring stations and satellite-derived estimates of PM2.5 and generalized estimating equations. It has showed that in the first trimester of pregnancy, the risk of preterm birth increased with increasing cumulative PM2.5 exposure.

Gou et al. (2018) declared a similar outcome with the study of Jae-Yeon Jang's.

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They collected birth outcomes of 426,246 pregnant women enrolled between January 2014 and December 2014 in National Free Pre-pregnancy Checkups Project (NFPCP) and estimated their individual PM2.5 exposure values from the China National Environmental Monitoring Centre. Result of this study indicated that there were 35,261 preterm birth in 426,246 births (8.3%). The conclusion confirm effect of each 10 $\mu g/m^3$ increase of PM2.5 on preterm birth was significant.

2.2.4 Summary

Impacts of PM2.5 on public health have become great concerns worldwide, especially in the developed countries.

Literatures above confirm the negative relationship between PM2.5 and human health. The higher the PM2.5 concentration is, the higher the rate of mortality and cardiovascular disease would be. According to these consequences, we are more certain about the importance of PM2.5 concentration reduction.

2.3 Role of mobile pollution source on PM2.5 levels

Mobile pollution source plays an important role in PM2.5 levels, either in we will have a detailed discussion in this chapter.

2.3.1 Portion of mobile pollution source

Tang (2017) used multivariate analysis to examine the factors which contributed to the episode of high PM2.5 pollution. He explored the relationship between PM2.5 concentration and related factors including meteorological parameters (temperature, wind speed, rainfall), land use (agricultural, industrial, road and residential types), and the traffic amount. The study found out that PM2.5 concentration has a positive correlation with temperature and traffic, but has a negative correlation with rainfall in Taiwan.

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Ryou et al. (2018) selected 21 studies which estimated sources of PM10 and PM2.5 performed for 2000–2017 in South Korea to summarize findings of PM source apportionment studies of South Korea and to explore study characteristics. In the selected studies, all six PM10 studies identified motor vehicle, soil dust, and combustion, while all 15 PM2.5 studies identified motor vehicle and soil dust. The study concluded that motor vehicle and secondary aerosol were the most common and influential sources for PM in South Korea.

Aynul Bari et al. (2018) conducted air quality characteristics and potential sources affecting PM2.5 levels study in the Canada city. The study was performed among 2014 to 2016 using hourly concentrations of criteria air pollutants at two monitoring stations. They observed that top three contributions in the city were secondary aerosol, combustion and traffic.

Vu et. al. (2015) reviewed lots of literatures about distributions from seven major sources. They concluded that the PM2.5 concentrations are strongly influenced by traffic emissions, which are identified as the main source of PM in urban environments.

2.3.2 Severity of mobile pollution source

Lung (2010) indicated that PM2.5 from mobile pollution source was usually near human activity areas, so even in the same concertation, PM2.5 exposure would be higher than stationary pollution source.

Requia (2018) used data which contained driving patterns, traffic volume, and speed, to examine the association between traffic emissions and human health. In this study, they performed a health risk assessment of PM2.5 emissions during congestion periods in the Greater Toronto and Hamilton Area. Their results suggest that traffic congestion has a substantial impact on human health, especially at the most congested

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period (7:00am).

Peter et al.（2004）found out association between exposure to traffic and the onset of a myocardial infarction. The time the subjects spent in cars, on public transportation, or on motorcycles or bicycles was consistently linked with an increase in the risk of myocardial infarction.

Xu et al. (2014) collected and analyzed sample of PM in China bus stop. The study suggested the relationship between PM and PAHs. And it also explains how PM and PAHs affect human health. Its results revealed that there would be higher carcinogenic risks during waiting bus in high traffic volume area. Manigrasso (2017) had a similar outcome in his study in Roman, he suggested that people should avoid direct contact with buses which were entering bus stops.

Jae-Yeon Jang et al. (2014) suggested that residents living around freeway infrastructures exposed daily to heavy PM2.5 emissions from diesel-powered vehicles, run a higher risk of cardiovascular and respiratory illnesses and, in turn, an increased risk of hospital admissions and premature mortality attributed to these diseases.

Tsai (2008) investigated formation, exposure and health effects of traffic emissions. The result showed that PM2.5 exposure concentration was differed from different vehicle. From highest to lowest were as follow: motorcycle (67.5μg/m^3), bus (38.5 μg/m^3), MRT (35.0 μg/m^3), cars (22.1 μg/m^3).

2.3.3 Summary

Mobile pollution source not only accounted for very great proportion of PM2.5 source, but also be more harmful to the human body than stationary pollution source because of high exposure rate and more PAHs generated. Since these two reasons, developing and prioritizing improvement strategies of PM2.5 from mobile pollution

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source is an essential task.

2.4 Air pollution policies about mobile pollution source around the world

2.4.1 Taiwan

As shown in Figure 2-3, PM2.5 concentration was listed on the Air Quality Standard in 2012 for the very first time. Taiwan EPA set 35 μg/m^3 to be the target value of 24-hour average, and 15 μg/m^3 for annual limit value. To ensure the protection of the citizen's health, Taiwan EPA constructed air quality monitoring network in 2013, the monitoring methods for suspended particulate matter are divided into "Manual monitoring" and "Automatic monitoring", and the adjustment principle of automatic monitoring was announced in 2014. Taiwan EPA carried out Clean Air Plan in 2015. It was the first plan about PM2.5 reductions which set 18 μg/m^3 to be the goal of PM2.5 concentration in 2019, but it didn't have clear strategies and enough funds. With limited decrease in PM2.5 concentration and more and more people complained about PM2.5 exposure. Executive Yuan, R.O.C. unveiled the Air Pollution Control Plan of Action that aims to halve the number of air quality red alert days and let PM2.5 concentration decrease to 18 μg/m^3 by 2019 in 2017. This plan can be seen as the second-phase plan of PM2.5 reductions in Taiwan. This plan was different from the former one. It not only laid out several indicator-based policy targets but also formulated detailed strategies and it even invested lots of money in these strategies. The main goals of this action plan were listed below:

1. Cut in half the number of air quality red alert days by 2019.
2. Reducing the PM2.5 concentration to 18 μg/m^3 by 2019.
3. Replace all new government vehicles and public buses with electric-powered versions by 2030.

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4. Ban all sales of nonelectric motorcycles and sell only fully electric ones by 2035.
5. Ban all sales of nonelectric four-wheel vehicles and sell only fully electric ones by 2040.

The action plan also outlines 14 control and prevention strategies to address larger sources of PM2.5 emissions. State-owned enterprises will be held to super-low emission standards that are the most stringent in the world, vehicles emitting thick smoke will be banned from all roads, and stricter controls will be placed on cooking fumes from restaurants as well as fugitive dust from roads, construction sites and riverbanks. The three-year plan, with a budget of NT$36.5 billion will be assessed in 2019 and the next plan is expected to be launched by that time.

To implement this plan successfully, Legislative Yuan, R.O.C. passed the amendment of the Air Pollution Control Act which is the first major overhaul of the Air Pollution Control Act in 16 years. The amendment focused on management of PM2.5 generated from mobile pollution source. Staple contents of it are as below,

1. Enable local governments to create ‘air quality protection zones’, restricting the access of diesel vehicles over 20 years old as well as two-stroke scooters.
2. Increase penalties for manufacturers whose industrial emissions exceed pollution limits: the maximum fine is now NT$20 million.
3. Offset scheme on the fixed pollution limits - Companies are able to gain industrial emissions credits by paying to take highly polluting old vehicles off the roads.
4. Requiring vessels in ports to replace onboard power auxiliary engines that run on heavy fuels with electricity generated onshore.
5. Give Taiwan EPA the mandate to establish strict emissions standards that all ten-year-old vehicles would have to meet.

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Taiwan EPA hopes to reduce PM2.5 emission from mobile pollution source by conducted these policies. For example, license plates may be revoked for vehicles that fail to meet standards or are not taken in for tests. That would accelerate the retirement of the older vehicles that are highly polluting.

Air Pollution Control Plan of Action will be expired by 2019, Taiwan EPA must formulate new management plans by that time to reduce PM2.5 concentration to meet to national standard at 15μg/m^3, or even at 10μg/m^3 that conform to standard of WHO.

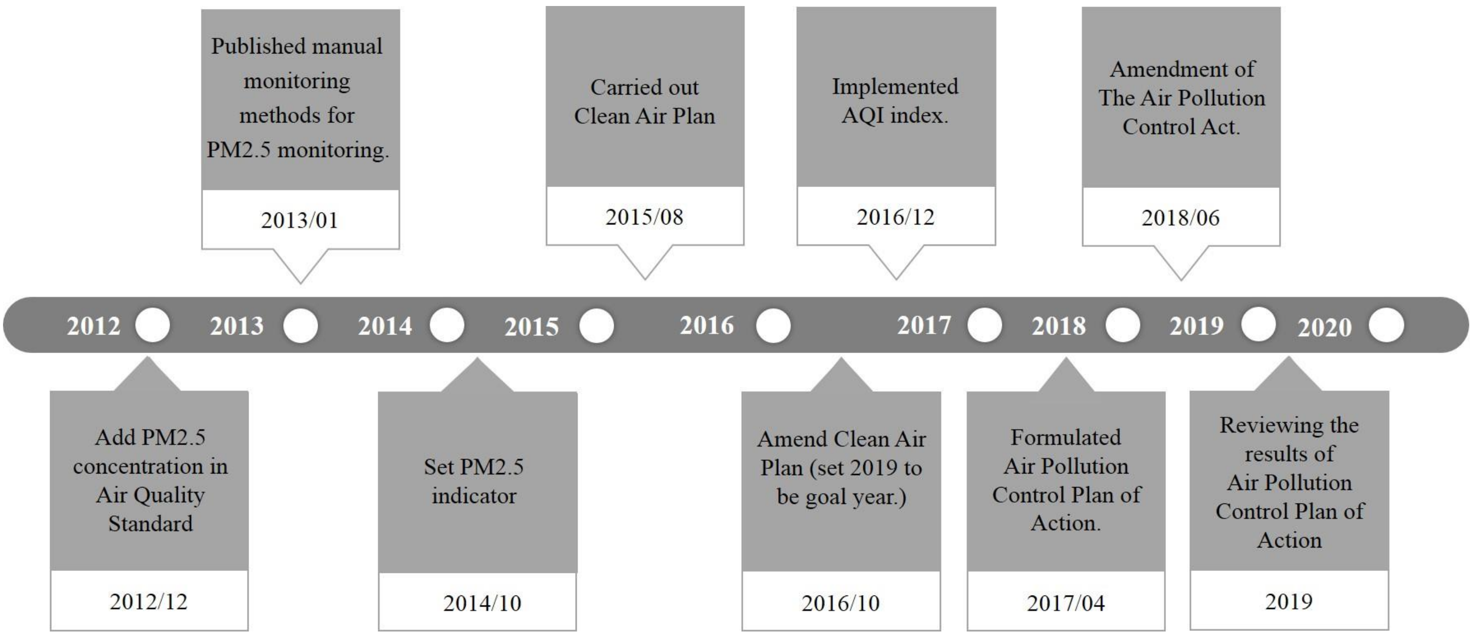

Figure 2-3 Timeline of PM2.5 policies in Taiwan

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Table 2-2 14 strategies in ‘Air Pollution Control Plan of Action’

Policy		Strategy
Stationary pollution source	Power facility control	Modify power industry emission standards,
	Boiler control	Promote 6,000 industrial boilers to cleaner fuels.
	Emission of agricultural control	Reduce second crops rice burning area by 90%.
	Construction particle control	Make 90% or more air pollution control facilities conform to the standard.
	Catering fume control	Add improvement facilities in 7,000 restaurants.
	Change customs	Reduce the use of firecrackers, incense sticks.
	River particle control	Reduce compact between river particle and wind.
Mobile pollution source	Diesel trucks manufactured before 1999 elimination	Phase out 80,000 diesel trucks manufactured before 1999.
	Diesel trucks manufactured after 1999 equipped with particulate filter	Equip 38,000 diesel trucks manufactured after 1999 with diesel particulate filter.
	Two-stroke motorcycle elimination	Phase out 1,000,000 two-stroke motorcycle.
	Transportation control in port area	Reduce pollution from ship transportation, set diesel vehicles restriction zone in port.
	Eletric vehicles promotion in fruit &vegetable market.	Switch three-wheeled diesel powered vehicles that used in vegetable market to electric power.
	Increase the number of public transport users.	Increase the number of trips using public transport each year to 1.244 billion.
	Rail freight capacity management	Increase the rail freight ratio of total freight volume to 15%.

Source: Taiwan EPA (2017)

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2.4.2 South Korea

In recent years, South Korea faced serious air pollution problems. It has the worst air quality among the Organization for Economic Cooperation and Development (OECD), a group of 35 developed economies. Levels of PM2.5 are nearly three times WHO guidelines. The new government which took office in 2017 designated PM concentration as one of its top priority issues, set up an inter-ministerial task force and announced its “Comprehensive Action Plan on Fine Dust” on September 26, 2017. “The Comprehensive Action Plan on Fine Dust” (also known as “September 26 measures”) was much more ambitious than its predecessors in many respects, with the aim of cutting PM2.5 emissions by 30 percent by 2022. The latest batch of measures aimed to bring about sweeping reductions in PM2.5 emissions throughout all areas of socioeconomic activities (including the industry, development and transportation sectors) centered in and around cities with severe PM2.5 levels. The ‘total emissions control’ program, previously applied only to the Seoul Metropolitan Area, is now extended to cover virtually the entire country.

“The Comprehensive Action Plan on Fine Dust” target to phase out up to 77 percent of old diesel vehicles before its current term ends. With a view to better dovetailing the antipollution drive with the government’s energy policies, the Plan also takes as its goals the spread of environment-friendly vehicles, tightening of the control of coal-based power plants that are in operation, and shifting to an energy mix that is environmentally sustainable with reduced coal-based power generation.

Another breaking through in this Plan was to designated children and older persons as “susceptible groups”. They developed measures such as “fine dust-free zones” and limiting the access of old diesel vehicles to them to help those various susceptible groups to better cope with the health hazards tied to PM2.5.

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This 7.2 trillion won ($6.3 billion) plan developed many strategies to cope mobile source PM2.5 pollution such as getting diesel vehicles off the road and curb polluting emissions from industrial plants, construction sites and ships. Strategies to cope mobile source PM2.5 in this plan and in related laws were organized as follows:

Table 2-3 Mobile source PM2.5 reduction strategies in South Korea

Policy	Strategy
Eco-friendly vehicles	Increase accumulate number of eco-friendly cars to 1.5 million to 2020. (electric cars: 250,000, hydrogen cars: 10,000, hybrid cars: 1,240,000)
	Subsidy program for eco-friendly cars.
	Increase the rate of mandatory eco-friendly vehicle purchase for administrative and public agencies(30%→50%).
	Build charging infrastructure (increase to 25% of gas stations until 2020).
	Incentives for charging facilities. (e.g. support exclusive parking)
	Tax benefit for businesses who have more than 50% electric vehicles.
	To provide incentives, introduce license plates exclusive for electric vehicles.
	Plan for discounted toll and exemption from parking lot fee
Ships	Tightened regulations on ships and port facilities.
Bus	Providing fuel tax subsidies and enlarging the charging infrastructure.
	For Metropolitan area express bus, new permits are issued only for eco-buses.
Construction machineries	Extended target for low-pollution construction machineries.
Motor vehicles	Tightened regulations on motor vehicles, and promote electric motor vehicles.
Old diesel vehicles	Extended low emission zone.(Banned vehicles from driving in specific area)
	Set standard on real-driving emission certification for new diesel vehicles.
	Tighten current standard for designating a diesel vehicle.

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2.4.3 Japan

In Japan, Japanese government has fought for cleaner air since 1969. Serious concern for PM2.5 within the Ministry of Environment Japan (MOEJ) began in 1997. The MOEJ established the “Advisory Committee on Evaluation of Health Effects of Fine Particulate Matters” in 2007 (MOEJ, 2007). According to this report, the environmental quality standards (EQS) of PM2.5 were set in 2009, which was determined in Japan states that the annual standard for PM2.5 should be less than or equal to 15 μg m^3, the administration of the national and local governments started to monitor PM2.5 concentration after that. As Figure2-4 shown, Japan controlled the PM2.5 level well.

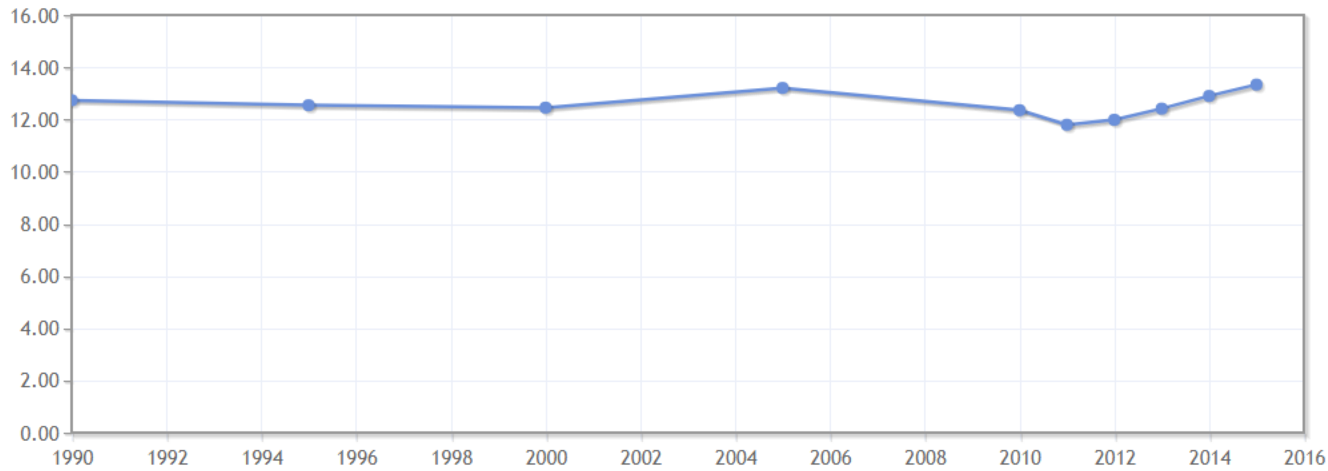

Figure 2-4 PM2.5 concentration in Japan

Source: Index mundy website (2017)

Their successful experience could be a nice mirror for Taiwan. Japanese strategies about PM2.5 reduction could divide into three parts: enactment of law, public transportation promotion and urban greening conduction implementation.

First, Japanese government has enacted a series of laws since 2000, such as “Basic Environment Act” and “The Air Pollution Control Act” to set reduction goals

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and penalties against air pollution. They have also posted stricter emission standards of diesel vehicles, almost all new diesel vehicles are now equipped with diesel particulate filters. Second, Japanese government has vigorously built a railway transportation network extending in all directions. The total length of the subway in Tokyo is 500 KM and the streetcar is 1500 KM, ranking first in the world's major cities. At present, the density of subway stations per square kilometer in Tokyo reaches 1.06 stations. Tokyo had one of most extensive and most used railway networks in the world. Rail is major means of passenger transport especially between major cities and within metropolitan areas. Since the convenience of public transportation, there are fewer and fewer people driving to work. Besides encouraging public transportation using, Japan government also tightened the emission of private vehicles, they launched low-emission vehicle certification, tax incentives, subsidies, and loan concessions were promoted. The number of low-emission vehicle in Japan has reached 20.55 million units, accounting for 27% of the total number of motor vehicles. Last, they devoted their efforts to urban greening, which is an important means of controlling PM2.5 in Japan. The relevant authorities in Tokyo have stipulated that green roofs should be built in new buildings. Greening in Tokyo rarely grew grass, but grew trees, not only pursuing green areas, but also pursuing greening volume. By all these strategies above, PM2.5 level in Japan got soothed.

Detailed policies and strategies about Mobile source PM2.5 reduction in Japan are consolidated into Table 2-4:

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Table 2-4 Mobile source PM2.5 reduction strategies in Japan

Policy	Strategy
Law enactment	Set reduction goals and penalties against air pollution in "The Air Pollution Control Act" .
	Enacted stricter emission standards of diesel vehicles.
	Large business operators must develop vehicle management plans.
Public transportation promotion	A convenient railway transportation network was built.
	Developed the habit of taking general publics to take public transport from childhood.
Non-motorized transport promotion	Tokyo doubled the amount of bike lanes and promoted biking (already 16% commuters use bikes.)
	Established "Cycling Embassy of Japan" to promote cycling
Urban greening	Stipulated that green roofs should be built in new buildings.
	Instead of greening area, urban greening pursued green volume.
Eco-friendly vehicle	Tax deductions and exemptions for eco-friendly vehicles.

2.4.4 Europe Union (EU)

Over the past three decades the EU has put in place a series of legislative and other policy measures that have brought significant progress in reducing air pollution. Despite these advances, however, other forms of air pollution, in particular high concentrations of PM2.5, continue to have serious impacts on human health and the environment. In order to limit PM2.5 concentration, the EU has policies in place limiting individual sources but also national totals of atmospheric emissions of the

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key pollutants. Together with the Ambient Air Quality Directives, the National Emission Ceilings (NEC) Directives and the source legislation underpinning them provide the legal framework for the EU's air policy. The new NEC Directive entered into force in 2016 and must be transposed by 2018. Each EU Member State is required to produce a National Air Pollution Control Programme by 2019 setting out the measures it will take to ensure compliance with the 2020 and 2030 reduction commitments.

According to The United Nations Environment Programme (UNEP) (2017), air pollutant emissions from transport are a main contributor to air quality problems in Europe. Emissions of particulate matter (PM), nitrogen oxides (NOx) and carbon monoxide (CO) are regulated in the EU. To regulate vehicle emission, EU adapted the type approval of cars, vans trucks, buses and coaches. EU renewed the approval standards by a new test method called Real-Driving Emissions test procedure (RDE). Because emissions during "real-world" driving conditions are often higher than those measured during the type approval test (in particular for diesel vehicles), a significant discrepancy with the laboratory testing has been confirmed in recent years, the Commission has developed the RDE, which applies from 2017. RED could better reflects the actual emissions on the road and reduces the discrepancy between emissions measured in real driving to those measured in a laboratory. Testing with RDE, the latest approval standards are Euro 6 for light-duty (cars and vans), and Euro VI for heavy-duty (trucks, buses and coaches).

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Table 2-5 Mobile source PM2.5 reduction strategies in EU

Policy	Strategy
Vehicle emission limit	Emissions standards for vehicles correspond to Euro 6 or Euro VI .
	European Union emission regulations for new light duty vehicles.
Fuel Sulphur content	More stringent fuel regulations that require “Sulphur-free” diesel and gasoline fuels (≤ 10 ppm) must be mandatory.
Restriction on used car importation	Banned, except if personal vehicle, which must be owned and should register for at least three months prior.
	Only small sized vehicles may be imported as household goods.
Actions to promote non-motorized transport	Include sidewalks and bike lanes in new road projects, car-free areas and clean air zone in new city plan etc.
Actions to expand, improve and promote public transport	More natural gas bus fleets and bus lane separation.
	Local levies, charges and fees can be used to promote public transport. (e.g. congestion charges in London.)
	Embedded into a concept of mobility management that combines all modes of transport and includes car sharing and cycling.
Eco-friendly vehicles	Development of charging stations for electric cars.
	Subsidies at Eco-friendly vehicles purchase.

2.4.5 Summary

There lots of merits in every mentioned country. For example, EU has a uniform legislative regime for tackling air pollution, South Korea launch many novel policies about mobile source pollution improvement. How to use these precious experience to

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create strategies that suitable for Taiwan will be an important lesson?

2.5 Related literature, improvement strategies of mobile pollution source

2.5.1 Non-exhaust sources improvement

Borken-Kleefeld (2014) estimated that if unit emissions of future vehicles will be within 150% of the type approval value from 2018 onwards (EURO 6), as Figure 2-4 shown, would lead to a decrease of PM, its emissions from road transport are expected to fall by 62% in 2020 and by 70% in 2030. The majority of PM emissions will then be caused by non-exhaust sources (tyre and brake wear, road abrasion). Thus, better brake pads and discs, as well as reformulated rubber mixtures for tyres might reduce wear by 30% and 50% in 2030 and 2050, respectively. This would translate to about 7 kt less PM2.5 mass emissions, roughly 10% and 14% in 2030 and 2050.

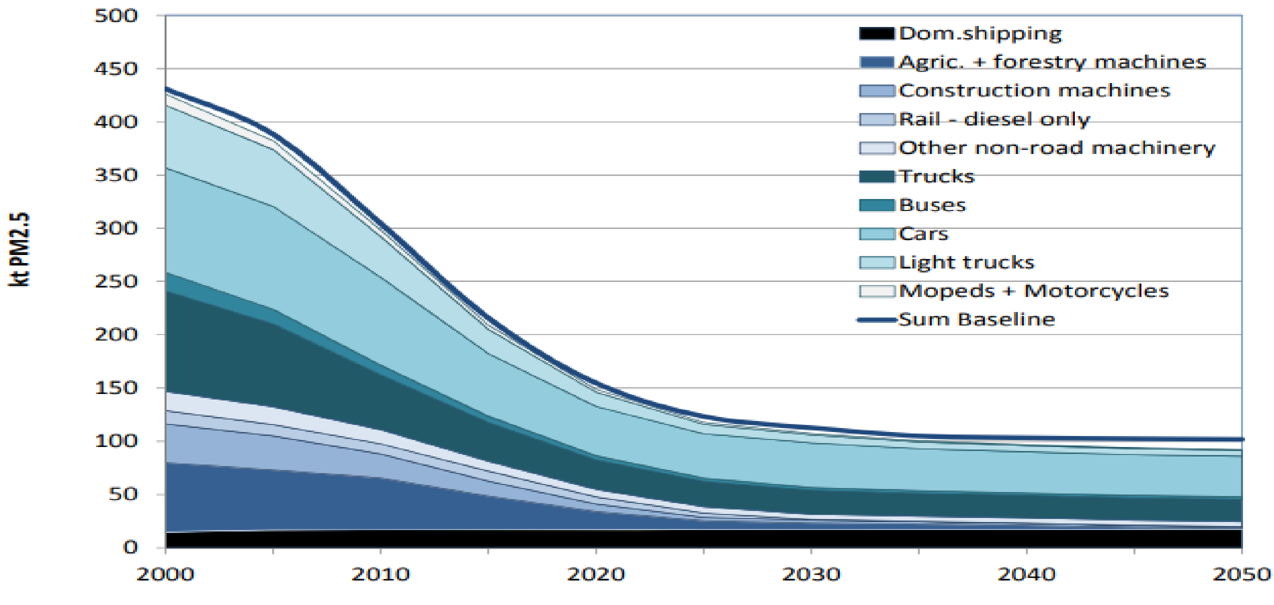

Figure 2-5 PM2.5 Mobile sources emission in EU for decarbonisation scenario. Source: Borken-Kleefeld (2017)

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2.5.2 New exposure indicator

Lin et al. (2017) pointed that the majority of previous studies have used daily mean concentrations as the exposure indicator to examine the short-term association between ambient PM2.5 and mortality, few studies investigated the association between hourly peak PM2.5 and mortality. This study analyzed 350,975 deaths from six Chinese cities, found out about 3.7% of all-cause mortalities were attributable to hourly peak PM2.5. The result demonstrated that hourly peak PM2.5 was significantly associated with increased mortality. This finding suggested that, compared with the hourly peak PM2.5, daily mean PM2.5 might have under-estimated the mortality burden of PM2.5.

Shi et al. (2015) applied poisson regressions to a Medicare population (≥ 65 years of age) in New England to simultaneously estimate the acute and chronic effects of exposure to PM2.5. They observed health effects of hourly peak PM2.5 may help to explain the adverse health effects during days with the daily mean concentration attaining the guidelines.

Madsen et al. (2012) used a time-stratified case-crossover design to estimate associations of traffic-related air pollution and daily mortality during a period of 10 years among residents above 50 years of age in Oslo, Norway. The results reported significant increased all-cause and cardiovascular mortality associated with an increase in peak PM2.5.

2.5.3 Non-Road Mobile Machinery (NRMM)

Wang et al. (2016) indicated that compared to on-road vehicles, less studies regarding emissions characterization have been conducted and investigated for non-road mobile sources in China, so they identified five types of non-road equipment

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were addressed in this study, including agricultural equipment, industrial equipment, river/ocean-going vessels, locomotives, and commercial airplanes. Their investigation has found that the research regarding emissions from non-road equipment is still at its early stage and there is a huge data gap for both activity and emissions factors. They also declared most of the non-road equipment are diesel-fueled and have been proved to be a key source for NOx and PM emissions.

Leung et al. (2013) indicated that NRMM include a wide range of mobile or transportable machinery powered by internal combustion engines and are used off-road, which are widely used at construction sites, container terminals and at the airport. They contribute 8% PM to Hong Kong's total air pollution in 2012. There were no emission standards for NRMM for use in Hong Kong. They suggested government should carry out preparation work in relation to proposed legislation to mandate the control of NRMM for local use.

2.5.4 Roadside Planting design

Gromke et al. (2016) suggested pollutant dispersion in the urban environment is an important dimension of providing solutions to reduce personal exposure to vehicle emissions. They found out that hedgerows can improve the problem of pollutant dispersion and the fact that one central hedgerow leads to greater improvements than two sidewise hedgerows. They suggested hedgerows should extend over the entire length of the street canyon without clearings. For a parallel approach wind, reduced concentrations of up to 30% at the facades and up to 60% at pedestrian level were measured with a sidewise continuous hedgerow arrangement. It is concluded that continuous hedgerows can effectively be employed to control concentrations of traffic pollutants in urban street canyons. They can advantageously affect the air quality at street level and can be a significant remedy to the pedestrians' and residents'

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exposure in the most polluted center area of a street canyon.

Wania et al. (2010) thought that vegetation planning practice needed to re-examine the impact of vegetation cover in the urban fabric given our evaluation of vegetation's effects on air quality, including the dispersion of traffic-induced particles at street level. Their study results revealed vegetation's effect on particle dispersion through its influence on street ventilation. In general, vegetation was found to reduce wind speed, causing inhibition of canyon ventilation and, consequently, an increase in particle concentrations.

Tong et al. (2015) suggested roadside vegetation barriers were potential to reduce near-road air pollution concentrations. They designed vegetation barriers to mitigate near-road air pollution requires a mechanistic understanding of how barrier configurations affect the transport of traffic-related air pollutants. Their analysis demonstrates that the impacts on roadside air quality are particle size-dependent. Two potentially viable design options with regard to roadside mitigation of near-road PM are revealed: (1) A wide vegetation barrier with high Leaf Area Density and width. (2) Vegetation–solid barrier combinations. (Planting trees next to solid barriers).

Yang (2017) found that the most important factor affecting the PM2.5 concentration in street canyon is the wind field. When the atmospheric flow in the street canyon is not good, PM2.5 is not easy to dispersion, and the trees in the street canyon is easy to cause obstruction of airflow and to enhance the concentration of PM2.5, but by adjusting the Leaf Area Intense, can reduce the impact of airflow obstruction. And appropriate planting shrubs can reduce the pollution concentration, but the increase in shrubs also enhance the PM2.5 concentration. So the future city streets Planting design should take into account the street environment, wind field and plant species to retard the traffic effect of PM2.5 concentration.

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2.5.5 Development of battery in electric vehicles

Cater (2012) proposed a novel energy control strategy for a battery vehicle, which is designed to be tunable to achieve different goals. By adding a pack of super capacitors are examined for a test vehicle using lead–acid batteries, the novel battery could not only improve the vehicle's efficiency and range but also reduce the peak currents in the battery pack to increase battery life.

Lee (2011) found the usage of electrical vehicles has not been quite common currently, and the results from that could be considered as, firstly, the electrical vehicles are far more expensive than others. Secondly, lacking of charging stations, and the limitation of battery life-cycle ...etc., and it all pointed out one key factor–battery. She conducted inductive analysis by interviewing with nine experts. The result showed that the overall trend in different period of developing time, short, medium, and long-term development of Ni-MH battery, $LiFePO_4$ battery and NMC battery these three different kinds of batteries in the future. Moreover, by conducting scenario analysis, she discovered that the policy of establishing power stations and charging stations which plays a crucial role of developing the electrical-vehicle industry, and it is also where every government throughout the world should to support.

2.5.6 Diesel engine improvement

Yamamoto (2011) suggested that diesel particulate filters (DPF) has been developed to reduce PM in diesel exhaust gas. As DPF removes PM, DPF will gradually become clogged with the PM that has been adsorbed, so the future generation of DPF technology should aim to develop a continuously regenerating DPF that continuously oxidizes adsorbed PM using a catalyst or a heater during operation of the vehicle.

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Wu (2018) analyzed how the hydrogen-rich gas addition with Exhaust Gas Recirculation (EGR), a device in waste heat recovery system of diesel vehicle, influenced PM2.5 emissions and combustion performance. The results of their study showed that the maximum increase rate of heat recovery efficiency with respect to reaction temperature is 17.5%. The heat recovery efficiency of the reformer rises with increasing engine load up to 24.8%. Adding hydrogen-rich gas with appropriate proportion of EGR helps reduce smoke and PM2.5 from a diesel engine.

2.5.7 Summary

These related literatures provided some new ideas about the PM2.5 reduction strategies formulation. Considering new exposure indicator and non-exhaust sources redesigning roadside planting are all feasible strategies that could apply in future policies.

2.6 PESTLE analysis and its variation

PESTLE is a strategic planning tool used to evaluate the impact of political, economic, social, technological, environmental and legal factors might have on a project (Collins, 2012). PESTLE could help organizations analysis strategies from a macroeconomic perspective so the objective of using the PESTLE Analysis is to ensure that nothing key has been overlooked. (Ahmed, 2016).

PESTLE is a tool, we can choose appropriate factors to conduct specific analysis. There are various forms of PESTLE with some using more factors and some using fewer than the six considered by PESTLE. SLEPT analysis is one of them. It evaluates the impact of Social, Legal, Economic, Political and Technological factors (Rastogi, 2016).

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2.7 Summary

This study adopted SLEPT analysis to decide the dimensions (Kotler and Armstrong, 2004). In accordance with related literatures, PM2.5 mobile pollution source improvement strategies in Taiwan, Japan, EU and South Korea and resources in Kaohsiung, this research summarizes these strategies in Table 2-6.

Table 2-6 Improvement strategies of PM2.5 from mobile pollution source

Dimension	Strategy	Source
Legislative Regulation (L)	New emission standard	E; J; K; T; BorkenKleefeld(2014)
	Old diesel vehicle elimination	J; K; T; Oanh et al. (2010)
	Examination of vehicles	E; K; T; Park et al. (2008)
	Regulation of NRMM	Wang(2016), Leung(2013)
Policy Promotion (P)	Electric vehicles subsidy	E; K; T; Lee et al. (2011)
	Development of charging stations	E; K; Cater et al.(2012)
	Vehicle restriction on PM2.5 alert day	E; K;T; Wu et al.(2009)
	Restriction on vehicle purchase	E; K; Chen et al.(2014)
Social Education (S)	Appropriate driving behavior	E; Autrup et al.(2010)
	Non-motorized transport promotion	E; Litnan et al. (2012)
	Develop public transports using habit	E; K; T; Shi (2017)
	Encouragement of MaaS	T; Kelly et al.(2016)
Environment& Sharing Economy (E)	Land utilization and urban planning	E; J; K; Romero et al.(1999)
	Road dust control	E; J; T; Duong & Lee (2011)
	Promote driverless electric buses and light-duty vehicles sharing	E; K; Kelly et al.(2016)
	Car-sharing platform development	E; Firnkorn et al.(2016)
Technology Change (T)	Novel battery in electric vehicles	E; Cater et al.(2012); Lee (2008)
	Wear resistant tyre and brake	E; Borken-Kleefeld(2014)
	Roadside Planting redesign	Gromke et al. (2016); Wania et al. (2010); Yang (2017)
	Build new style PM-proof roof	Xu et al. (2014); Natasha(2015)

Note: NRMM: Non-Road Mobile Machinery; MaaS: Mobility as a Service.

E: E.U.; K: South Korea; T: Taiwan; J: Japan

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Chapter 3 Research Design and Methodology

In this study, the preliminary framework of PM2.5 improvement strategies is defined regarding to literature review and related policies around the world. Based on this, a four-part analysis will begin. The first stage is to use the fuzzy Delphi method (FDM) with opinions from scholars and government officials to choose appropriate strategies. The second stage is based on the use of a fuzzy analytic hierarchy process (FAHP) to find the criteria weight. Third, calculate feasibility through expert questionnaires. In the last stage, use importance-achievability analysis (IAA) to find out the advantages and disadvantages about improvement strategies of mobile source PM2.5.

3.1 Framework of PM2.5 improvement strategies

The preliminary framework of PM2.5 improvement strategies is formulated regarding to the literature review and related policies around the world. PM2.5 improvement strategies for mobile source is divided into 5 dimensions and 20 strategies. The framework will be formulated and will be introduced in 3.1.1 to 3.1.5.

These dimensions and strategies will be examined by environmental experts including government officials, scholars and leaders of civil environmental groups to confirm the appropriateness of the concepts and strategies further.

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3.1.1 Legislative Regulation

Government could control the concentration of PM2.5 by setting regulation and amending laws, this kind of strategies and definitions are as Table 3-1 shown:

Table 3-1 Strategies and definitions of legislative regulation

	Strategy	Definition	Source
1	New emission standard	Using new emission test procedure like RDE in EU to make the emission standard correspond to real situation. New standard should also consider some factor that have been proven important, such as peak hour concentration.	EU; Japan; South Korea; Taiwan; Borken-Kleefeld(2014)
2	Old diesel vehicles elimination	Diesel vehicle account for a big part in PM2.5 emission. Phasing out diesel vehicles is an effective way to reduce PM2.5. Tightening current standard for old diesel vehicle and subsidizing customer to buy new car can accelerate the elimination.	Japan; South Korea; Taiwan; Oanh et al. (2010)
3	Examination of vehicles	Certification for diesel vehicles and motorcycle, regular inspection and increasing penalties are ways to control emission .License plates may be revoked for vehicles that fail to meet standards or are not taken in for tests.	EU; South Korea; Taiwan; Park et al. (2008)
4	Regulation of NRMM	Most of the non-road equipment are diesel-fueled and have been proven to be a key source for PM emissions. But there were no emission standards for NRMM in Taiwan. Government could carry out preparation work in relation to proposed legislation to mandate the control of NRMM for local use.	Leung et al. (2013); Wang et al.(2016)

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3.1.2 Policy Promotion

After integrating policies of other countries, recommended policies to manage PM2.5 concentration are shown in Table 3-2:

Table 3-2 Strategies and definitions of policy promotion

	Strategy	Definition	Source
1	Electric vehicles subsidy	In the world, the tide is turning in favor of zero-emission vehicles. Subsidies at electric vehicles purchase, discounted toll and exemption forms parking lot fee are useful way to promote electric vehicles. Government could also to provide incentives and introduce license plates exclusive for electric vehicles.	EU; South Korea; Taiwan; Lee et al. (2011); Ji et al. (2015)
2	Development of charging stations	Set incentives for charging facilities. (e.g., Diversify charging methods, support exclusive parking),and cooperate with business company to add charging stations density.	EU; South Korea; Cater et al.(2012)
3	Vehicle restriction on PM2.5 alert day	The goal is to reduce the number of vehicles on the road and to lower emissions from individual vehicles. (e.g., Allowing cars to be used on only certain days of the week, determined by the last digit of the car license number; impose congestion toll.)	EU; Korea; Wu et al. (2009); Yang et al. (2016); Lin et al. (2017)
4	Restriction on vehicle purchase	Only small and medium sized old vehicles may be imported as part of household goods. Meanwhile, impose extra expense when customer buy vehicles which don’t fit current emission standards.	EU; South Korea; Chen et al. (2014); Yang et al. (2016)

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3.1.3 Social Education

Education and environmental concept promotion are also important parts about PM2.5 improvements, strategies about that are shown in Table 3-3:

Table 3-3 Strategies and definitions of social education

	Strategy	**Definition**	**Source**
1	Appropriate driving behavior	Promote eco-driving, such as: Turn off ignition when idle speed, avoid excessive acceleration and deceleration. Appropriate driving behavior could let breaking distance shorter and save more oil. That will make engine and tire produce less PM2.5.	EU; Japan; Richmond et al. (2009); Autrup et al.(2010)
2	Non-motorized transport promotion	Concept like sidewalks and bike using could considered in new road projects, car-free areas and clean air zone in new city plan are also a nice promotion.	EU; Japan; Litnan et al. (2012)
3	Develop public transports using habit	Government could promote it by setting objects as below: 1. Highlighting advantages of public transport compared to individual transport. (e.g., money, parking and PM2.5 exposure) 2. Attracting new passengers while keeping the existing ones. 3. Improving provision of information about transport services. 4. Promote specific subsidy. (e.g., free transit in Kaohsiung winter) 5. Supplying convenient services. (e.g., book car at any time using mobile app)	EU; Japan; South Korea; Taiwan; Lung (2014); Kelly et al.(2016); Shi (2017)
4	Encouragement of MaaS	Kaohsiung is the first city in Taiwan to develop MaaS. Many people don’t know how MaaS work, so it can’t be promoted smoothly. Public explanatory meetings or internet marketing may be feasible plans.	Taiwan; Kelly et al.(2016)

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3.1.4 Environment& Sharing Economy

Considering technology and environmental change, sharing economy seems to be an inevitable trend around the world, reduction strategies about environment& sharing economy are shown in Table 3-4:

Table 3-4 Strategies and definitions of environment& sharing economy

	Strategy	Definition	Source
1	Land utilization and Urban planning	Great urban plan will improve air quality. (e.g., Bus dedicated lane that permits are issued only for electric buses; TOD concept using in future urban planning.)	EU; Japan; South Korea
2	Road dust control	In Taiwan, road dust accounted for approximately 10% PM2.5 emission. Road dust would be brought into the air when vehicles driving on the roads, so the best way to reduce road dust is private vehicle limitation. Moreover, government should also regulate roadwork and implement city greening and wetland protection.	EU; Japan; Taiwan; Duong & Lee(2011)
3	Promote driverless electric buses and light-duty vehicles sharing	Car-sharing has obvious benefits to cities such as reducing total vehicle miles and make cleaner air. Zipcar estimates that every shared vehicle replaces up to 20 private cars. In Kaohsiung, driverless buses could be used in short, fixed circuits and city bus routes while light-duty vehicles in long distance travel.	EU; South Korea; Kelly et al.(2016)
4	Car-sharing platform development	In an ideal car sharing system, users can book a car at any time using a mobile app or computer and can rent and park the car in separate locations. To accomplish that, an integration platform is needed.	EU; Firnkorn et al. (2016); Manigrasso et al. (2017)

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3.1.5 Technology Change

New technology and engineering applied in existing facilities will provide a new perspective about PM2.5 improvement strategies, related strategies are shown in Table 3-5:

Table 3-5 Strategies and definitions of technology change

	Strategy	Definition	Source
1	Novel battery in electric vehicles	Worries over battery life and the lack of coordinated charging networks have held back vehicle sales, even with generous government subsidies. Novel batteries could not only improve the vehicle's efficiency and range, but also reduce the peak currents in the battery pack to increase battery life. It will make electric car more durable and acceptable.	EU; Lee et al. (2011); Borken-Kleefeld(2014)
2	Wear resistant tyre and brake	The majority of PM emissions will then be caused by non-exhaust sources in the future (tyre and brake wear, road abrasion). Thus, better brake pads and discs, as well as reformulated rubber mixtures for tyres might reduce PM2.5 concentration.	EU; Borken-Kleefeld(2014)
3	Roadside Planting redesigning	Great roadside planting design will reduce PM2.5 concentration but bad design will affect PM2.5 concentration in revise way, roadside planting redesigning should be considered.	Gromke et al. (2016); Wania et al. (2010); Yang (2017)
4	Build new style Air Bubble Shield	Air Bubble Shield would reduce 70% exposure for individual when bus drive into bus stop. Current Air Bubble Shield can only accommodate 20 people. Larger and more effective Air Bubble Shield is worth to be built.	Taiwan; Xu et al. (2014); Natasha Khan. (2015)

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3.2 SLEPT Analysis

SLPET is variant from PESTLE modle. PESTLE is an abbreviation which in its expanded form denotes P for Political, E for Economic, S for Social, T for Technological, L for Legal and E for Environmental. It gives a view of the whole environment from many different angles that one wants to check and keep a track of while contemplating on a certain strategy or plan. All the dimensions of this technique are crucial for decision makers. More than just understanding the market, this framework represents one of the vertebras of the backbone of strategic management that accounts for an organization's goals and the strategies stringed to them.

The importance of each of the factors may be different to different kinds of industries, but it is imperative to any strategy a decision maker wants to develop that they conduct the PESTLE analysis as it forms a much more comprehensive version of the SWOT analysis (Theaker et al., 2017). There are many variants that build on the PESTLE framework such as SLEPT, STEPE and STRRPLE (Wikipedia; Collins et al., 2012).

This research uses SLEPT analysis to decide dimensions in the framework. Considering technology and environmental change, this research combines Environmental factor and Economic factor to one factor called Environment & Sharing economy. So the five dimension in the research are Legislative Regulation, Policy Promotion, Social Education, Environment & Sharing economy and Technology Change.

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3.3 Fuzzy Delphi Method (FDM)

3.3.1 Introduction

The Delphi method has been widely applied in many management areas, e.g. forecasting, public policy analysis, or project planning. The traditional Delphi Method is an effective method which enables forecasting by converging a possibility value through the feedback mechanism of the results of the questionnaire, based on expert ‘s judgement. The Delphi Method is a type of collective decision-making method (Linstone & Turoff, 2002). The Fuzzy Delphi Method is a methodology in which subjective data of experts are transformed into quasi-objective data using fuzzy operation. The Fuzzy Delphi Method is an analytical method based on the Delphi Method that draws on the ideas of the Fuzzy Theory. One of the weaknesses of this method is that it requires repetitive surveys of the experts to allow the forecast value to converge. It’s also costly and requires more time. To solve the problem of fuzziness in expert consensus in group decision, Ishikawa et al. (1993) used the Maximum-Minimum Method together with cumulative frequency distribution and fuzzy scoring to compile the expert opinions into fuzzy numbers making.

3.3.2 Process

By using double triangle fuzzy technique, the individual answers of experts are analyzed. After using this technique, opinions about important strategies evaluated by experts are integrated. The process of Delphi using double triangle fuzzy technique is characterized by the following steps:

Step 1. A group of n experts is requested to give possible processing values (including the optimistic value, the moderate value and the conservative value) of every strategy in an activity using a triangular fuzzy number.

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Step 2. Build a triangular fuzzy number for each factor based on collected values.

Step 3. The triangular fuzzy number for the most pessimistic index and the most optimistic index for each decision-making factor is determined. The minimum value (C_L^i and C_U^i), the geometric mean (C_M^i and O_M^i) and the maximum value (O_L^i and O_U^i)) of the experts' opinions on the most pessimistic index and most optimistic index are obtained.

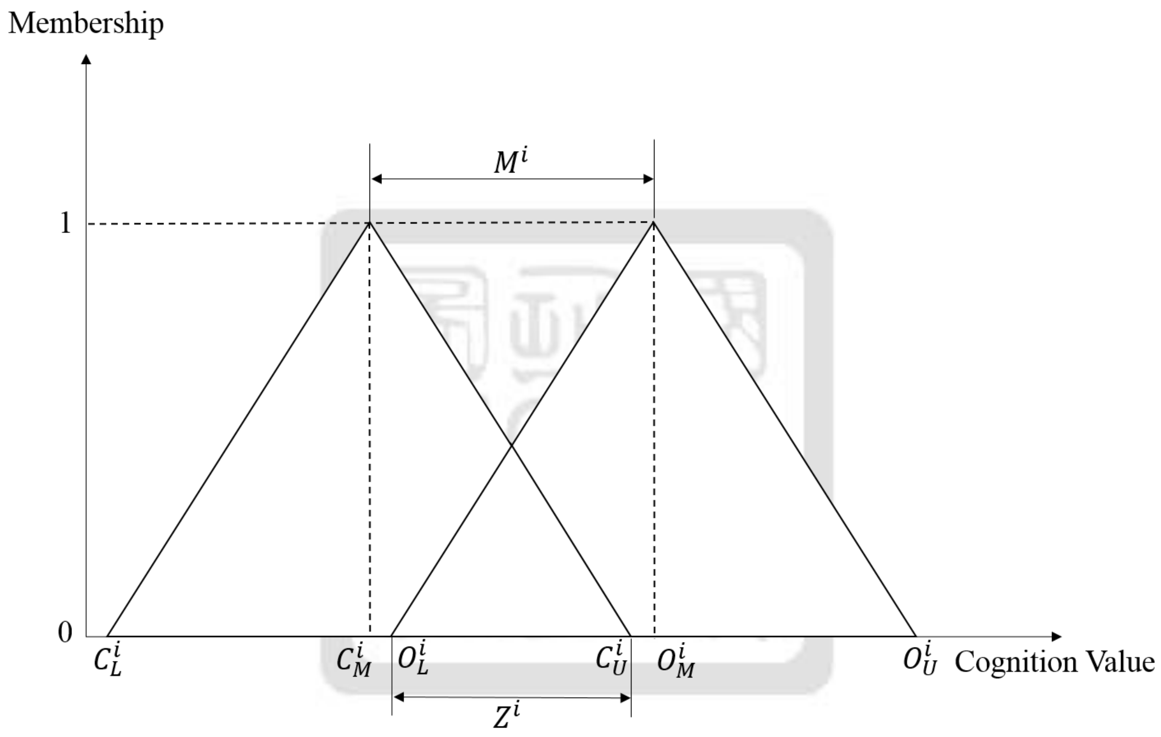

Figure 3-1 double triangle fuzzy technique

Step 4. The consensus of experts' opinions is examined and the consensus significance value of each factor is calculated. The gray zone in Figure is the overlap section of C_U^i and O_L^i is used to examine the consensus of experts in each decision-making factor. The consensus significance value of the decision-making factor G^i, is calculated by the following rules:

(1) If there is no overlap between C_U^i and O_L^i (no gray zone exists), then consensus significance value of the factor $G^i = \frac{C_M^i + O_M^i}{2}$.

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(2) If a gray zone exists and the gray zone interval value Z^i is smaller than the interval value between C_M^i & O_M^i, we called it $(O_M^i - C_M^i)$. The consensus significance value of the decision-making factor $G^i = \frac{C_U^i * O_M^i - O_L^i * C_M^i}{C_U^i - C_M^i + O_M^i - O_L^i}$.

(3) If a gray zone exists and the gray zone interval value Z^i is bigger than the interval value M^i, then a great discrepancy among the expert's opinions arises. Above all steps need to be repeated until a convergence is obtained.

3.4 Analytic Hierarchy Process (AHP)

Analytic hierarchy process (AHP) was first purposed by Saaty in 1971 to solve resource allocation problem in military. Through AHP, decision maker can deconstruct a complex problem to a simple hierarchy. This hierarchy can provide the information to support decision maker choose an appropriate option, and reduce the risk of making a wrong decision (Saaty, 1980). The primary advantage of AHP approach is simple, easy, and can effectively capture the opinion of experts and decision makers. (Zahedi et al., 1986)

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3.5 Fuzzy Analytic Hierarchy Process (FAHP)

3.5.1 Introduction

Fuzzy set theory was introduced by Professor L.A. Zadeh in 1965, to solve uncertainty of human decision problems (Zadeh, 1965). If the uncertainty (fuzziness) of human judgments is not taken into account, the results could be misleading. AHP method is used in nearly crisp decision applications and can't deal with the uncertainty judgment. Terms of expression such as "very likely", "probably so", "not very clear", "rather dangerous" that often use in daily life, these contain some degree of uncertainty (Sheng-Hshiung et al., 1997; Tsaur et al., 2002). So through the concept Zadeh proposed should be able to tolerate vagueness or ambiguity decision-making problems.

The Fuzzy AHP methodology extends from Satty's AHP method by combining it with fuzzy theory. In the FAHP, fuzzy ratio scales are used to indicate the relative strength of the factors in the corresponding criteria. For that, a fuzzy pair-wise comparison matrix can be constructed. After the "defuzzification" we can calculate the largest eigenvalue and its corresponding eigenvector of the pair-wise comparison matrix. The most widely used fuzzy numbers is the triangular fuzzy number, and which is a special case of the trapezoidal fuzzy number. This research used triangular fuzzy number and it is very common use in fuzzy applications (Lee et al., 2006; Lee et al., 2008).

FAHP is the application of AHP combine with fuzzy theory. By using triangular fuzzy numbers, via pairwise comparison, decision maker can fuzzify hierarchical analysis and find the fuzzy weights. Another advantage of the FAHP is easier and faster to get an overall ranking (Hsu et al., 2008).

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3.5.2 Process

The essential steps of FAHP are explained as below (Chang, 1992; Javanbarg et al., 2012; Lee & Seo, 2016):

Step 1. Establishing the hierarchical structure: Construct the hierarchical structure with decision elements, decision-makers are requested to make pair-wise comparisons between decision alternatives and criteria using a nine-point scale. All matrices are developed, and all pair-wises comparisons are obtained from each n decision-maker.

Step 2. Calculating the consistency: To ensure that the priority of elements is consistent, the maximum eigenvector or relative weights and λ_{max} are calculated. Then the consistency index (CI) for each matrix order n using Eq. (3.1) is computed. Based on CI and random index (RI), the consistency ratio (CR) is calculated using Eq. (3.2). The CI and CR are defined as follows (Saaty, 1980):

$$\mathrm{CI} = \frac{\lambda_{max} - n}{n-1} \qquad (3.1)$$

$$\mathrm{CR} = \frac{CI}{RI} \qquad (3.2)$$

where n is the number of items being compared in the matrix, λ_{max} is the largest eigenvalue, and RI is a random consistency index obtained from a large number of simulation runs, and it varies upon the order of the matrix (see Table 3-3).

Table 3-3 Random index (RI)

N	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty (1980)

Step 3. Sum up each row of fuzzy judgment matrix A to get the fuzzy number vector RS.

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$$RS = \begin{bmatrix} rs_1 \\ rs_2 \\ \cdots \\ rs_n \end{bmatrix} = \begin{bmatrix} \sum_{j=1}^{n} a_{1j} \\ \sum_{j=1}^{n} a_{2j} \\ \cdots \\ \sum_{j=1}^{n} a_{nj} \end{bmatrix} = \begin{bmatrix} \sum_{j=1}^{n} l_{1j}, \sum_{j=1}^{n} m_{1j}, \sum_{j=1}^{n} u_{1j} \\ \sum_{j=1}^{n} l_{2j}, \sum_{j=1}^{n} m_{2j}, \sum_{j=1}^{n} u_{2j} \\ \cdots \\ \sum_{j=1}^{n} l_{nj}, \sum_{j=1}^{n} m_{nj}, \sum_{j=1}^{n} u_{nj} \end{bmatrix}$$

Step 4. Normalize the row fuzzy number vector RS to get the fuzzy synthetic extent value vector S.

$$\tilde{S} = \begin{bmatrix} \tilde{s_1} \\ \tilde{s_2} \\ \cdots \\ \tilde{s_n} \end{bmatrix} = \begin{bmatrix} rs_1 \otimes (\sum_{j=1}^{n} rs_j)^{-1} \\ rs_2 \otimes (\sum_{j=1}^{n} rs_j)^{-1} \\ \cdots \\ rs_n \otimes (\sum_{j=1}^{n} rs_j)^{-1} \end{bmatrix}$$

Where $(\sum_{j=1}^{n} rs_j)^{-1}$ is the derivative of the sum of the fuzzy number vector RS and it is calculated by Eq. (3.3).

$$(\sum_{j=1}^{n} rs_j)^{-1} = \left(\frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} u_{kj}}, \frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} m_{kj}}, \frac{1}{\sum_{k=1}^{n}\sum_{j=1}^{n} l_{kj}}\right) \ldots\ldots\ldots\ldots\ldots\ldots(3.3)$$

Step 5. Compute the degree of possibility to get the non-fuzzy weight vector V.

$$V = RS = \begin{bmatrix} V_1 \\ V_2 \\ \cdots \\ V_n \end{bmatrix} = \begin{bmatrix} minV(\tilde{s_1} \geq \tilde{s_k}) \\ minV(\tilde{s_2} \geq \tilde{s_k}) \\ \cdots \\ minV(\tilde{s_n} \geq \tilde{s_k}) \end{bmatrix}$$

where for element i, the subscript k $\in$ {1,2…,n} and k $\neq$ i. Also the degree of possibility of $\tilde{s_2} = (l_2, m_2, u_2) \geq \tilde{s_1} = (l_1, m_1, u_1)$ is obtained by Eq. (3.4).

$$V(\tilde{s_2} \geq \tilde{s_1}) = \begin{cases} 1, & if\ \ m_2 \geq m_1 \\ 0, & if\ \ l_1 \geq u_2 \\ \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.4)$$

Step 6. Define the final non-fuzzy normalization weight vector W.

$$W = \begin{bmatrix} w_1 \\ w_2 \\ \cdots \\ w_n \end{bmatrix} = \begin{bmatrix} v_1 / \sum_{i=1}^{n} v_i \\ v_2 / \sum_{i=1}^{n} v_i \\ \cdots \\ v_n / \sum_{i=1}^{n} v_i \end{bmatrix}$$

Step 7. Consistency check and deriving priorities. This step checks for consistency by CI and extracts the priorities from the pairwise comparison matrices.

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3.6 Improvement Achievability Analysis

Experts use improvement achievability assessment scores which represented by five-scale linguistic variables to evaluate the achievability of improvement strategies. The scores given by experts are transformed into triangular fuzzy numbers, for example: d_{krt}, t=1,2…m represents the linguistic membership function of k assessment items under r criterion given by expert; Triangular fuzzy number of k assessment items in r linguistic membership function as follows:

$A_{krt} = (L_{krt}, M_{krt}, U_{krt})$

Where $L_{krt} = \min \{ d_{kr1}, d_{kr2}, d_{kr3}, \ldots, d_{krm} \}$

$M_{kr} = \prod_{t=1}^{m} dkrt$ ....(3.5)

$U_{kr} = \max \{ d_{kr1}, d_{kr2}, d_{kr3}, \ldots, d_{krm} \}$

Defuzzification by using centroid method to change fuzzy value into nonfuzzy value:

$DF_i = [(U_{ri} - L_{ri}) + (M_{ri} - L_{ri})] / 3 + L_{ri}, \forall i$ ....(3.6)

After calculating defuzzification, the resulut represents the achievability score and their ranking means relative achievability.

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Chapter 4 Analysis and Results

4.1 Fuzzy Delphi Method (FDM) results

4.1.1 Questionnaire information

After developing PM2.5 improvement strategies by the literature review and related policies around the world. PM2.5 improvement strategies for mobile source is divided into 5 dimensions and 20 strategies, the framework is listed in Table 2-6. For choosing the adequate strategies from these strategies, Fuzzy Delphi Method (FDM) is used to select appropriate strategies listed in Table 2-6. FDM is applied to improvement strategies of each perspective to find consensus significance value (G^i). The questionnaire of this research is formulated based on the framework in Table 2-6. However, this questionnaire will be distributed to Taiwanese experts, so the Chinese questionnaire will be provided. The questionnaire in Chinese is presented in Appendix A. This research sent out 10 FDM questionnaires, 5 for government officials and 5 for scholars in university. The summary about FDM questionnaire is shown as Table 4-1.

Table 4-2 shows the background information of the experts, involving five government officials with more than ten years' experience in the bureau of transportation or environmental protection and five academic researchers in the field of transportation science or environmental science.

Table 4-1 Summary of FDM questionnaire response rate

	Sent out	Return	Response Rate (%)	Effective Questionnaire	Rate of Effectiveness (%)
Government	5	4	80	4	80
Academia	5	5	100	4	80

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Table 4-2 Experts profile of FDM questionnaire

Attribute	No.	Institution/ Company	Characteristics	No. of valid QNR
Government	1	Transportation Bureau of Kaohsiung City Government	Government officials in the bureau of transportation or environmental protection with more than 10-year experience.	4
	2	Transportation Bureau of Kaohsiung City Government		
	3	Transportation Bureau of Kaohsiung City Government		
	4	Environmental Protection Bureau of Kaohsiung City Government		
	5	Environmental Protection Bureau of Kaohsiung City Government		
Academia	6	National Cheng Kung University	Professors in the field of transportation science or environmental science.	4
	7	National Chiao Tung University		
	8	Chang Jung Christian University		
	9	National Kaohsiung University of Hospitality and Tourism		
	10	National Yunlin University of Science and Technology		

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4.1.2 Threshold value selection

Experts used score (From 1 to 10) to evaluate the appropriateness. The higher the score is, the more appropriate the strategy is. This research eliminates scores that over than two standard deviations from the mean to avoid impact of extreme values.

FDM is applied to improvement strategies of each expert questionnaire to find consensus significance value G^i. Adequate strategies were selected if its consensus significance value G^i is greater than or equal to the threshold value which is subjectively determined by the decision maker (Chang, 1998). In this research, according to the scatter plot of G^i value which was shown in Figure 4-1, G^i threshold is set at 6.00 (Klir & Folger, 1988). The results of FDM for this research were listed in Table 4-3. 14 strategies are chosen out of 20. Strategy (P3), (S3), (T3) and (T4) don't reach the threshold value.

In the other hand, strategy (E3) and (T2) didn't obtained convergence ($Z^i > M^i$), so they need another questionnaire survey.

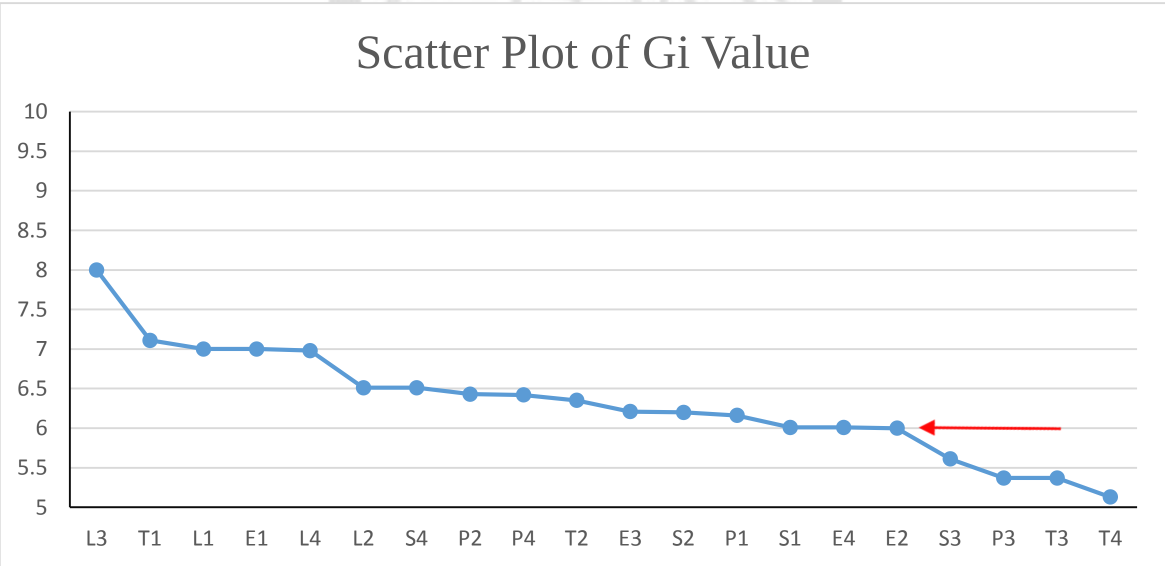

Figure 4-1 Scatter Plot of G^i Value

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4.1.3 Results of first phase FDM

According to the FDM results in the first phase, this research eliminated strategies that didn't reach the threshold value and carried out the second phase FDM questionnaire survey to obtain convergence in two strategies. This research also revised definition of some strategies and added one new strategies in the second phase FDM questionnaire survey by suggestion from experts. The detailed amendment is as below:

(1) Strategy(P3) 'Vehicle restriction on PM2.5 alert days', strategy(T3) 'Roadside Planting redesign' and strategies (T4) 'Build new style PM-proof roof' have been deleted because of unsatisfactory G^i.

(2) Strategy(T2) 'Wear resistant tyre and brake' and (E3) 'Promote light-duty vehicles sharing' don't obtain convergence ($Z^i > M^i$), but their discrepancy between Z^i and M^i was very little. So they need another questionnaire survey.

(3) Strategy(S3) 'Develop public transports using habit' doesn't reach the threshold value. However, some experts suggested it as an important one. After summarizing the advice from them, this research revises definition of this strategy and amends the it to 'Lower the usage rate of private vehicle'.

(4) Because of expert suggestions and policy encouragement, this research adds a new strategy 'ORVR system in motorcycle'. Onboard refueling vapor recovery system (ORVR) is a vehicle fuel vapor emission control system that captures volatile organic compounds (VOC) during refueling. By reducing diffuse VOC, PM2.5 concentration will be lower. Currently, ORVR systems are usually attached in cars or buses. If this kind of system can apply on motorcycles, it will help reducing PM2.5.

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Among all the twenty strategies, fourteen strategies (70 %) are included in the ultimate framework because their G^i values are higher than the threshold value (6.00) and obtains convergence. As table 4-3 and Table 4-4 shown, all of strategies in ‘Legislative Regulation’ is accepted and their ranking are all in top 6. This may mean that the dimension is very important. On the contrary, there were only one strategy is accepted in ‘Technology Change’ on first phase survey. This probably because the development time, costs and the results are difficult to predict.

Then we will discuss strategies that got the highest G^i value in each dimension. First, for ‘Legislative Regulation’ dimension, ‘Examination of vehicles’ gets the highest G^i value. That means experts believe that current standards can’t present real emissions and is unable to reduce PM2.5 concentration effectively. Second, in ‘Policy Promotion’ dimension, ‘Development of charging stations’ has the greatest G^i value. If there were more charging stations, the usage rate of electric vehicles might have a significantly increase. Third, in ‘Social Education’ dimension, ‘Encouragement of MaaS’ obtains the highest G^i value. It shows that experts think Maas has great potential in Kaohsiung. Then, in ‘Environment & Sharing Economy’ dimension, ‘Land utilization and urban planning’ gets a high G^i value. Nice urban planning will increase public transport usage rate and ruduce mileage of using private vehicles. With the extension of the Kaohsiung MRT, the government should think about how to do urban planning well. At the last, in ‘Technology Change’ dimension, ‘Novel battery in electric vehicles’ gets the highest G^i value. It is also the second highest in overall ranking. Novel batteries could not only improve the vehicle’s efficiency and range, but also increase battery life.

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Table 4-3 FDM results of improvement strategies in the first phase survey

Dimension	Strategy	C^i		O^i		Geo-Mean		Z^i	M^i	G^i
		Min	Max	Min	Max	C^i	O^i			
Social Education(S)	(S1) Appropriate driving behavior	3	7	5	9	4.67	7.36	2	2.69	6.01
	(S2) Non-motorized transport promotion	3	8	5	10	4.36	7.45	3	3.09	6.20
	(S3) Develop public transports using habit	3	6	5	10	4.61	7.18	1	2.57	5.61
	(S4) Encouragement of MaaS	3	8	5	10	4.95	8.08	3	3.12	6.51
Legislative Regulation(L)	(L1) New emission standard	3	7	7	10	5.55	8.84	0	3.29	7.00
	(L2) Old diesel vehicle elimination	3	7	5	10	5.83	8.56	2	2.73	6.51
	(L3) Examination of vehicles	6	8	8	10	6.72	9.47	0	2.75	8.00
	(L4) Regulation of NRMM	3	8	6	10	5.66	8.24	2	2.58	6.98
Environment& Sharing Economy(E)	(E1) Land utilization and urban planning	3	7	7	10	4.70	8.19	0	3.50	7.00
	(E2) Road dust control	3	6	6	10	4.48	7.63	0	3.15	6.00
	(E3) Promote light-duty vehicles sharing	2	8	5	10	4.46	7.41	3	2.95	6.21
	(E4) Car-sharing platform development	2	7	5	10	4.55	7.49	2	2.94	6.01
Policy Promotion(P)	(P1) Electric vehicles subsidy	3	7	5	10	5.11	7.60	2	2.49	6.16
	(P2) Development of charging stations	3	7	5	10	5.79	8.06	2	2.27	6.43
	(P3) Vehicle restriction on PM2.5 alert day	1	6	5	8	3.27	6.64	1	3.37	5.37
	(P4) Restriction on vehicle purchase	3	8	5	10	4.73	7.94	3	3.21	6.42
Technology Change(T)	(T1) Novel battery in electric vehicles	4	8	6	10	6.09	8.39	2	2.30	7.11
	(T2) Wear resistant tyre and brake	3	8	5	10	4.75	7.66	3	2.91	6.35
	(T3) Roadside Planting redesign	3	6	5	10	3.75	6.35	1	2.6	5.37
	(T4) Build new style PM-proof roof	1	8	3	10	3.45	6.37	5	2.92	5.13

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Table 4-4 Rank of significance value

Dimension	Strategy	G^i	Rank (Dimension)	Rank (All)
Social Education(S)	(S1) Appropriate driving behavior	6.01	3	14
	(S2) Non-motorized transport promotion	6.20	2	12
	(S3) Develop public transports using	5.61	4	17
	(S4) Encouragement of MaaS	6.51	1	6
Legislative Regulation(L)	(L1) New emission standard	7.00	2	3
	(L2) Old diesel vehicle elimination	6.51	4	6
	(L3) Examination of vehicles	8.00	1	1
	(L4) Regulation of NRMM	6.98	3	5
Environment & Sharing Economy(E)	(E1) Land utilization and urban	7.00	1	3
	(E2) Road dust control	6.00	4	16
	(E3) Promote light-duty vehicles	6.21	2	11
	(E4) Car-sharing platform development	6.01	3	14
Policy Promotion(P)	(P1) Electric vehicles subsidy	6.16	3	13
	(P2) Development of charging stations	6.43	2	8
	(P3) Vehicle restriction on PM2.5 alert	5.37	4	18
	(P4) Restriction on vehicle purchase	6.42	1	9
Technology Change(T)	(T1) Novel battery in electric vehicles	7.11	1	2
	(T2) Wear resistant tyre and brake	6.35	2	10
	(T3) Roadside Planting redesign	5.37	3	18
	(T4) Build new style PM-proof roof	5.13	4	20

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4.1.4 Results of second phase FDM

To examine the appropriateness of amendments above. This research implemented second phase FDM questionnaire survey in January, 2019. The second phase FDM questionnaire includes four strategies. It is presented in Appendix B. The second phase questionnaire was sent to same experts who had participated in the first phase questionnaire survey. After analyzing valid questionnaires, FDM results of improvement strategies in the second phase survey are shown as Table 4-5. The G^i value of two new strategies, (S3) and (T3), were both above 7.00 which beyond threshold value 6.00. So the two new strategies are accepted in the second questionnaire survey. In the other hand, strategy (E3) and (T2) get experts' convergence, so these two strategies are also accepted as well.

All four strategies are accepted on the second phase questionnaire and the ultimate framework of this research was summarized in Figure 4-2.

Table 4-5 FDM results of improvement strategies in the second phase survey

Strategy	**C^i**		**O^i**		**Geo-Mean**		**Z^i**	**M^i**	**G^i**
	Min	**Max**	**Min**	**Max**	**C^i**	**O^i**			
(S3) Lower the usage rate of private vehicle	4	8	6	10	5.52	8.77	2	3.25	7.06
(E3) Promote light-duty vehicles sharing	1	7	6	9	3.50	7.29	1	3.79	6.27
(T2) Wear resistant tyre and brake	3	8	7	9	4.20	7.58	1	3.38	7.13
(T3) ORVR system in motorcycle	3	6	7	9	4.50	7.97	-1	3.47	6.24

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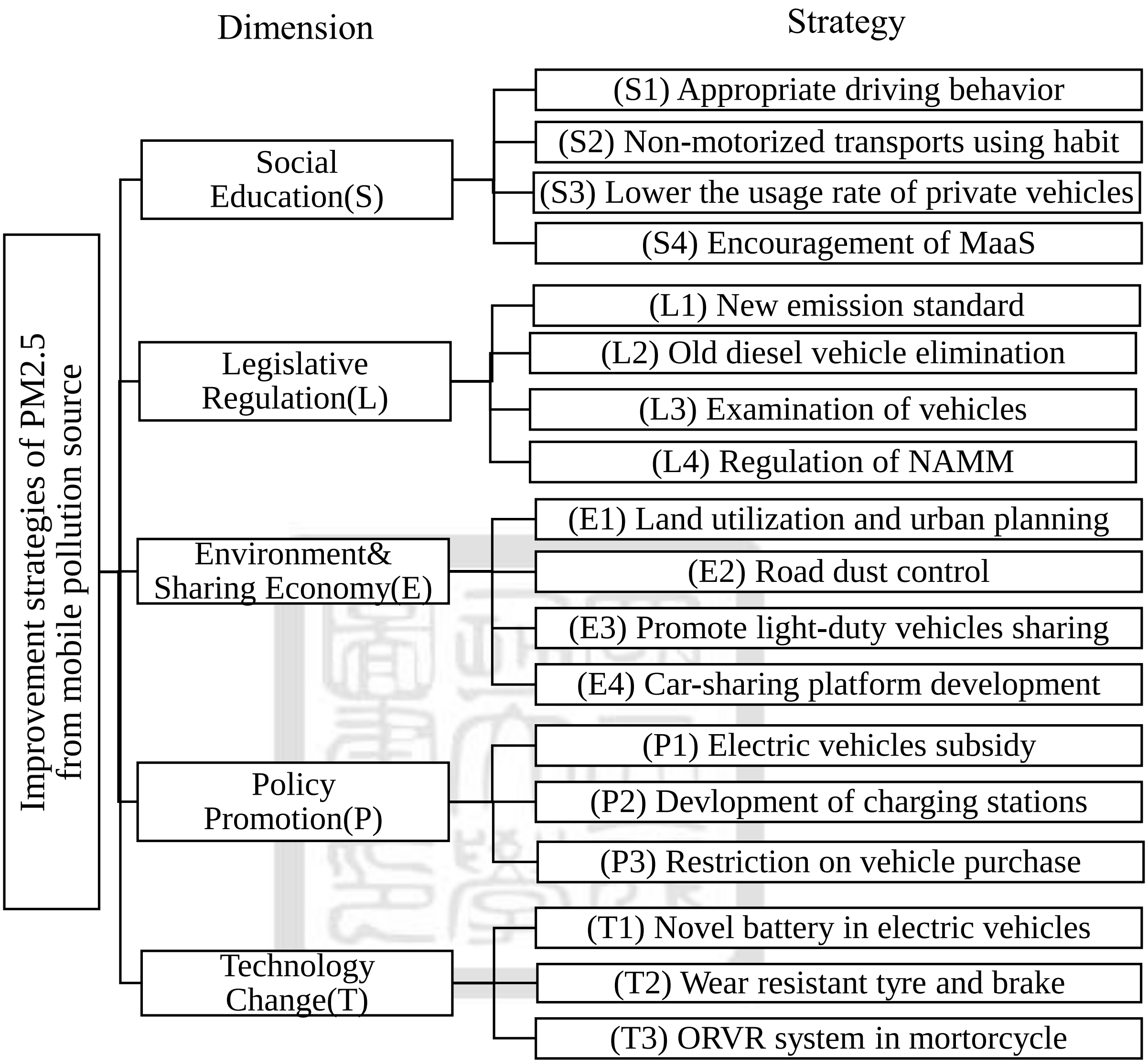

Figure 4-2 Framework of mobile source PM2.5 improvement strategies

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4.2 Fuzzy Analytic Hierarchy Process (FAHP) results

4.2.1 Questionnaire information

After selecting strategies by suggestions of experts, this research carried out the FAHP questionnaire survey to develop the relative importance. Same as the FDM questionnaire, we provide the Chinese questionnaire to Taiwanese experts. The questionnaire in Chinese is presented in Appendix C. This research sent out 19 FAHP questionnaires. The summary about FAHP questionnaire is shown as Table 4-6.

Table 4-7 shows the background information of the experts, involving 6 government officials with more than 10 years' experience in the bureau of transportation or environmental protection, 5 academic researchers in the field of transportation science or environmental science, 6 leaders in the environmental groups and 2 managers in electric motor company.

Table 4-6 Summary of FAHP questionnaire response rate

	Sent out	Return	Response Rate (%)	Questionnaire With CR<0.2	Rate of Effectiveness (%)
Evi-Group	8	4	50	4	50
Government	6	6	100	5	83.3
Academia	5	5	100	5	100

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Table 4-7 Experts profile information of FAHP questionnaire

Attribute	No.	Institution/ Company	Characteristics	No. of valid QNR
Environmental Group / Electric Motor Companies	1	Citizen of the Earth, Taiwan	Leaders in environmental group which is in response to air pollution issues or Managers in electric motor company.	4
	2	Citizen of the Earth, Taiwan		
	3	Taiwan Environmental Protection Union		
	4	Taiwan Environmental Protection Union		
	5	Air Clean Taiwan		
	6	Air Clean Taiwan		
	7	Kunpin Technology Company		
	8	Lokovei Company		
Government Officials	9	Transportation Bureau of Kaohsiung City Government	Government officials in the bureau of transportation or environmental protection with more than 10-year experience.	5
	10	Transportation Bureau of Kaohsiung City Government		
	11	Transportation Bureau of Kaohsiung City Government		
	12	Environmental Protection Bureau of Kaohsiung City Government		
	13	Environmental Protection Bureau of Kaohsiung City Government		
	14	Environmental Protection Bureau of Kaohsiung City Government		
Academia	15	National Cheng Kung University	Professors in the field of transportation science or environmental science.	5
	16	National Chiao Tung University		
	17	Chang Jung Christian University		
	18	National Kaohsiung University of Hospitality and Tourism		
	19	National Yunlin University of Science and Technology		

4.2.2 Consistency Ratio (CR) test

This research uses the consistency ratio (CR) to assess the reliability of the questionnaire. When $CR < 0.1$, it indicates that the deviation in decision makers'

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evaluation of each strategy weight when constructing the paired-comparison matrix was acceptable, verifying the consistency (Saaty, 1980). And according to Bodin & Gass (2003), the CR of the FAHP questionnaire is hard to be less than 0.1. Therefore, if CR is slightly larger than 0.1 would also be acceptable. In order to make the results more objective, more experts opinions need to be included.

Considering that some experts are the first time to fill out a FAHP questionnaire, so this research set 0.2 to be the threshold value for CR. As shown in Table 4-8, some CR values in questionnaire NO.8 are higher than 0.2, so it has been rejected. As CR values in other questionnaires are lower than 0.2, all the other experts are consistent and comparison matrix is satisfactory.

Table 4-8 Consistency Ratio (CR) of questionnaires

Questionnaire Number	Dimension	Social Education (S)	Legislative Regulation (L)	Environment & Sharing Economy (E)	Policy Promotion (P)	Technology Change (T)
NO.1	0.183	0.187	0.138	0.120	0.141	0.103
NO.2	0.031	0.063	0.032	0.019	0.008	0.093
NO.3	0.060	0.019	0.0074	0.045	0.003	0.019
NO.4	0.118	0.072	0.132	0.115	0.046	0.046
NO.5	0.162	0.062	0.000	0.089	0.016	0.016
NO.6	0.055	0.008	0.019	0.043	0.000	0.003
NO.7	0.094	0.084	0.096	0.043	0.158	0.158
NO.8	0.513	0.294	0.208	0.115	0.317	0.187
NO.9	0.033	0.027	0.042	0.097	0.000	0.000
NO.10	0.085	0.086	0.090	0.089	0.046	0.187
NO.11	0.022	0.032	0.022	0.023	0.033	0.046
NO.12	0.053	0.043	0.047	0.082	0.056	0.180
NO.13	0.158	0.127	0.149	0.101	0.033	0.025
NO.14	0.053	0.043	0.063	0.043	0.158	0.033
NO.15	0.126	0.087	0.047	0.082	0.107	0.019

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4.2.3 Analysis for dimensions

Normalized weight values of the five dimensions are shown in Table 4-9. Based on all the experts' opinion, legislative regulation is suggested to be the most important aspect. Technology change ranks second, while policy promotion is the next. Social education is the fourth and environmental & sharing economy is the last important.

If each attribute is analyzed separately, the ranking will roughly show the similar trend. Legislative regulation is the most important dimension in three different attributes, we could infer that most of experts believe that the intensity of law enforcement and the revision of regulations are very important. How to make laws keep pace with the times is the biggest challenge in the future. Policy promotion is also considered to be an essential dimension. It has the top three ranking in all aspects. However, experts' opinions have great differences in technology change, it is the second important dimension in environmental groups' suggestion and is the third in academia. But in the ranking of government, it is the last. We suspect that it may be caused by different occupational characteristics. Environmental groups focus on solving air pollution problems from some new perspective, while the government is committed to promoting laws and policies with existing resources. Generally speaking, government agencies would not regard the strategy that full of uncertainty as an important development direction. The academia pays attention to the balanced development between practical experience and new technology research.

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Table 4-9 Group fuzzy weight vectors

Dimension	Environmental Group		Government		Academia		Overall	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Social Education (S)	0.080	4	0.259	2	0.083	4	0.172	4
Legislative Regulation (L)	0.309	1	0.376	1	0.543	1	0.335	1
Environment & Sharing Economy (E)	0.076	5	0.119	4	0.077	5	0.095	5
Policy Promotion (P)	0.236	3	0.178	3	0.201	2	0.182	3
Technology Change (T)	0.299	2	0.069	5	0.095	3	0.216	2

4.2.4 Analysis for strategies

Table 4-10 presents the relative weights and rankings of all strategies in separate attribute and overall status.

In the term of relative importance, new emission standard (L1), novel battery in electric vehicles (T1), examination of vehicles (L3), lower the usage rate of private vehicle (S3) and electric vehicles subsidy (P1) are 5 top-ranking strategies. Compare to the rankings of each dimension above, legislative regulation, the most important dimension, has two strategies in the 5 top-ranking strategies while the last important dimension environment & sharing economy has none.

Then, this research will discuss the top five strategies in order.

1. ‘New emission standard’ is the most important of all 18 strategies. It has been unanimously recognized by experts in various fields. Experts believe that the government can use new testing techniques to establish new benchmarks that are

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more realistic. Based on this benchmark, government should also consider the type of vehicle and the year of manufacture. After that, new emission standards that can effectively reduce pm2.5 emissions will be set.

2. ‘Novel battery in electric vehicles’ is the second important strategies. As Table 4-10 shows, the opinions of experts on this strategy are very different. Experts in environmental group and academia think this strategy is within the top 6 rank, but the experts in government suggest that the importance of this strategy is on the final list of importance. This discrepancy may be due to differences in thinking angles, the successful development of new batteries will definitely help the goal of PM2.5 reduction. However, the air pollution budget of municipal government is limited and citizens always hope to see results about PM2.5 reduction immediately. Without a clear timetable, government can’t regard it as an important strategy. Nevertheless, in the long-term perspective, the development of new batteries is still imperative. Only when batteries can be used with nice endurance and cheap price will people really eliminate their doubts about purchasing electric vehicles.
3. ‘Examination of vehicles’ is also on the 3 top-ranking strategies, according to new emission standards, government should make detailed specifications for each type of vehicle. They should set the standard and time of inspection clearly. If the standard is not met, penalties will be imposed to maintain enforcement intensity.
4. ‘Lower the usage rate of private vehicle’ is the fourth important strategy on the list. Contrary to the new battery above, the experts in government consider it to be very important, but other experts rank it in the middle. In addition to the increase in parking fees, the introduction of congestion tax and other methods to

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increase the cost of private vehicles, a large percentage of Kaohsiung's private vehicles use is in short- distance transportation. If government could enhance the ability of mass transit, transporting passengers from point to point, use rate of private would be lower.

5. 'Electric vehicles subsidy' is the fifth. Currently, the government already has subsidies for the purchase of electric vehicles. But in the future, they can refer to the policies of other countries, to provide subsidies for batteries and charging stations. With the examination mention above, government can accelerate the replacement of electric vehicles.

Beside mentioned strategies above, the most important strategy in dimension 'Environment & Sharing Economy' is 'land utilization and urban planning' which ranks 9 in the overall ranking. With the development of LRT and the MRT extension in Kaohsiung, the living sphere of citizens may also change. The government can reduce the short-term trips of the citizens by establishing a central business district (CBD), or they can even conduct new urban planning with TOD concept.

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Table 4-10 The value and rank of achievability

Strategy	Environmental Group		Government		Academia		Overall	
	Weight	Rank	Weight	Rank	Weight	Rank	Weight	Rank
(S1)Appropriate driving behavior	0.005	18	0.034	11	0.019	13	0.022	15
(S2)Non-motorized transport promotion	0.018	13	0.026	13	0.018	14	0.020	17
(S3)Lower the usage rate of private vehicle	0.037	10	0.130	2	0.024	11	0.086	4
(S4)Encouragement of MaaS	0.012	16	0.042	8	0.027	9	0.027	14
(L1)New emission standard	0.143	2	0.192	1	0.208	1	0.150	1
(L2)Old diesel vehicle	0.072	5	0.082	5	0.078	5	0.063	7
(L3)Examination of vehicles	0.051	6	0.095	3	0.189	2	0.098	3
(L4)Regulation of NRMM	0.019	12	0.024	16	0.044	7	0.030	11
(E1)Land utilization and urban planning	0.041	9	0.036	10	0.035	8	0.031	9
(E2)Road dust control	0.012	15	0.040	9	0.018	15	0.031	10
(E3)Promote light-duty vehicles sharing	0.014	14	0.018	17	0.011	18	0.013	18
(E4)Car-sharing platform development	0.009	17	0.026	14	0.016	16	0.020	16
(P1)Electric vehicles subsidy	0.140	3	0.059	6	0.090	4	0.079	5
(P2)Development of charging stations	0.094	4	0.053	7	0.106	3	0.072	6
(P3)Restriction on vehicle purchase	0.034	11	0.082	4	0.026	10	0.060	8
(T1)Novel battery in electric vehicles	0.210	1	0.025	15	0.054	6	0.136	2
(T2)Wear resistant tyre and brake	0.041	8	0.009	18	0.024	12	0.030	13
(T3)ORVR system in motorcycle	0.049	7	0.027	12	0.013	17	0.030	12

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4.3 Achievability analysis results

4.3.1 Questionnaire information

The questionnaire of achievability analysis was sent with FAHP questionnaire in January, 2019. The questionnaire is presented in Appendix C. This research sent out 19 FAHP questionnaires and we received 15 questionnaires. Among these questionnaires, there are 4 from environment groups, 6 from government and 5 from academia. Each expert uses 20-100 to express their opinions about achievability of these strategies. The higher the score is, the more achievable the strategy is. In this research, we use fuzzy numerical ordering method that is proposed by to calculate defuzzification of improvement achievability. The gravity center method is used to defuzzify the triangular fuzzy numbers, and the clear optimal value would be found.

4.3.2 Results of achievability analysis

According to Table 4-11, in the overall ranking, the top five are only in two dimension, legislative regulation and policy promotion. Furthermore, 8 out of the top 10 overall ranking strategies are in three dimension, legislative regulation, policy promotion and technology change. This may indicate that the experts believe that these three dimensions are suitable for the beginning of a new PM2.5 reduction plan.

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Table 4-11 Group ranking outcomes

Strategy	Environmental Group		Government		Academia		Overall	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank
(S1)Appropriate driving behavior	55.86	17	77.30	9	50.34	15	65.81	15
(S2)Non-motorized transport promotion	68.16	8	56.01	18	71.84	11	60.14	16
(S3)Lower the usage rate of private vehicle	59.42	11	80.71	4	50.34	15	67.98	12
(S4)Encouragement of MaaS	59.42	11	79.71	6	89.16	2	71.80	7
(L1)New emission standard	88.20	1	89.81	1	82.12	5	82.36	1
(L2)Old diesel vehicle elimination	69.76	6	80.71	4	90.49	1	80.45	5
(L3)Examination of vehicles	79.57	4	82.83	3	89.16	2	82.24	2
(L4)Regulation of NRMM	59.42	11	68.40	15	76.80	10	68.30	11
(E1) Land utilization and urban planning	60.87	9	79.43	7	59.08	14	68.82	10
(E2) Road dust control	57.55	14	71.06	12	40.32	17	58.41	17
(E3) Promote light-duty vehicles sharing	49.66	18	67.02	16	40.32	17	56.80	18
(E4) Car-sharing platform development	57.55	14	58.33	17	79.66	8	67.11	14
(P1)Electric vehicles subsidy	81.08	3	79.43	7	89.16	2	80.86	4
(P2)Development of charging stations	82.67	2	89.81	1	80.00	7	81.94	3
(P3)Restriction on vehicle purchase	57.55	14	69.92	13	67.85	12	67.58	13
(T1)Novel battery in electric vehicles	71.48	5	72.08	11	80.86	6	79.27	6
(T2)Wear resistant tyre and brake	69.76	6	69.07	14	79.66	8	70.50	8
(T3)ORVR system in motorcycle	60.87	9	77.30	9	67.85	12	68.83	9

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4.3.3 Comprehensive analysis of importance and achievability

This section integrates the results of FAHP and achievability analysis. Looking at the means, the relative importance of PM2.5 reduction strategies obtained from the FAHP approach and improvement-achievability scores are classified into high and low in Figure 4-3. The x-axis of the grid indicates the relative importance of PM2.5 reduction strategies and the horizontal axis represents their improvement-achievability. By pairing these two sets of rankings (Table 4-12), 18 mobile source PM2.5 improvement strategies are placed into one of the four quadrants of the importance-achievability grid to establish the comprehensive analysis diagram of improvement strategies of PM2.5 from mobile pollution source.

Martilla et al. (1977) suggested that when plotting such a graph, the researcher should use the median as the original point. However, if the mean can show the result better than the median, the average can also be used as the original point. In this research, median was adopted to be original point. According to Chang & Wong (2012), Figure 4-3 divides the strategies into four quadrants, the first quadrant (Top priority implementation zone), the second quadrant (Key challenge zone), the third quadrant (Long-term promotion zone) and the fourth quadrant (Possible integration zone).

1. The top priority implementation zone:

Improvement strategies allocated in this zone are seen to as being highly important and having potential for improvement-achievability and include: new emission standard, old diesel vehicle elimination, examination of vehicles, electric vehicles subsidy, development of charging stations and novel battery in electric vehicles. Experts believed that strategies in this zone should be actively

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implemented. For example, the amendment of the Air Pollution Control Act has already stated that the car must be inspected. The Kaohsiung City Government can use this as a basis for setting new testing standards and inspection schedules.

2. The key challenge zone:

Improvement strategies in this zone are referred to as being highly important but having low improvement-achievability. The key challenges here are of restriction on vehicle purchase, lower the usage rate of private vehicle and land utilization and urban planning. The strategies in the key challenge zone should be considered for implementation, but their budget and human resources must be carefully evaluated.

For example, lower the usage rate of private vehicle and land utilization and urban planning are both important strategies that experts consider to be important. But the implementation of both requires a lot of budget and involves the benefits of many people. Therefore, the government must make more assessments before these strategies are implemented and carry out them carefully.

3. The long-term promotion zone:

Improvement strategies allocated here are of low importance and low improvement-achievability and include improvement strategies such as: regulation of NRMM, appropriate driving behavior, non-motorized transport promotion, road dust control, promote light-duty vehicles sharing and car-sharing platform development.

Most of the strategies in this zone require long-term observation. For example, experts suggest that prompting appropriate driving behavior is very difficult. And even if it is successfully promoted, the reduction of PM2.5 emissions may not be much. So strategies like this need to be planned from a long-term perspective.

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4. The possible integration zone:

Improvement strategies in the integration zone are referred to as having low importance but high improvement-achievability and embrace encouragement of MaaS, wear resistant tyre and brake and ORVR system in motorcycle. Strategies in the possible integration zone may be easier to implement than other strategies. But whether the government implements it depends on the overall goal. For instance, the ORVR system is currently used in car systems, so it may not be too difficult to apply this technology to the motorcycle system successfully. But experts believe that this strategy can only reduce PM2.5 emission in a limited amount. Therefore, this strategy will not be the top priority. In fact, Ministry of Science and Technology began to seek ORVR proposals in 2018. This shows that the government wants to start the implementation of the plan after determining the reduction effect. This case is consistent with the results of this study.

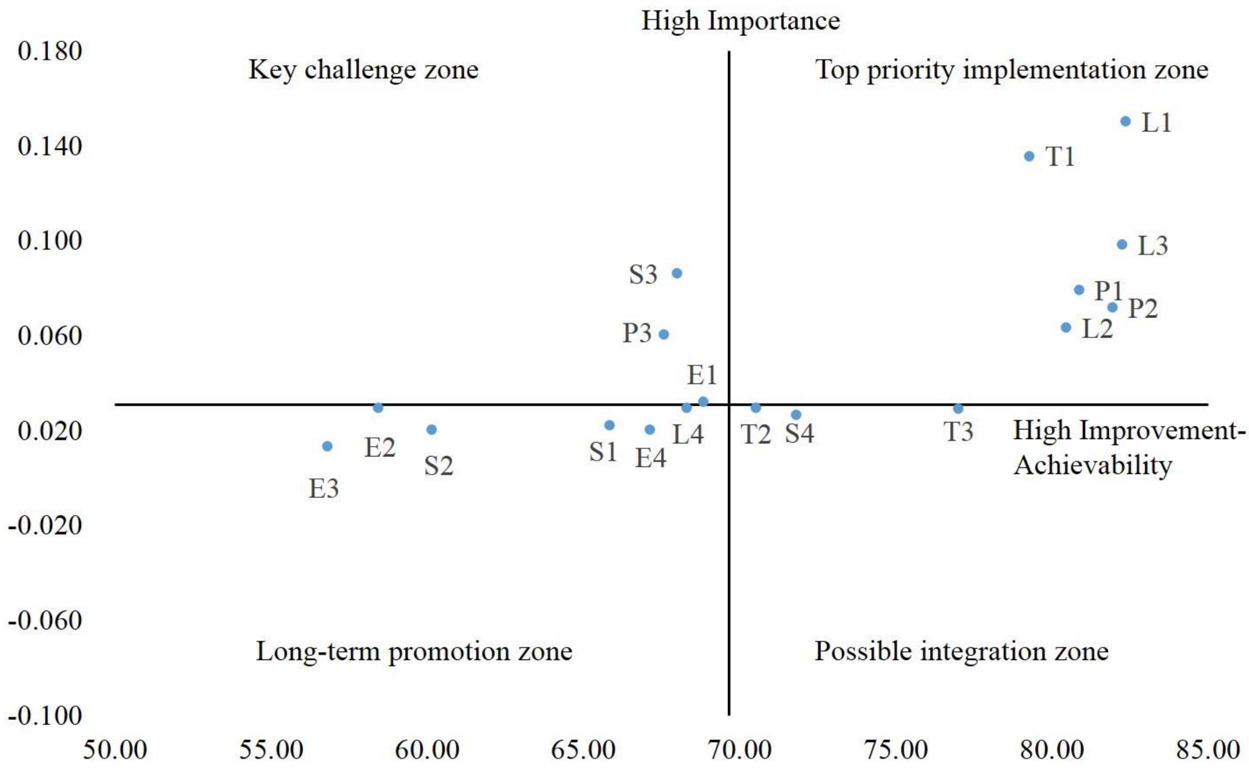

Figure 4-3 Comprehensive analysis diagram of improvement strategies of PM2.5

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Table 4-12 The value and rank of importance and achievability for each strategy

Strategy	Weight	Rank	Achievability	Rank
(S1) Appropriate driving behavior	0.022	15	65.81	15
(S2) Non-motorized transport promotion	0.020	17	60.14	16
(S3) Lower the usage rate of private vehicle	0.086	4	67.98	12
(S4) Encouragement of MaaS	0.027	14	71.80	7
(L1) New emission standard	0.150	1	82.36	1
(L2) Old diesel vehicle elimination	0.063	7	80.45	5
(L3) Examination of vehicles	0.098	3	82.24	2
(L4) Regulation of NRMM	0.030	11	68.30	11
(E1) Land utilization and urban planning	0.031	9	68.82	10
(E2) Road dust control	0.031	10	58.41	17
(E3) Promote light-duty vehicles sharing	0.013	18	56.80	18
(E4) Car-sharing platform development	0.020	16	67.11	14
(P1) Electric vehicles subsidy	0.079	5	80.86	4
(P2) Development of charging stations	0.072	6	81.94	3
(P3) Restriction on vehicle purchase	0.060	8	67.58	13
(T1) Novel battery in electric vehicles	0.136	2	79.27	6
(T2) Wear resistant tyre and brake	0.030	13	70.50	8
(T3) ORVR system in motorcycle	0.030	12	68.83	9

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Chapter 5 Conclusions and suggestions

5.1 Research conclusions

The conclusions can be drawn that reflect the purposes of this study as below:

5.1.1 **Identify preliminary improvement strategies of mobile source PM2.5**

One of objectives in this research is 'Identify preliminary reduction strategies of mobile source PM2.5 by literature review and related policies around the world'. After studying a large number of studies related to mobile source PM2.5 reduction and reviewing policies in Japan, Korea, European Union and Taiwan. The preliminary improvement framework with 20 strategies of government is constructed. Besides, this study categorizes the 20 strategies into five dimensions including legislative regulation, policy promotion, social education, environment & sharing economy and technology change.

5.1.2 **Formulate appropriately improvement strategies of mobile source PM2.5**

The second objectives in this research is 'Formulate improvement strategies regarding to the results of consensus significance value in FDM'. According to the experts, 'Vehicle restriction on PM2.5 alert day', 'Roadside Planting redesign' and 'Build new style PM-proof roof' have been deleted because of unsatisfactory G^i. 'Wear resistant tyre and brake' and 'Promote light-duty vehicles sharing' don't obtain convergence so they need one more survey, this research also revises definition of 'Develop public transports using habit' and amends the it to 'Lower the usage rate of private vehicle'. Besides, this research adds a new strategy 'ORVR system in motorcycle'. The final 18 strategies recognized by experts have been formulated after second phase questionnaire, the results can serve as a good

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reference for government to draft an improvement plan. And relative importance of them can help government allocate finite resources to the right strategic action plan.

5.1.3 **Calculate relative importance & achievability of improvement strategies**

The third objective is 'Discovery the advantages, disadvantages and insufficiencies of these strategies by relative importance and improvement achievability analysis'. This research analyses relative importance and improvement achievability of all 18 strategies and develop a comprehensive analysis graph of importance and achievability. The urgency and effectiveness of each strategy can be seen from the graph. According to the graph, this research finds out that 'new emission standard', 'old diesel vehicle elimination', 'examination of vehicles', 'electric vehicles subsidy', 'development of charging stations' and 'novel battery in electric vehicles' are important and highly feasible.

5.2 Research suggestions

Regarding to the results, there are some suggestions provide to citizens, government and future researchers, shown as follows:

5.2.1 **Suggestions to citizens**

In the results of this research, there are some important but less feasible strategies such as 'restriction on vehicle purchase', 'lower the usage rate of private vehicle' and 'land utilization and urban planning'. We can infer that these three strategies are considered to be difficult to implement because the habits of the public are difficult to change. Once the government formulates relevant implementation plans, citizens often complain about that, so the government will postpone these plans to avoid public grievances. This study suggests that citizens can give up some convenience for their own health and let everyone enjoy better air quality. And citizens also have the

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responsibility to convey correct concept such as driving habit or mass transportation using to their children. Only when the people actively participate and cooperate with government policies can the improvement strategy be successfully promoted.

5.2.2 **Suggestions to central government**

The mobile source PM2.5 improvement strategies provided in this research can be a good and practical checklist for government to examine future PM2.5 reduction plan. Among 5 dimensions in this research, dimension "Legislative Regulation" and "Technology Change" are biased towards the central government's powers and responsibilities. Therefore, in this section, this study will analyze the strategies in these two dimensions according to the quadrants. Strategies in the top priority implementation zone is that government can actively carry out. Specifically, the government can set inspection dates and new emission standards according to the characteristics of private vehicles and test results using new inspection methods. In the other hand, they should provide incentives and subsidies to help industry develop new style battery. And then, strategies in the possible integration zone is suitable for government implementation but the effect may be limited. They should find a balance between input and reduction results. For instance, central government has started research on wear resistant tire and motorcycle ORVR system, but they should estimate that is the input and cost worthy or not. At last, strategies in the long-term promotion zone is considered to be less important and more difficult to implement. These strategies can be used as a reference for future policies, but detailed implementation rules still need to be reworked. For central government, laws about regulation of NRMM could be considered as an amendment plan, but it might need more discussions.

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5.2.3 Suggestions to local government

As mentioned above, dimension "Policy Promotion", "Social Education" "Environment & Sharing Economy" are that local governments can focus on. This study divides the strategies into four quadrants. Next, we will discuss the strategies that local governments can adopt according to these quadrants. First, in the top priority implementation zone, Kaohsiung city government can cooperate with merchants to launch more exclusive parking spaces for electric vehicles and set up charging stations in cooperation with gas stations. Second, for strategies in the key challenge zone, local government needs to draw up a suitable plan. For example, if the government wants to reduce the use of private vehicles, they currently start by promoting public transportation. They may also cooperate with school education in the future. Third, in the possible integration zone, although MaaS has been promoted in Kaohsiung in recent year, the number of people using it and the effect of reduction still need to be strengthened. Maybe Kaohsiung city government could try some new marketing methods to improve the performance. At last, according strategies in the long-term promotion zone, Kaohsiung city government may consider strengthening education advocacy and incorporating the concept of sharing into future plans.

5.2.4 Suggestions to future research

This research structure mobile source PM2.5 improvement strategies by former literature and related policies around the world. However, due to the current lack of research on the reduction effect in Taiwan, this study does not calculate the emissions that may be reduced in detail by each strategy. After more relevant research emerges in the future, future researcher could consider it as a variable. In the other hand, traffic-related public strategies are often strongly influenced by funds and public. The grievances that may be caused by strategies must be considered. It is suggested that

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future research can estimate the amount of emissions that each strategy can reduce, and even calculate the cost of possible inputs so that experts can make further considerations and the government could convince citizens to follow the policies. These may influence the way of the mobile source PM2.5 improvement strategies and would be a good issue for future studies to examine.

5.3 Research contributions

This research identifies the mobile source PM2.5 improvement strategies regarding to analysis results and experts' opinions. In the past, the literatures emphasized the reduction of single strategy. This research is the first to integrate various improvement strategies of mobile source PM2.5. By putting all strategies in a framework to analysis. Government can easily understand what should to be done by considering the relative importance and achievability instead of wasting resources and time.

This is definitely a great contribution for government to maximize their limited resources. Moreover, the literature review in this study and the results of four quadrant classifications provide direction of further research for future researchers. They can use this as a benchmark to adjust and add new strategies as policies and technology change.

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Appendix A

問卷編號：__________

各位專家 您好：

本研究為國立成功大學交通管理科學所之碩士論文—「細懸浮微粒(PM2.5)移動污染源改善策略探討-以高雄市區為例」。

本研究希望藉由您的專業知識及寶貴意見評估此以政府觀點出發的 PM2.5 計畫中各項策略的重要度及影響，作為政府及相關單位計畫時之參考。

問卷所有資料僅作為學術研究參考之用，絕不對外公開。本研究需要您的專業建議及指導，敬請您於 2019 年 1 月 11 日前填寫完畢並寄回問卷，感謝您撥冗惠賜指教。

敬祝

身體健康 平安順利

【問卷填寫說明】

1. 本研究透過文獻回顧以及參考各國政策的方式，將 PM2.5 改善策略之二十項策略分為五大構面：「法規管制」、「政策推廣」、「社會教育」以及「環境與共享經濟」、「科技演變」，期透過分析結果，找出 PM2.5 改善計畫中各項策略間的重要度及影響，以利政府將有限的資源做有效的運用。
2. 本次問卷之相關構面與政策之詳細定義將於附件中說明。
3. 本研究將以兩階段專家問卷進行探討，第一階段為改善策略之選定，第二階段為策略間相對權重與各改善策略達成預測值之衡量以及改善可行性衡量。

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【附件】

圖一 PM2.5 移動污染源改善策略之架構圖

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表一 PM2.5 移動污染源改善策略之政策說明

構面	改善策略	定義
法規管制	制定新排放標準	學習歐盟之檢測技術(如 RDE)，並納入過去未考慮但已被證實顯著影響健康之重要因素(如尖峰小時濃度)，來訂定更符合實際狀況的排放標準，供新出產之車輛檢驗與現行車輛改善。
	淘汰老舊柴油車	柴油大客車在移動污染源裡是占比最高的排放源，因此淘汰造成嚴重污染的一期柴油大客車(1999 年前生產)實為當務之急。
	車輛的定期檢驗	空污法修正案已給予相關機關檢驗並處罰未達排放標準車輛之權力，未來應配合新的排放標準，就不同車型訂定檢驗期限與各項改善標準，未達標或未檢驗者可參考南韓直接禁止其上路。
	非道路車輛	目前未有法規管制裝卸機、推土機、流動發電機、挖泥機和機場內用車等非道路車輛的 PM2.5 排放，未來應對非道路車輛的排放研擬法規。
政策推廣	電動車補貼優惠	為了增加電動車的購買誘因以達成環保署的汰換目標，除了購買補貼外，可參考他國，採用電動車專用停車場、公司擁有一定比例電動車可以節稅等措施來增加民眾購買意願。
	廣設電動車充電站	電動車充電站不足一向是消費者對購買電動車望之怯步之重要原因，目前高雄市政府已與中山大學等學校合作設置充電站，未來可與停車場、商家合作，提高充電站密度，增加購買意願。
	警戒日之車輛限行	高雄市一年有超過一半的天數處於 PM2.5 濃度警戒，在警戒日裡，可採用車輛限行的方式來降低濃度，如法國的單雙數車牌限行、中國的工作日擇一日禁行以及倫敦的擁擠稅。
	高排放車輛購買加嚴	限制大型舊車的進口，並對購買未符合現行排放標準車輛的消費者徵收額外費用。

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表一 PM2.5 移動污染源改善策略之政策說明(續)

構面	改善策略	定義
社會教育	良好的駕駛習慣	推廣環境友善駕駛，如怠速熄火、避免急加速或急減速，良好的駕駛習慣可以減少輪胎及煞車板磨損並減少耗油，降低 PM2.5 之產生。
	推動非機動運輸	非機動運輸往往是城市清淨交通成功的關鍵因素，高雄可透過人行道與自行車道的規劃，並配合滑板、電動滑板車等新潮運具的推廣來達成。
	培養公共運具的搭乘習慣	目前高雄已推出月票「搭到飽」的方案並在冬季實行免費運輸來提升使用率。高雄擁有捷運、輕軌、渡輪等多樣的交通工具,未來可善用這些資源並配合 MaaS 的方案積極推廣，使民眾逐步養成搭乘公共運具的習慣。
	鼓勵公共運輸行動服務(MaaS)	高雄市全臺第一個推出 MaaS 的城市，其整合各種公共運輸，藉由分析大數據，不斷改善轉乘路徑，並增闢路線、班次或增加計程車排班點,但因民眾對 MaaS 並不熟悉，可能降低其使用意願，故公開說明會及校園推廣是未來可採取的策略。
環境與共享經濟	都市規劃與土地利用	許多研究都指出良好的大眾運輸使用率與都市規劃與土地利用有正向關係，高雄在未來開發時可考慮以大眾運輸導向型發展(TOD)來做發展軸心，並可考慮以中心商業區(CBD)的方式來規劃未來新商圈位置，並注重城市綠化與溼地保育。
	道路揚塵管制	道路揚塵約占臺灣 10%的 PM2.5 排放量，而超過半數的道路揚塵與車輛行駛有關，除了減少私人運具持有外與汽車限行外,高雄也可參考日本的工地管理守則,避免留下過多的微小顆粒物在道路上,形成道路揚塵。
	推廣無人車及小巴共享	目前世界上主要的汽車共享多以推廣無人電動車與輕量小巴為未來發展目標。在高雄，等級四無人電動可用於固定路線或封閉路線的接駁(如駁二特區等觀光區及市區公車路線)，而輕量小巴則可用於較長距離的行駛租用。
	車輛共享平台的開發	良好的共享平台是車輛共享推廣成功的必要條件，除了可以隨時用手機或電腦預約外，甲地租乙地還的系統也可增加使用便利性，建置共通共享的平台系統是成功執行關鍵。

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表一 PM2.5 移動污染源改善策略之政策說明(續)

構面	改善策略	定義
科技演變	開發新型電動車電池	電動車電池的耐久性與充電時間是電動車使用問題之一，新型的電動車電池分為快充式與高電容式兩種，快充式電池可用於小型巴士，而高電容式多用於長途旅行的車輛。未來除了持續研發更短充電時間與更長使用時間的新型電池外，如何統一各家廠商電池的充電規格也是政府推動電動車成功的關鍵因素之一。
	研發更耐磨的輪胎及煞車板	根據歐盟研究指出，未來在排放標準持續加嚴的情況下，由煞車板摩擦和路面摩擦所產生的 PM2.5 在移動污染源裡的佔比將持續增加(由 10%提升至 30%以上)，因此開始開發新型的輪胎與煞車板也是改善 PM2.5 排放的策略之一。
	重新設計道路行道樹	行道樹設計從樹種、樹高、距離到排列形式都會影響道路的 PM2.5 濃度，良好的行道樹設計可以幫助 PM2.5 逸散並讓部分細懸浮微粒沉積於土壤，而不良的的行道樹設計則可能讓 PM2.5 無法飄散，使得濃度更高，因此可聘請專家研究最適合高雄的行道樹設計，以減少移動污染源排放濃度。
	建置新型空污防護屋頂	2015 年由英國團隊在北京建置的空污防護屋頂可以在公車進站時有效減少 70%的 PM2.5 濃度，但僅能容納 20 人同時於底下候車。研究指出公車進站時車站內的濃度會是平時的 5 至 10 倍，因此可容納更多人且更有效率的空污防護屋頂是值得開發研究的建設。

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【填寫範例說明】

經由權數值之評估，表示對於不同策略有不同的重要性估計，然而個權數值所代表之定義亦有不同之處，如下表所示:

重要性權數						
權數值	1	3	5	7	9　10	2　4　6　8
重要性	非常不重要	不重要	普通	重要	非常重要	介於鄰近尺度衡量值

而專家對於影響因子之重要性程度其最有可能之單一值(1-10)與可接受之最大最小值則分別表示如下表:

評估準則	可接受範圍(1-10 分)		
	可接受之最小值	最有可能之單一值	可接受之最大值
影響因子 F1	(　)	(　)	(　)
影響因子 F2	(　)	(　)	(　)

影響因子之重要性程度:係指評估此因子對上一層級因子之重要性程度，並請受測者填入對此因子重要性程度的單一值。

【舉例說明】

假如您認為影響因子 F1 之重要性程度值，其最有可能之單一值為 7，表示您人為該影響因子位具有「重要性」，然而如您認為該因此之權數值重要性難以確定時，建議您對於該因子之權數值可運用「可接受範圍」的數值來確定您個人認為可接受之最大與最小值(如本例分別為 9 和 5)，如下所示:

評估準則	可接受範圍(1-10 分)		
	可接受之最小值	最有可能之單一值	可接受之最大值
1.影響因子 F1	(5)	(7)	(9)

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【問卷內容】

請依序回答下列問項(請完整填寫):

一、 以「PM2.5 移動污染源改善策略之探討」為主題考量時，所用之研究構面重要性為何?

研究構面	合適性程度分數(1-10 分)		
	最小值	最可能值	最大值
1.法規管制			
2.政策推廣			
3.社會教育			
4.環境與共享經濟			
5.科技演變			
6.其他建議:__________________			

二、以「法規管制」構面而言，下列所用之改善策略重要性為何?

研究構面	合適性程度分數(1-10 分)		
	最小值	最可能值	最大值
1.制定新排放標準			
2.淘汰老舊柴油車			
3.車輛的定期檢驗			
4.非道路車輛管制			
5.其他建議:__________________			

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三、以「政策推廣」構面而言，下列所用之改善策略重要性為何?

研究構面	合適性程度分數(1-10 分)		
	最小值	最可能值	最大值
1.電動車補貼優惠			
2.廣設電動車充電站			
3.警戒日之車輛限行			
4.高排放車輛購買加嚴			
5.其他建議:__________________			

四、以「社會教育」構面而言，下列所用之改善策略重要性為何?

研究構面	合適性程度分數(1-10 分)		
	最小值	最可能值	最大值
1.良好的駕駛習慣			
2.推動非機動運輸			
3.培養公共運具的搭乘習慣			
4.鼓勵公共運輸行動服務(MaaS)			
5.其他建議:__________________			

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五、以「環境與共享經濟」構面而言，下列所用之改善策略重要性為何?

研究構面	合適性程度分數(1-10 分)		
	最小值	最可能值	最大值
1.都市規劃與土地利用			
2.道路揚塵管制			
3.推廣無人車及小巴共享			
4.車輛共享平台的開發			
5.其他建議:__________________			

六、以「科技演變」構面而言，下列所用之改善策略重要性為何?

研究構面	合適性程度分數(1-10 分)		
	最小值	最可能值	最大值
1.開發新型電動車電池			
2.研發更耐磨的輪胎及煞車板			
3.重新設計道路行道樹			
4.建置新型空污防護屋頂			
5.其他建議:__________________			

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受訪者基本資料

姓名：________________

1. 性別：☐男　☐女
2. 年齡：☐30 歲以下　☐31~40 歲　☐41~50 歲　☐51~60 歲　☐61 歲以上
3. 教育程度：☐高中職　☐專科　☐大學　☐研究所及以上
4. 您目前的任職單位：__________________________、任職年資：_____年_____月
5. 您目前的職務(職稱)：__________________________、目前職務年資：_____年_____月
6. 過去相關經歷：

____

____

____

7. 若有其他對於 PM2.5 移動污染源改善策略之寶貴建議，請書寫於下方：

____

____

____

____

____

____

【本問卷到此結束，謝謝您的填答】

請將問卷放入回郵信封內，於您方便時盡速寄出，誠摯地感謝您的協助！

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Appendix B

【問卷內容】

在第一階段問卷中，專家建議將「培養公共運具的搭乘習慣」更改為「降低私有運具使用率」並加入新策略「機車ORVR系統之設計研發」，另外由於「推廣無人車及小巴共享」及「研發更耐磨的輪胎及煞車板」在第一階段問卷中未達收斂，故也須請各位專家再次評估填寫:

改善策略	合適性程度分數(1-10 分)		
	最小值	最可能值	最大值
降低私有運具使用率			
推廣無人車及小巴共享			
研發更耐磨的輪胎及煞車板			
機車 ORVR 系統之設計研發			

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Appendix C

PM2.5 移動污染源改善策略探討 第二階段問卷

您好：

本問卷為國立成功大學交通管理科學所之碩士論文━「細懸浮微粒(PM2.5)移動污染源改善策略探討-以高雄市區為例」的第二階段專家問卷。

本研究希望藉由您的專業知識及寶貴意見評估此以政府觀點出發的 PM2.5 計畫中各項策略的重要度及影響，作為政府及相關單位計畫時之參考。

問卷所有資料僅作為學術研究參考之用，絕不對外公開。本研究需要您的專業建議及指導，敬請您於 2019 年 02 月 01 日前填寫完畢並裝入回郵信封寄回問卷，感謝您撥冗惠賜指教。

敬祝

身體健康 平安順利

【問卷填寫說明】

1. 本研究透過文獻回顧以及參考各國政策的方式，將 PM2.5 改善策略之十八項策略分為五大構面：「法規管制」、「政策推廣」、「社會教育」、「環境與共享經濟」以及「科技演變」，期透過分析結果，找出 PM2.5 改善計畫中各項策略間的重要度及影響，以利政府將有限的資源做有效的運用。
2. 附件圖一為本研究構面與改善策略之架構，表一為改善策略之定義說明。
3. 此問卷為本研究第兩階段專家問卷，希望分別對各項構面與改善策略進行相對重要性評比。本問卷目的在於透過層級分析法衡量其相對權重值並對改善策略進行可行性衡量，請您參考問卷填寫說明及範例作答。

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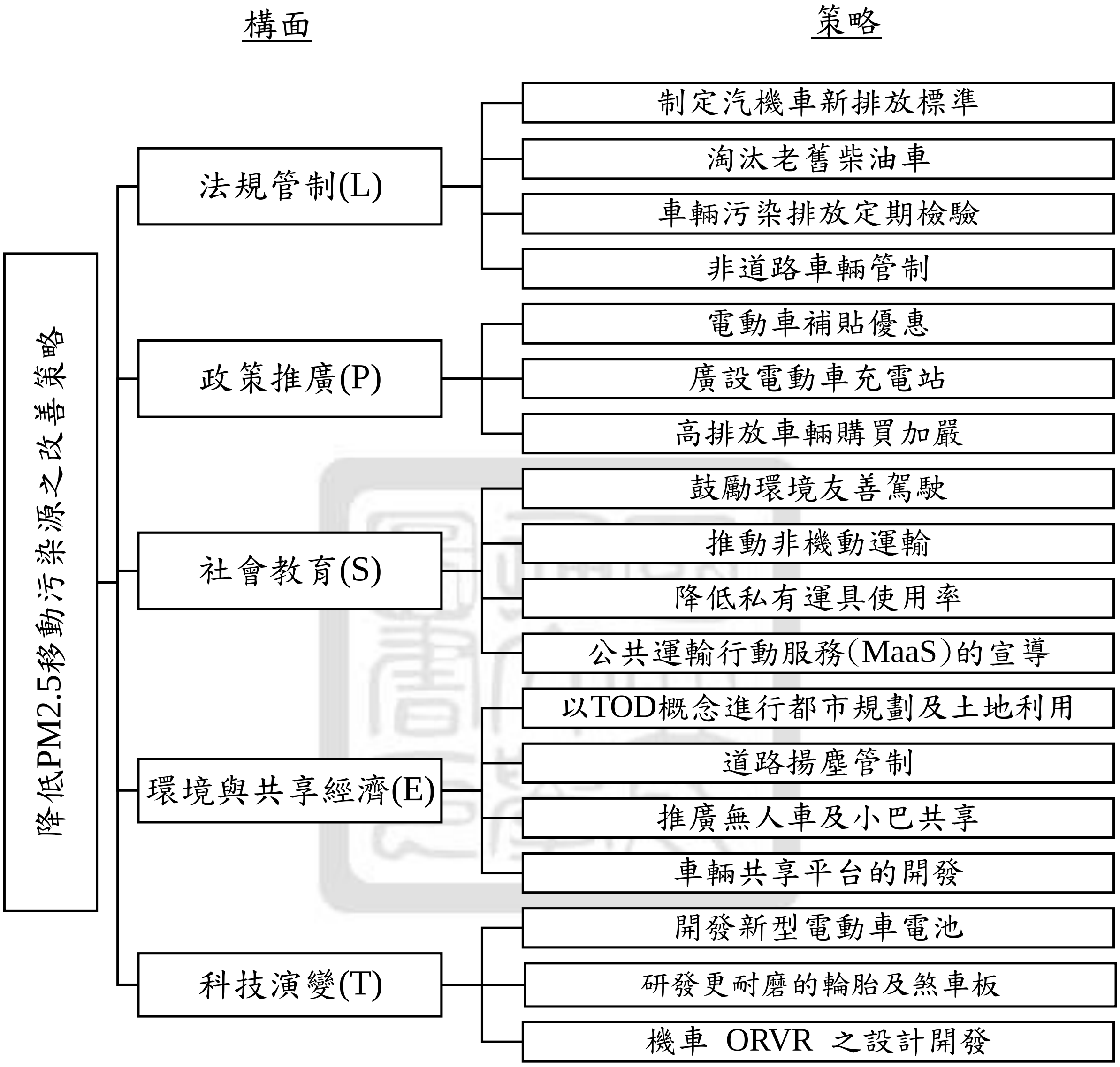
【附件】



圖一 PM2.5 移動污染源改善策略之架構圖

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表一 PM2.5 移動污染源改善策略之政策說明

構面	改善策略	定義
法規管制	制定汽機車新排放標準	學習歐盟之檢測技術(如 RDE 汽車實際排放檢測)，並納入過去未考慮但已被證實顯著影響健康之重要因素(如整體車輛尖峰小時濃度)，來訂定更符合實際狀況的排放標準，供新出產之車輛檢驗與現行車輛改善。
	淘汰老舊柴油車	柴油大客車在移動污染源裡是占比最高的排放源(約占移動汙染源之 40%)，因此淘汰造成嚴重污染的一期柴油大客車(1999 年前生產)實為當務之急，除配合環保署空氣污染防制法修正案的目標進度以外，地方政府也應嚴格執行未符合排放標準車輛的淘汰。
	車輛污染排放定期檢驗	空污法修正案已給予相關機關檢驗並處罰未達排放標準車輛之權力，未來應配合新的排放標準，就不同車型訂定檢驗期限與各項改善標準，未達標或未檢驗者可參考南韓直接禁止其上路。
	非道路車輛管制	在臺灣，對於裝卸機、推土機、流動發電機、挖泥機和機場內用車等非道路車輛的 PM2.5 排放管制法規未臻完善，又多數非道路車輛為柴油引擎，故未來應對非道路車輛的排放研擬新法規。
政策推廣	電動車補貼優惠	為了增加電動車的購買誘因以達成環保署的汰換目標，除了購買補貼外，可參考他國，採用電動車專用停車場、公司擁有一定比例電動車可以節稅等措施來增加民眾購買意願。
	廣設電動車充電站	電動車充電站不足一向是消費者對購買電動車望之怯步之重要原因，目前高雄市政府已與中山大學等學校合作設置充電站，未來可與停車場、商家合作，提高充電站密度，增加購買意願。
	高排放車輛購買加嚴	限制大型舊車的進口，並對購買未符合現行排放標準車輛的消費者徵收額外費用並要求其加裝濾煙器或改善至符合標準才可上路。

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表一 PM2.5 移動污染源改善策略之政策說明(續)

構面	改善策略	定義
社會教育	鼓勵環境友善駕駛	鼓勵環境友善駕駛，如怠速熄火、避免急加速或急減速，良好的駕駛習慣可以減少輪胎及煞車板磨損並減少耗油，降低 PM2.5 之產生。
	推動非機動運輸	非機動運輸往往是城市清淨交通成功的關鍵因素，高雄可透過人行道與自行車道的規劃，並配合滑板、電動滑板車等新潮運具的推廣來達成。
	降低私有運具使用率	目前高雄已推出月票「搭到飽」的方案並在冬季實行免費運輸來鼓勵民眾減少使用私有運具。除配合大眾運具的吸引外，增加私有運具使用成本，如提高私人車輛牌照稅、擁車證及增加路邊停車收費。也是降低私有運具使用率的重要方法，
	公共運輸行動服務(MaaS)的宣導	高雄市全臺第一個推出 MaaS 的城市，其整合各種公共運輸，高雄擁有捷運、輕軌、渡輪等多樣的交通工具，藉由分析大數據，不斷改善轉乘路徑，並增闢路線、班次或增加計程車排班點，但因民眾對 MaaS 並不熟悉，可能降低其使用意願，故公開說明會、校園推廣及網路行銷是未來可採取的策略。
環境與共享經濟	以 TOD 概念進行都市規劃及土地利用	許多研究都指出良好的大眾運輸使用率與都市規劃與土地利用有正向關係，高雄在未來開發時可考慮以大眾運輸導向型發展(TOD)來做發展軸心，並可考慮以中心商業區(CBD)的方式來規劃未來新商圈位置，並注重城市綠化與溼地保育。
	道路揚塵管制	道路揚塵約占臺灣 10%的 PM2.5 排放量，而超過半數的道路揚塵與車輛行駛有關，除了減少私人運具持有外與汽車限行外，高雄也可參考日本的工地管理守則，避免留下過多的微小顆粒物在道路上，形成道路揚塵。
	推廣無人車及小巴共享	目前世界上主要的汽車共享多以推廣無人電動車與輕量小巴為未來發展目標。在高雄，等級四的無人電動可用於固定路線或封閉路線的接駁(如駁二特區等觀光區及市區公車路線)，而輕量小巴則可用於較長距離的行駛租用。
	車輛共享平台的開發	良好的共享平台是車輛共享推廣成功的必要條件，除了可以隨時用手機或電腦預約外，甲地租乙地還的系統也可增加使用便利性，建置共通共享的平台系統是成功執行關鍵。

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表一 PM2.5 移動污染源改善策略之政策說明(續)

構面	改善策略	定義
科技演變	開發新型電動車電池	電動車電池的耐久性與充電時間是電動車使用問題之一，新型的電動車電池分為快充式與高電容式兩種，快充式電池可用於小型巴士，而高電容式多用於長途旅行的車輛。未來除了持續研發更短充電時間與更長使用時間的新型電池外，如何統一各家廠商電池的充電規格也是政府推動電動車成功的關鍵因素之一。
	研發更耐磨的輪胎及煞車板	根據歐盟研究指出，未來在排放標準持續加嚴的情況下，由煞車板摩擦和路面摩擦所產生的 PM2.5 在移動污染源裡的佔比將持續增加(由 10%提升至 30%以上)，因此開始開發新型的輪胎與煞車板也是改善 PM2.5 排放的策略之一。
	機車 ORVR 系統之設計研發	車載油氣回收設施(Onboard Refueling Vapor Recovery, ORVR)係在加油時，將油氣導至車輛之回收罐，而其所收集的汽油中，液態會回流至油箱，氣態則導入引擎燃燒利用，ORVR 系統可減少油氣逸散所造成 PM2.5，但目前此項技術多用於四輪的車輛上，在機車的運用上仍有技術上的疑慮，考量臺灣，特別是高雄的機車數量極多且使用頻繁，在未來可以評估 ORVR 技術應用於機車的效益和可行性，並開始開發 ORVR 應用於機車上的技術。

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就**「PM2.5 移動汙染源減量」**目標而言，請對「1.法規管制」、「2.政策推廣」、「3.社會教育」、「4.環境與共享經濟」及「5.科技演變」五項構面評估其相對重要程度。請依重要性排序（填數字序號即可）:(　　)≧(　　)≧(　　)≧(　　)≧(　　)

構面	重要性程度																	構面
	絕對重要		極為重要		頗為重要		稍微重要		同等重要		稍微重要		頗為重要		極為重要		絕對重要	
尺度	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	尺度
法規管制																		政策推廣
																		社會教育
																		環境與共享經濟
																		科技演變
政策推廣																		環境與共享經濟
																		社會教育
																		科技演變
社會教育																		環境與共享經濟
																		科技演變
環境與共享經濟																		科技演變

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二、 各改善策略間之相對重要性比較

（一）就**「法規管制」**構面而言，請對「1.制定汽機車新排放標準」、「2.淘汰老舊柴油車」、「3.車輛污染排放定期檢驗」及「4.非道路車輛管制」四項改善策略評估其相對重要程度。

1. 請依重要性排序（填數字序號即可）:（　　）≧（　　）≧（　　）≧（　　）

2. 請依上述排序，以成對比較方式勾選評估準則間之「相對重要程度」。

改善策略	重要性程度																	改善策略
	絕對重要		極為重要		頗為重要		稍微重要		同等重要		稍微重要		頗為重要		極為重要		絕對重要	
尺度	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	尺度
制定汽機車新排放標準																		淘汰老舊柴油車
																		車輛污染排放定期檢驗
																		非道路車輛管制
淘汰老舊柴油車																		車輛污染排放定期檢驗
																		非道路車輛管制
車輛污染排放定期檢驗																		非道路車輛管制

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（二）就**「政策推廣」**構面而言，請對「1.電動車補貼優惠」、「2.廣設電動車充電站」及「3.高排放車輛購買加嚴」三項改善策略評估其相對重要程度。

1. 請依重要性排序（填數字序號即可）:（　　）≧（　　）≧（　　）

2. 請依上述排序，以成對比較方式勾選評估準則間之「相對重要程度」。

改善策略	重要性程度																	改善策略
	絕對重要		極為重要		頗為重要		稍微重要		同等重要		稍微重要		頗為重要		極為重要		絕對重要	
尺度	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	尺度
電動車補貼優惠																		廣設電動車充電站
																		高排放車輛購買加嚴
廣設電動車充電站																		高排放車輛購買加嚴

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（三）就**「社會教育」**構面而言，請對「1.鼓勵環境友善駕駛」、「2.推動非機動運輸」、「3.降低私有運具使用率」及「4.公共運輸行動服務(MaaS)的宣導」四項改善策略評估其相對重要程度。

1. 請依重要性排序（填數字序號即可）:（　　）≧（　　）≧（　　）≧（　　）

2. 請依上述排序，以成對比較方式勾選評估準則間之「相對重要程度」。

改善策略	重要性程度																	改善策略
	絕對重要		極為重要		頗為重要		稍微重要		同等重要		稍微重要		頗為重要		極為重要		絕對重要	
尺度	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	尺度
鼓勵環境友善駕駛																		推動非機動運輸
																		降低私有運具使用率
																		公共運輸行動服務(MaaS)的宣導
推動非機動運輸																		降低私有運具使用率
																		公共運輸行動服務(MaaS)的宣導
降低私有運具使用率																		公共運輸行動服務(MaaS)的宣導

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（四）就**「環境與共享經濟」**構面而言，請對「1.以 TOD 概念進行都市規劃及土地利用」、「2.道路揚塵管制」、「3.推廣無人車及小巴共享」及「4.車輛共享平台的開發」四項改善策略評估其相對重要程度。

1. 請依重要性排序（填數字序號即可）：(　　)≧(　　)≧(　　)≧(　　)

2. 請依上述排序，以成對比較方式勾選評估準則間之「相對重要程度」。

改善策略	重要性程度																	改善策略
	絕對重要		極為重要		頗為重要		稍微重要		同等重要		稍微重要		頗為重要		極為重要		絕對重要	
尺度	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	尺度
以 TOD 概念進行都市規劃及土地利用																		道路揚塵管制
																		推廣無人車及小巴共享
																		車輛共享平台的開發
道路揚塵管制																		推廣無人車及小巴共享
																		車輛共享平台的開發
推廣無人車及小巴共享																		車輛共享平台的開發

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（五）就**<u>「科技演變」</u>**構面而言，請對「1.開發新型電動車電池」、「2.研發更耐磨的輪胎及煞車板」、「3.機車 ORVR 系統之設計研發」三項改善策略評估其相對重要程度。

1. 請依重要性排序（填數字序號即可）:(　　)≧(　　)≧(　　)
2. 請依上述排序，以成對比較方式勾選評估準則間之「相對重要程度」。

改善策略	重要性程度																	改善策略
	絕對重要		極為重要		頗為重要		稍微重要		同等重要		稍微重要		頗為重要		極為重要		絕對重要	
尺度	9:1	8:1	7:1	6:1	5:1	4:1	3:1	2:1	1:1	1:2	1:3	1:4	1:5	1:6	1:7	1:8	1:9	尺度
開發新型電動車電池																		研發更耐磨的輪胎及煞車板
																		機車 ORVR 系統之設計研發
研發更耐磨的輪胎及煞車板																		機車 ORVR 系統之設計研發

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第二部份：各策略之可行性評估

此部分為第一部分各項策略相對重要性之延伸，本研究想了解您認為「細懸浮微粒(PM2.5)移動污染源改善策略」各項策略之可行性如何。此部分只有可行性之評估，並無相對之比較，敬請您耐心填答本問卷最後一部分，感謝您的幫忙。

【問卷填寫說明】

一、為了解細懸浮微粒(PM2.5)移動污染源改善策略在管理實務改善上的「可行性」，請針對各項改善策略，依您的專業認知勾選您的判斷值。

二、 本研究用「很低」至「很高」五個尺度，**尺度值越大，越趨近於高或很高的程度，表示此改善策略可行性越高；反之則趨近於低或很低的程度，表示可行性越低**。

【範例】

若您認為策略 A 的可行性為高時，請在策略 A 的部分勾選「高」。

	很低	低	中	高	很高
可行性分數	0-20	20-40	40-60	60-80	80-100
				✓	

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【問卷內容-可行性評估】請回答下列問項並完整填寫

構面	改善策略	改善可行性分數				
		很低	低	中	高	很高
		0-20	20-40	40-60	60-80	80-100
法規管制	制定汽機車新排放標準					
	淘汰老舊柴油車					
	車輛污染排放定期檢驗					
	非道路車輛管制					
政策推廣	電動車補貼優惠					
	廣設電動車充電站					
	高排放車輛購買加嚴					
社會教育	鼓勵環境友善駕駛					
	推動非機動運輸					
	降低私有運具使用率					
	公共運輸行動服務(MaaS)的宣導					
環境與共享經濟	以 TOD 概念進行都市規劃及土地利用					
	道路揚塵管制					
	推廣無人車及小巴共享					
	車輛共享平台的開發					
科技演變	開發新型電動車電池					
	研發更耐磨的輪胎及煞車板					
	機車 ORVR 系統之設計研發					

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受訪者基本資料

1. 姓　　名：____________

2. 聯絡電話：____________________________

3. 電子信箱：____________________________

4. 您目前的任職單位：______________、任職年資：______年 ______月

5. 您目前的職務（職稱）：______________、目前職務年資： ______年______

6. 過去相關經歷:

7. 若您對於本研究有寶貴建議，請書寫於下方：

【本問卷到此結束，謝謝您的填答】

請將問卷放入回郵信封內，於您方便時盡速寄出，誠摯地感謝您的協助!

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